PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

ISO 3382-3: NECESSARY BUT NOT SUFFICIENT

A NEW APPROACH TO ACOUSTIC DESIGN FOR ACTIVITY-BASED-WORKING OFFICES

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ABSTRACT

Since the room acoustic parameters in ISO 3382-3 were published, there have been various international attempts to classify offices achieving different values. However, recent summaries of acoustic satisfaction demonstrate little correlation with the room acoustic parameters that may drive the design. While the parameters of ISO 3382-3 are essential to understand how the room responds to sound, they are of limited use in helping designers to understand how people respond to their office environment.

A new approach – proposed for inclusion within ISO/WD 22955 - assesses acoustic conditions within activity-based working (ABW) offices, or between different use types generally. The Liveliness term can be used to characterise suitable acoustic environments for different types of activities; background sound levels can also be attributed, by measurement or design. A matrix of signal-to-noise ratios can be derived for a particular office, to account for source level vibrancy and receiver sensitivity. This enables a design framework for the in-situ attenuation of speech between workstations, $D_{n,A,s}$. From the in-situ attenuation requirement, the ABW layout design can be developed accordingly. This method can identify potential for conflicts between different types of use or activity where there is insufficient attenuation between them, to inform the workspace designer where enhanced in-situ attenuation can improve the acoustic conditions for occupants.

Keywords: Acoustics, Open plan office, ABW, activity-based working office, flex office

1. INTRODUCTION

The acoustic requirements for people within a workspace are strongly dependent on the workspace culture, and cannot be realistically determined without understanding how people operate within the workspace. A model originally proposed by Hongisto (1) has been followed with many studies identifying the extent of distraction by intelligible speech – the irrelevant speech effect (ISE). Laboratory experiments by many researchers including Chevret (2), Kostallari (3), Ellermeier (4), and Schlittmeier (5) demonstrate the decrease in performance that can be objectively measured when people perform tasks when subject to noise containing intelligible speech. The concept of a distance at which the intelligibility of speech at normal levels crosses a threshold for intelligibility (typically STI = 0.5) has informed acoustic parameters for office design. ISO 3382-3 describes the room acoustic parameters that can be measured in an open plan office; these metrics are increasingly being used to describe Classes of performance for the office.

Haapakangas (6) et al conclude that distraction distance predicts perceived disturbance by noise in open-plan offices. The data shown in Figure 1 from reference (6) with a solid circle are conventional offices, while triangle symbols denote activity-based working offices. The data presented by would suggest that there are many other factors that may be more significant in determining noise annoyance or acoustic satisfaction than distraction distance alone. The conclusion on distraction distance was

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made by looking at 21 workspaces with a mix of different study types as changing from private office to open plan office, relocation from open plan office to another open plan office, evaluation due to complaints and more. Interview studies from three major Norwegian companies (7), employees randomly selected from different business areas and different job descriptions (n=200), showed that 76 % preferred the office type (cell office, open plan office or flex office) they already had.

Haapakangas denotes activity-based offices differently, and the data indicates that noise annoyance in these offices is generally much lower than the average. Haapakangas also demonstrates that there is also little or no correlation with noise annoyance with other parameters such as speech level at 4 m, $L_{p,A,S,4m}$, spatial decay of speech, $D_{2,S}$, and background sound level, $L_{p,B}$.

Achieving lower (better) values for distraction distance has significant design implications for the height of screens between desks, the sound absorption, and the background sound level, as illustrated by Larrieu (8) et al. The design implications noted by Larrieu often do not match either the design aspirations of clients or workplace designers. Does this mean that "good acoustic design" according to the emerging national guidelines for the parameters in ISO 3382-3 is simply inevitably in conflict with the current workplace design aesthetics?

The parameters from ISO 3382-3 can be useful to demonstrate how acoustic conditions may be improved by increasing sound attenuation between desks in traditional open plan offices; however, these parameters are determined in an unoccupied office. These parameters cannot tell us anything about the occupants' activities, the type of work, individual control over place of work, office culture, occupation density, or other factors that may be significant when considering acoustic satisfaction. Acoustic design can begin with the occupants' acoustic needs, rather than the room response to sound. This represents a paradigm shift. We start by exploring the typical practice of workplace designers, and then look at the development of a new ISO Standard for acoustics in open plan offices. The opportunities to align these activities offers benefits for designers and the future occupants of the workspaces that may be developed.

