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NOISE CONTROL FOR A BETTER ENVIRONMENT

The Application of the STI-Matrix – a powerful strategy to support the planning of acoustically optimized offices, restaurants and rooms where human speech may cause problems.

Michael Böhm[a)]
DataKustik GmbH
Dornierstr. 4
82205 Gilching
Germany

ABSTRACT

Complaints about noise in offices, restaurants and other public areas mostly originate in unwanted intelligibility of speech from other areas or in a lack of intelligibility within the own communication area. For any planning scenario these problems can be uncovered and minimized using computer-based simulation techniques. An innovative method which checks the requirements for the intelligibility by an automated calculation of the Speech Transmission Index STI for every pair of workplaces/positions will be presented using practical examples. The most important steps of a target-oriented acoustic planning are demonstrated – including the determination of the background noise, the STI calculation to the interpretation of the intelligibility-based "assessment-matrix".

Keywords: STI, STI-matrix, indoor, office, open plan office, simulation,
I-INCE Classification of Subject Number: 76

1 INTRODUCTION

VDI 2569[1] and ISO 3382-3[2] asses the acoustic quality in open plan offices taking into account the decay of speech along several measurement paths along a set of workplaces.
The concept of the STI-matrix presents a new and more comprehensive approach which includes the relations between any pair of workplaces and therefore provides a more profound basis for any evaluation.

In this paper, the STI-matrix and its application are presented for offices intended for focused individual work. The background noise in these offices is typically determined by technical equipment like the ventilation system or noise from outside. Any kind of noise which erupts from this background noise is considered to disturb the concentration of the persons working in this office. However, very often this disturbance is caused by speaking coworkers. This frequent issue is addressed by the STI-matrix by deducing the number of disturbed persons by any one speaking

[a)] email: michael.boehm@datakustik.com

person taking in to account the speech signal levels as well as the background noise level. The concept and the general dependencies are at first pointed out in the case of an artificial test room. Afterwards the application of the STI-matrix for two real office planning scenarios is demonstrated.

2 ARTIFICAL TEST ROOM

Figure 1 contains the layout of the artificial test room. It has a squared shape with 17,5m x 17,5m and is 3m high. The "workplaces" are positioned in regular order as squares with 3,5m x 3,5m working area per place. The position of the head of the sitting worker is in the middle of the workplace at 1.20 m height. The sound power level and the spectrum for speech are assigned according to ISO 3382-3.

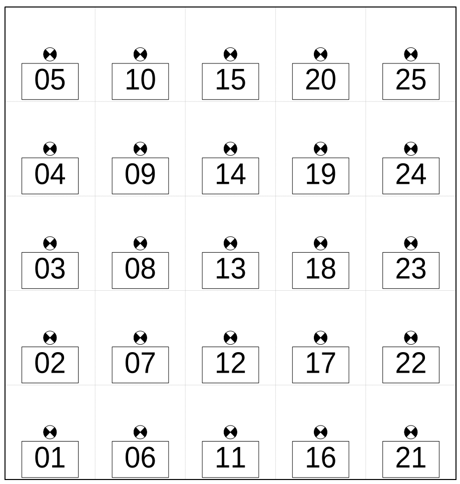

Fig. 1 – Layout of the artificial test room with 25 workplaces. Total dimensions:17,5m x 17,5m x 3m.

The test room will be studied in three configurations as shown in figure 2:

a) as a reverberant room with an absorption coefficient of 0.1 for each octave at ceiling, floor and walls.
b) With an added acoustic ceiling (absorption coefficient 0.85 for each octave).
c) With acoustic ceiling and additional non-absorbing screens with 1.6 m height between the workplaces.

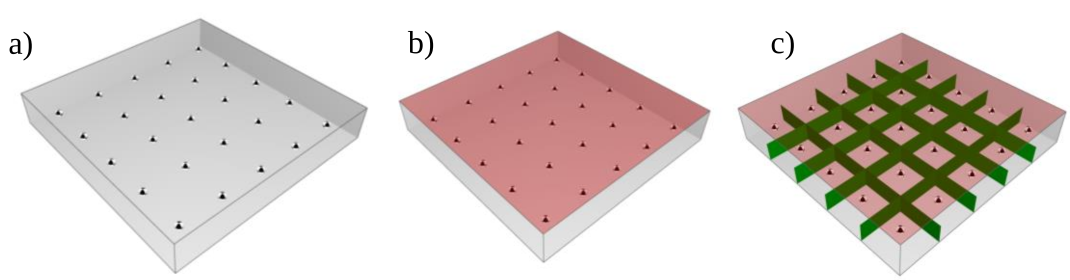

Fig. 2 – Configurations of the artificial test room: a) reverberant room, b) with acoustic ceiling,

c) with acoustic ceiling and screens.