2. THE WORKPLACE DESIGN PROCESS

The strategy for the workplace may consider the approach to working, and may be developed by a professional who specialises in that type of work (e.g. an architect or architectural technologist), or may be inferred or explicitly developed by a workplace designer, facilities manager or client. There may be a wide range of formality for the workplace strategy - it may be simply inferred from the brief for the workspace, or it may be systematically derived from an engagement process between the workplace strategist and client.

Workplace designers will often consider those activities that may generate higher sound levels and locate them in such a way as to minimise the impact on other areas: designers implicitly consider acoustic requirements. A taxonomy of open plan offices is described by Neil Usher (9), revealing the significant variation of possibilities for workspace concept and design. Perhaps, from an acoustic perspective, the most significant difference is the extent to which people are able to exercise choice over where they work at any particular time. Control over one's environment is a strong modifier of annoyance. While the irrelevant speech effect (ISE) can objectively impair cognitive performance, it may be that annoyance is a more significant impact. Annoyance may not be simply proportional to the ISE, because of the modifying effect of the sense of personal control.

3. OPPORTUNITY IN THE NEW ISO/WD 22955

The new ISO/WD 22955 will have criteria for different types of space, where these predominate across the floor plate. The new standard is inspired by the French Standard NF-S31-199 (10), and takes the same approach, starting with the acoustic requirements of the workers who are the users. There are three stages of description of the acoustic environment that workers need to undertake different types of work. The open plan office is conceived in a traditional manner, comprising workstations at desks. The acoustic targets and requirements are described for:

- The acoustic conditions at the workstation - described with a target in-situ level for ambient sound from all sources, including activities within the office. The range here is a target rather than a requirement of the Standard.
- The acoustic relationship to the adjacent workstations - described as an in-situ attenuation of speech, $D_{n,A,S}$ from one workstation to another.

- The acoustic characteristics of the floorplate, described in terms of the spatial decay of speech, $D_{2,S}$, and the speech level at 4 metres, $L_{p,A,S,4m}$, as defined in ISO 3382-3.

The different types of activity currently proposed, for acoustic classification purposes, are:

- Breakout
- Phone
- Collaborative
- Non-collaborative

An additional section considers acoustic requirements between different activity types. This has led to the development of a new method proposed below.

4. A NEW APPROACH

A new approach is proposed to assess acoustic conditions between different types of functional areas within an open plan office. This may be particularly suitable for assessing activity-based working (ABW) offices, or for the partial remodeling of existing floor plates to introduce more varied workplace settings within an otherwise traditional layout. For example, the introduction of collaborative areas, or seating for focused activity - either individual work or phone calls, adjacent to traditional desking, can all benefit from acoustic consideration. Previously there have been no practical tools available to the acoustician to assess these adjacencies.

The new approach is summarised as:

1. Use Liveliness to characterise the acoustic environment that would be suitable for the different activities - this may be measured if the environment already exists, or assessed.
2. Consider the source voice level – i.e. "normal", higher or lower depending on the context for the source.
3. Determine appropriate background noise levels - this can be measured if the environment exists, otherwise it may be designed with a masking sound system, or assessed based on the size of the open plan office and the activities taking place.
4. Adopt a suitable unwanted-speech signal-to-noise ratio (SNR) for the sensitive receptor from the source in question. The difference in Liveliness ratings for the two spaces gives the SNR requirement considered appropriate, but an alternative may be adopted.
5. Determine the requirement for the in-situ attenuation of speech between workplace settings in terms of $D_{n, A, s}$., which informs the layout design.

This new approach can be used to identify potential for acoustic conflicts between different types of use or activity - where the calculated $D_{n, A, s}$ falls short of the value determined for good acoustic conditions. This method can 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. However, the context should always be considered and the values adopted modified to suit the circumstances, rather than applying the method consistently in different offices. For example, the duration for which the particular source of noise may be present can be considered: an impact which may not be desirable if the source is continuous (e.g. a worker continually on the telephone) may be acceptable if it is only occasional (e.g. occasional phone calls).

4.1 Use types to consider adjacencies

Although ISO/WD 22955 contains general use types that may prevail over an area or floor plate, a few additional use types are necessary to consider adjacencies between specific functional uses. The proposed use types are shown in Table 1. These are intended to cover the main acoustic categories of use type, as examples to compare with project-specific requirements. Note that the category "breakout" can have a plethora of meanings as well as a wide variety of uses at different times.

4.2 Liveliness

The term "Liveliness" is used to characterise the in-use open plan office acoustic environment, as described by Vellenga (11). The semantic description is correlated with an objective measure, based on 5 minute sample periods. The objective measure is a combination of the A-weighted sound level, $L_{Aeq,5min}$, and the fluctuation strength. The fluctuation strength is measured as the difference between the statistical level of A-weighted sound exceeded for 5 % of the time, $L_{A5,\ 5\ min}$, and the $L_{Aeq,5min}$. Liveliness is measured by recording the sound in five minute samples at a workstation (i.e. a normal working position) that is unoccupied during the measurements. Liveliness is likely to vary both spatially across an office, and also temporally at any one position, as both local and more distant activities vary. The temporal variation at different places can exhibit different patterns. In an ABW office the acoustic environment should vary for the different areas to be suitable for different activities. Liveliness is simple to measure, and understanding its meaning is straight forward, as the objective rating is correlated with semantic descriptions.

4.3 Determining Liveliness ratings and background sound level

When remodeling an existing office, it is prudent to measure the ambient sound around the locations that will remain with their current use. The temporal distribution of Liveliness and background sound levels can be evaluated from the survey data. When designing a new office environment, assumptions must be made to determine suitable values for Liveliness and background sound level.

The principal source of background sound in larger open plan offices is usually the distant activity of people; in smaller open plan offices, background sound levels can be low. Paradoxically, low background sound levels can lead to complaints from occupants that "it is too noisy"; this may be interpreted as "speech is too distracting" in the acoustician's lexicon. Thus as well as the type of activities being undertaken, the size of the office is a significant factor when assessing potential background sound levels. Background sound levels can vary spatially across an open plan office, particularly if there is significant screening between different areas or zones. Depending on the type of office and type of work being undertaken, the example values shown in Table 1 may be suitable to adopt.

Table 1 – Use types, example values of Liveliness and assumed background sound that may be suitable

Use type	Liveliness rating	Background L_b, dB(A)	Notes
Breakout	8	-	"Breakout" can refer to a wide range of different types of activity. In this example, Breakout is assumed to be an amenity space where people seek refreshment, restoration, and talk about non-work-related topics.
Meetings	7	48	Meetings are collaborative in nature, hence a relatively Lively rating is assumed. Meeting spaces for two people are likely to have a different impact from larger meeting spaces within an open plan area
Phone (call centre)	6	48	The background sound level here is taken from the lower end of the target range for ambient sound from NF S31-199.
Collaborative	6	45	The background sound level is taken from the lower end of the target range for ambient sound in NF S31-199.
Non-collaborative	5	42	Preferably calmer than collaborative spaces. The background sound level is taken from the middle of the target range for ambient sound in NF S31-199.
Focused phone	6/4	42	A protected area for making phone calls, rated with a higher Liveliness as a source compared to rating as a receptor.
Focused individual work	3	40	A specially-protected area, enabling lower background sound levels. May be in a shared cellular room or area for acoustic protection, or an individual booth.

4.4 Signal to noise ratio to describe intrusion and impact of unwanted speech

ISO 3382-3 relies on STI to assess speech intelligibility. The new method uses signal to noise ratio (SNR) in the first instance, so that the acoustic designer can gain more insight into the different acoustic components that combine to give the STI - ie source level, attenuation in transmission, reverberation, and masking sound level. SNR has been correlated with other measures of intelligibility by Lazarus (12), an extract of which is reproduced in Table 2.

Table 2 – Speech Intelligibility Evaluation, from Lazarus, 1987

Parameter	Value for comparison					
STI	0.1	0.2	0.3	0.4	0.5	0.6
SNR, dB	-12	-9	-6	-3	0	3

The new approach is based on the impact of one workstation on another in terms of signal to noise ratio (SNR), where the "signal" is the unwanted speech. The "noise" level is based on the background sound level that includes sound from the more distant activity within the office. The acoustic parameter used to describe this noise level is the statistical parameter for the A-weighted sound level exceeded for more than 90% of the time, $L_{A90,T}$. This parameter reflects more a measure of the "quiet" rather than the "noise", as it is only for 10% of the time that the ambient sound is below this level. Hence it may be a reliable level when considering the effect of masking unwanted speech.