For each of the three configurations a set of calculations is performed in an automated manner. Starting with a speaking person at position one, the speech level and the energy based impulse response is determined at each other position. This process is repeated with the speaking person at each position.

3 LEVEL-MATRIX

The first result of these calculations is the matrix of the speech levels. It is displaying the speech levels occurring at any listener position caused by any one speaking person (only one person speaking at the same time). A part of the level-matrix for the test room with acoustic ceiling (configuration b) is shown in figure 3. For example, a speech level of 49,6 dBA is caused at listener position 7 (IO07) if the speaker at position 3 (SP03) is speaking.

L_{pA} [dB]		Speaker position							
		SP01	SP02	SP03	SP04	SP05	SP06	SP07	...
Listener position	IO01		52.6	48.9	46.9	46.2	52.6	50.4	...
	IO02	52.6		51.8	48.3	46.9	50.4	51.4	...
	IO03	48.8	51.9		51.8	48.9	48.1	49.6	...
	IO04	46.9	48.2	51.9		52.6	46.6	47.5	...
	IO05	46.2	46.9	48.8	52.6		46.0	46.6	...
	IO06	52.6	50.5	48.1	46.6	46.0		51.5	...
	IO07	50.4	51.4	49.6	47.6	46.6	51.4		...
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

Fig. 3 – Part of the level-matrix for the test room with acoustic ceiling (configuration b) showing the speech level caused by one simultaneously speaking person at any listener position.

In total the level-matrix contains all 600 possible "speech-channels" between any speaker to any listener position. It is convenient to display these speech levels in the way known from VDI 2569 and ISO 3382-3 as speech levels over distance between speaker and listener (figure 4) – now containing any of the 600 speech channels. This level diagram is the first key-figure for the assessment of these type of offices.

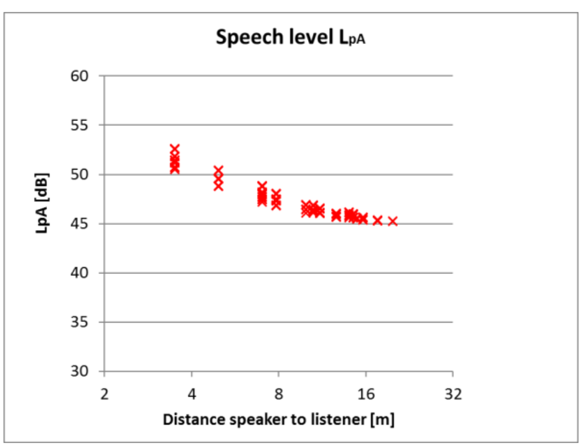

Fig. 4– Graphic display of the speech levels for the test room with acoustic ceiling (configuration b) showing the speech levels as a function of the distance between speaker and listener.

4 STI-MATRIX

The second result of the simulation calculations is the STI-matrix. It is deduced from the energetic impulse responses taking into account the background level. Figure 5 shows a part of the STI matrix for the test room with acoustic ceiling assuming a constant background noise of 40 dBA at each listener position.

STI		Speaker position							
L_B 40 dBA		**SP01**	**SP02**	**SP03**	**SP04**	**SP05**	**SP06**	**SP07**	**...**
Listener position	**IO01**		0.71	0.57	0.50	0.48	0.71	0.63	...
	IO02	0.71		0.67	0.54	0.50	0.63	0.66	...
	IO03	0.57	0.67		0.68	0.57	0.54	0.59	...
	IO04	0.50	0.54	0.68		0.71	0.49	0.51	...
	IO05	0.48	0.50	0.57	0.71		0.47	0.49	...
	IO06	0.71	0.63	0.54	0.49	0.48		0.66	...
	IO07	0.64	0.66	0.59	0.51	0.49	0.66		...
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

Fig. 5 – Part of the STI-matrix for the test room with acoustic ceiling (configuration b) displaying the STI-values resulting at any listener position with one speaking person at any speaker position assuming a constant background noise of 40 dBA.

For example, if one person at position 2 (SP02) is speaking, the STI at the listener on position 6 (IO06) has a value of 0,63 assuming a background noise of 40 dBA.