This is a deliberately simplistic approach to quantifying the impact of the ISE. There are many advantages of a simplistic approach, not least the ease of understanding and accessibility to a wide range of people. The simplification means that many of the subtleties around factors governing the impact of the ISE are lost. For example, the reduced intelligibility of speech due to the reverberant characteristics of the room is not included in a simple SNR assessment. This may be included in the manner proposed by Wenmaekers et al (13), by reducing the effective SNR by 3 dB to account for the reverberant effect of the room on speech intelligibility. The general simplification of using SNR rather than STI is considered an acceptable compromise for most situations; of course, the assessment can revert to using STI if transmission has strong frequency characteristics, for example.

4.5 Annoyance depends on control, expectations and sensitivity

The expectation for and tolerance to intrusive or distracting sounds is highly dependent on the type of activity undertaken, and the level of control that the user has over the source of noise and which workplace location they occupy. For example, people engaged in individual focused work are likely to be more sensitive to intrusive sounds compared to people collaborating on a task. However, if they can choose where they go within the office to perform their work, and the source noise is in character with the environment they have chosen, they may be less annoyed than people at assigned desks subject to the same intrusive sound level.

A requirement for an increase in acoustic protection from one location to another can be characterised in terms of a preference for a decreased SNR. The increase in acoustic protection that is appropriate between dissimilar uses or tasks can be related to the difference in the expected Liveliness rating between those uses, but this approach should not be applied without consideration of the context.

The activity described as "focused phone" is used to describe a place for making phone calls that requires more than the normal level of attention. Such a place would preferably have lower ambient noise levels than a call centre, and a lower SNR for speech from other workers compared with a call centre. This is an example of a type of activity that does not support many workers engaging in the same activity to be grouped together within an open plan office without acoustic protection between workstations. The Liveliness rating of this activity as a source of noise differs from its rating for tolerance to noise.

4.6 Identifying suitable SNRs

A matrix of SNRs to describe the enhanced protection from one particular activity to another would be of great use in the design process. However, there are so many contextual factors that any such example matrix must be approached with a large degree of caution. The initial concept to grade the acoustic separation between dissimilar spaces is to use the difference in Liveliness rating between source of noise and receptor as a multiplier for the SNR requirement in decibels. A multiplier of 3 is used in the example values to determine a predicted SNR requirement, as shown in Equation 1. This predicted value is then modified by considering each adjacency pair in turn to identify a SNR that may be suitable; the modified values are shown in Table 3. In practice the particular context should be considered rather than simply adopting the values in Table 3.

$$Predicted\ SNR\ requirement = (Source\ Liveliness\ rating - receptor\ Liveliness\ rating) * 3dB \quad (1)$$

4.7 From SNR to in-situ attenuation

Background sound levels may be assumed for each type of space, as illustrated in Table 1. A suitable source noise level can also be assigned to the particular source area. This may be a standard speech source level of 57 dB(A) @ 1m as described in ISO 3382-3; it may also be a raised voice (63 dB(A) @ 1m), a low voice (51 dB(A) @ 1m), or another level. The in-situ level difference, $D_{n,A,s}$ can be determined between different types of spaces, based on the SNR requirement, speech source level, background noise level. The calculation for $D_{n,A,s}$ is shown in Equation 2, with potential values illustrated in Table 4 based on a standard speech source level.

$$D_{n,A,s} = L_{s,A} - SNR - L_b \quad (2)$$

Where, from Table 3:
SNR is the potential signal to noise ratio required
L_b is the background sound level, described for example in Table 1.
$L_{s,A}$ is the speech source level at 1 m in the freefield, based on the speech sound power.

Table 3 – Potential SNR ratings between different activities, and associated background sound levels

Source / receiver space type	Liveliness rating	Meetings (open plan)	Phone (call centre)	Collaborative	Non – collaborative	Focused phone	Focused individual work
Liveliness rating		7	6	6	5	4	3
Assumed L_b		48	48	45	42	42	40
Breakout	8	-6	-6	-6	-9	-12	-15
Meeting (open plan)	7	-6	-3	-3	-6	-9	-12
Phone (contact centre)	6		0	0	-3	-6	-9
Collaborative	6			0	-3	-6	-9
Non-collaborative	5				0	-3	-6
Focused phone	4					-6	-9
Focused indiv' work	3						0

Table 4 – Potential $D_{n,A,s}$ requirements between different types of spaces, based on a standard speech level