Since STI-values above 0.50 are considered to have a strong negative effect on the cognitive capabilities (see e.g. [1] and [2]), the STI-matrix now allows to determine the actual number of persons which are disturbed in their concentrated work by the speech signal of a speaking coworker by simply counting the listeners affected by a STI of more than 0.50 for a given speaker. Averaging the number of persons with an STI of more than 0.50 over all speaker positions gives a good measure how many persons are disturbed in their concentrated work if any one coworker is speaking. It describes the range of the negative effects of a speaking person expressed in a number of disturbed persons.

This average number of persons with STI > 0.5 is in the same way obtained for further background noise levels by re-evaluating the STI-matrix from the stored impulse responses taking into account the new background noise levels. This results in the following key-figure showing the dependency of the disturbed persons for various background noise levels.

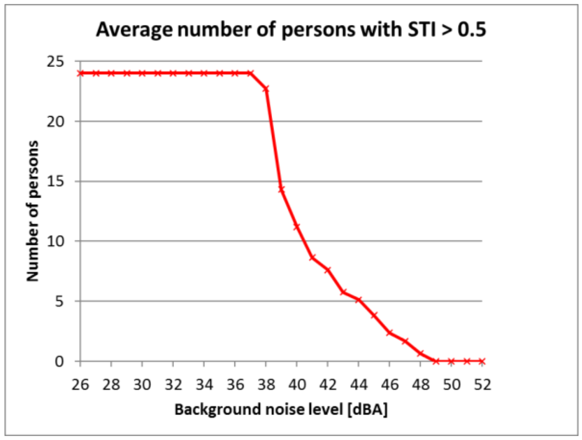

Fig. 6 – Average number of persons with STI above 0.5 for various background noise levels for the test room with acoustic ceiling (configuration b). This gives the average number of workers disturbed in their concentrated work by the speech signal of any one speaking coworker at a given background noise level.

As expected, the number of workers disturbed by the speech signal of a coworker strongly depends on the background noise level. In this scenario for background noise levels of 38 dBA and below one speaker in the test room would disturb any other coworker in his concentrated work. With background levels of 49 dBA and above the background level masks the speech signal strong enough that the speech signal itself does not disturb any coworker anymore. Of course, these quite high background levels themselves may be considered acoustically undesirable.

To study the general dependencies, the key-figures which are deduced from the level-matrix and the STI-matrix are now presented for all three configurations of the test room.

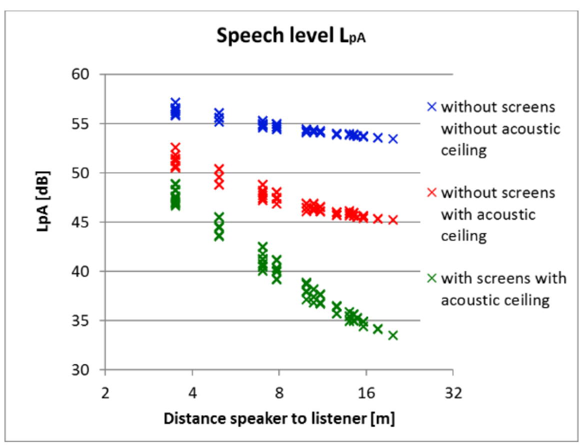

Fig. 7 – Graphic display of the speech levels for the test room in three configurations.

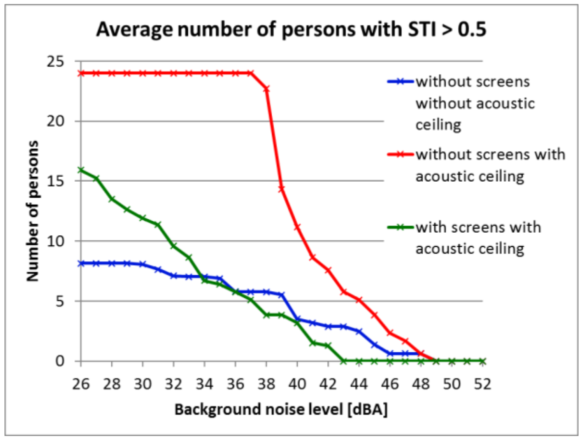

Fig. 8 – Average number of persons with STI above 0.5 for various background noise levels for the test room in three configurations.