Source / receiver space type	Meetings (open plan)	Phone (call centre)	Collaborative	Non – collaborative	Focused phone	Focused individual work
Breakout	15	15	18	24	27	32
Meeting (open plan)	15	12	15	21	24	29
Phone (contact centre)			12	18	21	29
Collaborative				18	21	26
Non-collaborative					18	23
Focused phone					21	26

5. Design implications

The primary requirement for achieving acoustic satisfaction is to enable the set of project-specific SNRs within an overall ambient noise environment that is also appropriate and conducive to the type of work undertaken. As the SNR is achieved with the combination of attenuation between source and receiver, and the background sound level, an appropriate balance is required between these two otherwise separate aspects of the acoustic design to facilitate effective functioning of the workspace.

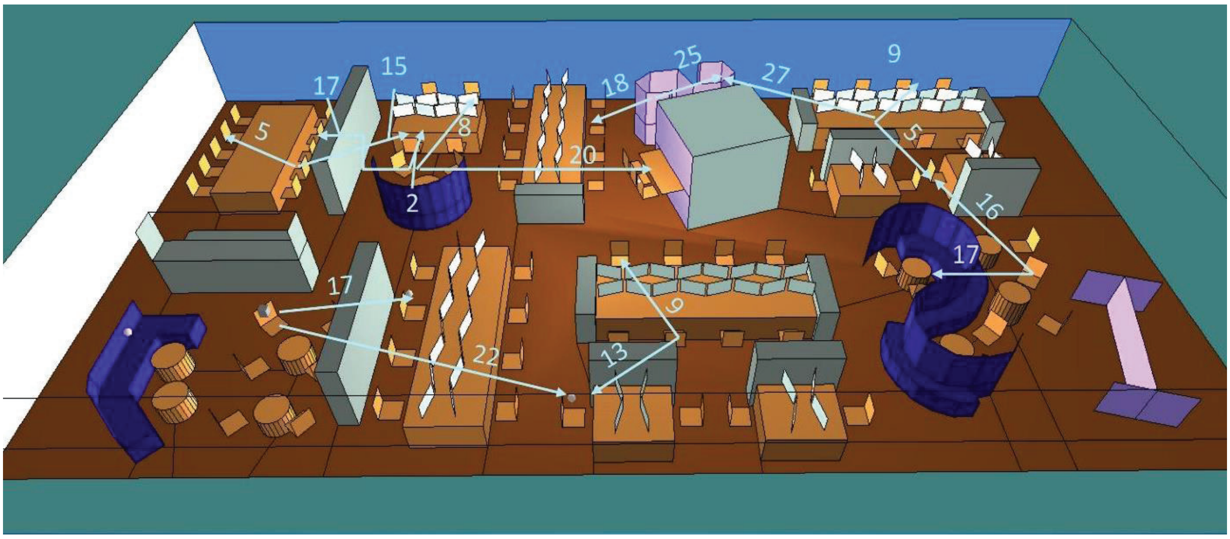
5.1 Managing the background sound level

A raised background noise environment, if sufficiently loud, can mask any particular intrusive sound. Sound masking systems may provide some assistance by avoiding the problem of offices being so quiet that speech from greater distances becomes distracting. Workers often report this type of office to be "too noisy", when the acoustician may consider it to be "too quiet". The use of masking sound systems is controversial; the level and type of sounds that may be acceptable to most people are often too quiet to provide much effective masking, according to Martin (14). Martin also notes that annoyance at the level of masking sound may not preclude its benefits in reducing distraction and improving task performance. Background sound levels that are found to be acceptable may depend strongly on the size of the office, as well as the type of work being undertaken. In larger offices there is likely to be more sound from greater distances, whereas in smaller offices there is a greater risk of lower background sound levels. The German VDI 2569: 2016 makes a distinction between "small" and "large" multi-person offices where the maximum distance between workstations is 8 m. When considering background sound levels, a larger size may be required in order to rely on the background sound from more distant activities.

5.2 Managing attenuation between workstations

The in-situ attenuation of speech, $D_{n,A,s}$ is a new parameter. It is important to gain some feeling for the implications of the values described in Table 4 – to understand the design implications. As currently described in the French Standard NF S31-199, the parameter $D_{n,A,s}$ is measured between the positions of a seated talker and seated listener, unless otherwise noted, with source and microphone positions 1.2 m above floor level. NF S31-199 does not describe A-weighted attenuation based on the speech source spectrum – this additional detail is added in ISO/WD 22955. Figure 1 illustrates an extract from a CATT acoustic model, with the values of $D_{n,A,S}$ indicated between selected positions. These calculated values are interpreted as a little higher than values that may be measured in practice.