Comparing the reverberant room (blue color in figure 7 and 8) with the room with acoustic ceiling (red color in both figures) without screening effects shows that adding the acoustic ceiling leads to decreased speech levels (figure 7) but also increased intelligibility and therefore increased disturbance caused by a speaking person over a wide range of background noises (figure 8). This effect is reported frequently: after adding absorbing material at ceiling, floor or walls of an office which has been considered as uncomfortably reverberant, the workers complain that they now clearly understand speaking coworkers located far away from their own working space.

It is obvious, that in these situations screens provide an effective measure to avoid the unwanted increased intelligibility. Consequently, it can be seen in figure 7 and 8 (green color) that additional screens further decrease the speech levels while also limiting the number of workers which are disturbed by a speaking coworker.

Comparing the number of disturbed workers in figure 8 in the reverberant room (blue) with the one with acoustic ceiling and screens (green) it has to be pointed out that the effects limiting the intelligibility are different in both cases (see also [3]). In the reverberant room the modulation depth of the speech signal is reduced, the signal is “smeared out” and therefore not intelligible. The speech signal is loud, but not clear. In the not reverberant room with screens the speech signal is clear but not loud enough to stand out over the background noise. The intelligibility is then limited because the speech signal is masked by the background noise.

These two key figures – the level-diagram and diagram showing the average number of disturbed persons – efficiently display the general dependencies for the acoustic planning and optimization of these kind offices for focused individual work. The figures always have to be considered together: The target is a minimal number of disturbed persons with low speech levels at the same time.

4 REAL OFFICE EXAMPLES

Although in real cases an acoustic office optimization usually combines screening measures with measures to reduce reverberation, the targets remain as discussed at the artificial test room: decreased intelligibility at a broad range of background noises and decreased speech levels at the same time. The following two examples show such successful acoustic optimizations.

A model of the first office example created and calculated with the software CadnaR [4] is displayed in figure 9. The office has an elongated layout with 21 workplaces. The existing situation is colored in gray. Workers in the office complained that speaking coworkers have been understood too good, concentrated work was difficult if any coworker was speaking. To improve the situation the acoustic measures displayed in red in figure 8 have been introduced: absorbing screens and absorbers at ceiling and walls have been added.

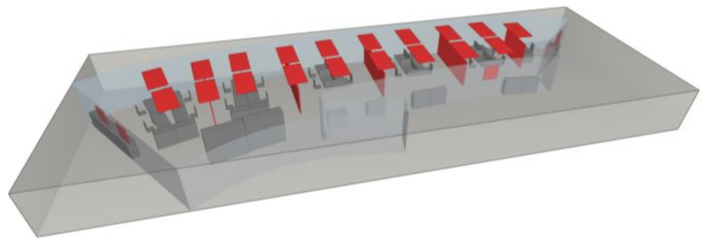

Fig. 9 – Office example one. Elongated layout with 21 workplaces. The existing situation is displayed in gray. The measures to acoustically improve the situation are displayed in red: absorbing screens and absorbing elements at the wall and the ceilings.

The key-figures deduced from level-matrix and STI-matrix are figure 10 and 11. The effect of the acoustic optimization is clearly visible in both the reduced speech levels and the reduced intelligibility.

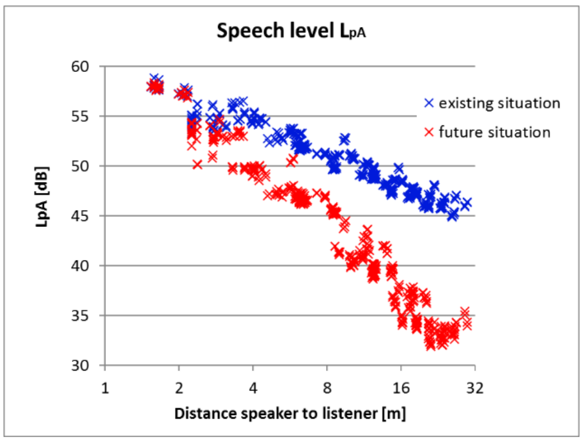

Fig. 10 – Graphic display of the speech levels for office example one.

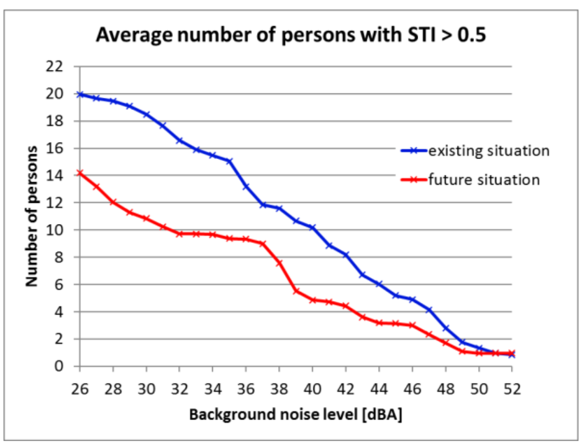

Fig. 11 – Average number of persons with STI above 0.5 for various background noise levels for office example one.

The second office example with 24 workplaces is displayed in figure 12. The existing situation is colored gray whereas the acoustic improvements -absorbing screens- are colored in red.

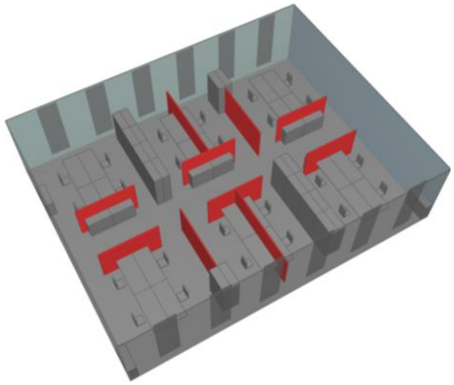

Fig. 12 – Office example two with 24 workplaces. The existing situation is displayed in gray. The absorbing screens to acoustically improve the situation are displayed in red.

The key-figures 13 and 14 clearly show that the screens are effective in reducing the speech levels and the intelligibility. Nevertheless, their effect is limited due to the high occupation density of about 9 m^2 per workplace. Higher distances between the individual workplaces would further improve the situation.

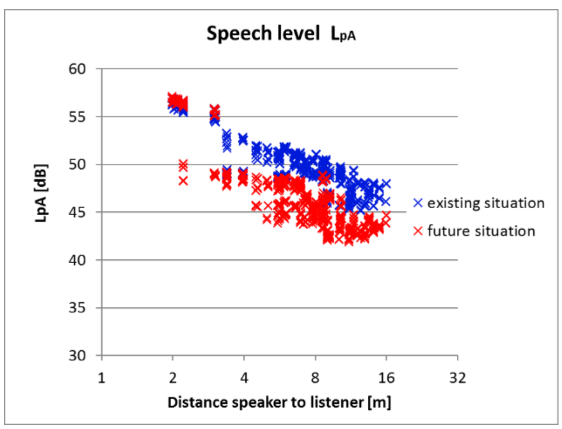

Figure 13 – Graphic display of the speech levels for office example two.

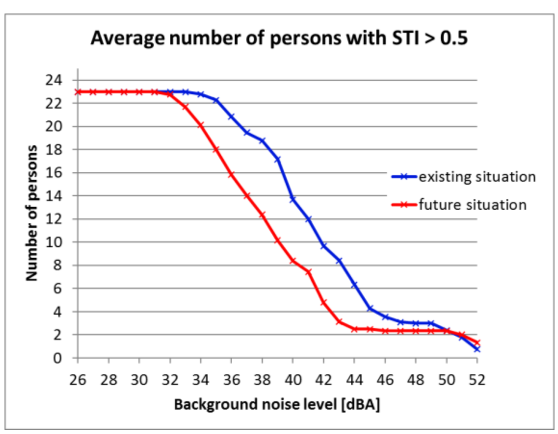

Figure 14 – Average number of persons with STI above 0.5 for various background noise levels for office example two.

5 CONCLUSION AND OUTLOOK

The level-matrix and the STI-matrix and their deduced key-figures level-diagram and diagram showing the average number of disturbed persons prove to be a profound basis for the evaluation and assessment of the acoustic situation in offices intended for focused individual work taking into account every pair of speaker and listener.

In a further step a classification for the speech levels (e.g. for the speech level in 4m distance from the speaker and the spatial decay rate $D_{2,S}$) and the average number persons with STI above 0.5 in certain background noise level intervals could be introduced.

The concept of the STI-matrix is also applicable for offices with other intended uses. At first, it has to be defined if intelligibility is desired (for example for a good communication within the same team of workers) or if it is unwanted (for disturbance or privacy reasons). The second step is to determine the adequate background noise. This can be achieved by assuming a constant background noise or calculating the background noise from known technical sources or other speaking workers in the office (e.g. in callcenters). In the third step is a tailored acoustic planning taking into account the requirements for the intelligibility, the background noise and possibly even additional spatially restricted masking systems.

6 REFERENCES

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