Figure 1: Calculated values for $D_{n,A,S}$ between particular positions from a CATT Acoustic model



6. CONCLUSIONS

The theory that reducing the intelligibility of unwanted speech can improve acoustic satisfaction is well established and demonstrated in laboratory studies. However, acoustic satisfaction in real workplaces is only loosely correlated with the distraction distance, r_D, measured over the floor plate. If acoustic designers are only motivated and equipped to propose features in the pursuit of achieving lower values of r_D, the inferred design requirements may be in conflict with other aesthetic aspirations for the accommodation and internal environmental conditions; more importantly, the overall goal of acoustic satisfaction and workplace efficacy may be missed entirely.

Control over one's environment is likely to be a stronger indicator for workers' acoustic satisfaction than any technical acoustic features. As the nature of the workplace changes to become more fluid and less based on assigned workstations, people's tolerance to intrusive sounds may well also adapt.

The proposed method for ISO/WD 22955 extends the concept of the impact of unwanted speech and intrusive sounds; these preferences can be used to determine in-situ attenuation requirements between specific workstations. This can be most effectively achieved within an environment that has appropriate treatment for sound absorption. The proposed method for ISO/WD 22955 supports, rather than conflicts, the work of the workplace designer.

ACKNOWLEDGEMENTS

As well as the authors, many other people contributed to the ideas in this paper, in particular Patrick Chevret (INRS) and Remy Wenmaekers (Level Acoustics). Thanks also to the ISO/WD 22955 committee for sharing their views.

REFERENCES

1. Hongisto V. A model predicting the effect of speech of varying intelligibility on work performance, Indoor Air 2005; 15: 458–468.
2. Chevret P, Parizet E, Kostallari K. A simple sound metric for evaluating sound annoyance in open-plan offices, in ICBEN, Zurich, 2017.
3. Kostallari K, Parizet E, Chevret P, Amato J-N, Galy E. Irrelevant Speech Effect In Open Plan Offices: A Laboratory Study, in ICSV24, London 2017.
4. Ellermeier W, Rost K, Schlittenlacher J. Pixelated speech: Manipulating the temporal resolution of spectral and level changes in disruptive irrelevant background noise, in Internoise, Hamburg, 2016.
5. Schlittmeier SJ, Liebl A. The effects of intelligible irrelevant background speech in offices – cognitive disturbance, annoyance, and solutions, Facilities, Vol. 33 Iss 1/2 pp. 61 – 75, http://dx.doi.org/10.1108/F-05-2013-0036.
6. Haapakangas A, Hongisto V. Distraction distance and perceived disturbance by noise—An analysis of 21 open-plan offices, The Journal of the Acoustical Society of America 141, 127 (2017); https://doi.org/10.1121/1.4973690.
7. Skogland M, Skjæveland O. Cells, open landscape or free seating? The changing architecture of the office workspace, The Norwegian Review of Architecture 2016; 06
8. Larrieu F, Harvie-Clark J. Contrasting Open Plan Office Design Implications from Emerging French, German and Finnish Standards, in ICSV24, London 2017.
9. Usher N. Blog at http://workessence.com/alltheworkstyleswehaveeverloved/
10. NF S31-199: 2016. Acoustique – Performances acoustiques des espaces ouverts de bureaux. AFNOR.
11. Vellenga S, Bouwhuis T, Höngens T. Proposed Method for Measuring 'Liveliness' in Open Plan Offices, in ICSV24, London, 2017.
12. Lazarus H. Prediction of Verbal Communication in Noise – A development of Generalized SIL Curves and Quality of Communication (part 2)*, Applied Acoustics 20 (1987) 245 - 261
13. Wenmaekers R, Hak C. Spatial decay rate of speech in open plan offices: the use of $D_{2,S}$ and $L_{p,A,S,4m}$ as building requirements. Proc EuroNoise 2015, 31 May - 3 June, Maastricht, Netherlands
14. Martin N, Liebl A. Sound Masking in Office Environments - Trade-off between Masking Effect and User Acceptance, The Journal of the Acoustical Society of America 141, 3598 (2017); https://doi.org/10.1121/1.4987690.