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### ► To cite this version:

Tobias Renz, Max Funk. Source-receiver matrix to assess room acoustic parameters in open-plan offices. e-Forum Acusticum 2020, Dec 2020, Lyon, France. pp.2195-2200, <10.48465/fa.2020.0091>. <hal-03235214>

**HAL Id: hal-03235214**

**<https://hal.science/hal-03235214v1>**

Submitted on 13 Jun 2021

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# SOURCE-RECEIVER MATRIX TO ASSESS ROOM ACOUSTIC PARAMETERS IN OPEN-PLAN OFFICES

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## ABSTRACT

Acoustical privacy is one of the most crucial, yet least satisfying aspects in open-plan offices. The assessment of acoustical conditions in occupied offices is challenging, and hence room acoustic parameters are commonly determined in unoccupied offices. This paper presents a new approach to apply a source-receiver matrix to determine the room acoustic parameters of open-plan offices similar to ISO 3382-3. The method is used to compare the effects of acoustic screens and wall absorption.

## 1. INTRODUCTION

Background speech in offices deteriorates subjective well-being and work performance (e.g. [1–5]). The speech transmission index (STI) is suggested to predict both subjective noise disturbance and work performance (e.g. [1, 3, 5–8]). Using the STI is an established method applied during the design and development phase of open-plan offices [7, 9, 10]. Recent findings show that the highest change in short-term memory performance occurs between STI values of 0 and 0.5 [7, 11]. However, STI measurements can only estimate the disturbing impact of a simulated speech source on one distinct transmission path. They cannot assess multi-talker environments and differing acoustical situations that frequently occur in occupied open-plan offices.

The national standards in France, Finland and Germany focus on the the acoustical design of open-plan offices. The French standard NF S31-199 [12] recommends spatial decay rates  $D_{2,S}$  of more than 7–9 dB and reverberation times below 0.6 s. Target values are provided for four different work types, namely telephone work, collaborative work, low-level or non-collaborative work, and public receptions, depending on the A-weighted sound pressure level (SPL). The Finnish standard guideline RIL 243-3-2008 [13] classifies the target values into four classes. The values are based on the following measurement parameters: spatial decay rate of speech  $D_{2,S}$ , A-weighted SPL of speech at a distance of 4 m  $L_{p,A,S,4m}$ , and distraction distance  $r_D$ . *Haapakangas et al.* [1] showed that a higher distraction distance correlates with increased disturbance by noise whereas the other above-mentioned quantities may not alone be associated with noise disturbance. The Finnish room acoustic regulations from 2018 mention target values of reverberation times below 0.6 s and STI values below 0.5 in open-plan offices (cf. [9]). The German guideline VDI 2569 [14] classifies the recommenda-

tions for maximum reverberation times and sound propagation into three groups. While target values of  $D_{2,S}$  and  $L_{p,A,S,4m}$  are provided, target values for STI measurements are not included.

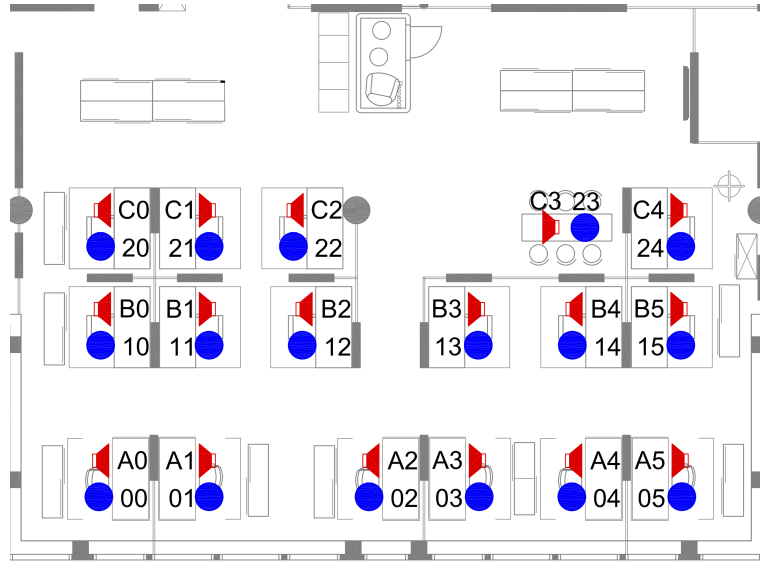
*Dickschen et al.* [10] presented an approach to evaluate STI parameters in acoustic simulations by considering the STI values for all possible source-receiver combinations in a room. They suggested the evaluation of a source-receiver matrix to determine problematic areas with high STI values.

According to ISO 3382-3 [15] the measurement of room acoustic parameters in open-plan offices is done on measurement paths, which can result in notable measurement deviations (e.g. [16–19]). In this study, source-receiver matrices of SPL and STI values are determined by means of simulations. Based on all possible combinations, the SPL of speech at 4 m distance  $L_{p,A,S,4m}$ , the spatial decay rate of speech  $D_{2,S}$ , and the distraction distance  $r_D$  are evaluated. Additionally, the reverberation time is considered. Five different acoustic designs with different acoustic screens and wall absorption are evaluated and discussed. The results indicate that  $D_{2,S}$  cannot alone predict the acoustic quality of open-plan offices. Contrary to the concerns of practitioners, reducing the reverberation time from 0.5 s to 0.4 s or 0.3 s does not predict an increase in speech intelligibility and distraction distance  $r_D$ , while on the other hand the SPL of speech at 4 m distance  $L_{p,A,S,4m}$  is reduced with increasing absorption.

## 2. DESIGN AND PROCEDURE

Acoustic simulations are performed with CATT-Acoustic v9.0c (CATT, Gothenburg, Sweden). A typical office layout with 17 workplaces is selected for this study (see Fig. 1). The dimensions of the office are 16.5 m x 12.0 m x 3.0 m. An overview of the material properties is given in Tab. 1.

Five acoustic designs are evaluated, as summarized in Tab. 2. The ceiling type (cooling ceiling with medium absorption and mineral ceiling), the screen height of sound screens consisting of glazing and an acoustic panel (1.5 m and 3.0 m), and the wall absorption are varied. The speaker and background noise SPL are constant. The SPL  $L_{p,A}$  and STI values are calculated for all possible source-receiver combinations. All STI and SPL values are plotted over the distance (on a logarithmic distance axis) and linear regression is used to predict the average distance at which the STI reaches 0.5, the distraction distance  $r_D$ , and to calculate



**Figure 1.** Layout of the modeled office.

Material \ . Absorption coefficient	$\alpha_{125Hz}$	$\alpha_{250Hz}$	$\alpha_{500Hz}$	$\alpha_{1,000Hz}$	$\alpha_{2,000Hz}$	$\alpha_{4,000Hz}$
Carpet	.02	.04	.12	.20	.36	.57
Walls	.20	.15	.10	.05	.03	.02
Wall absorber	.49	.99	.99	.99	.99	.99
Desk	.02	.14	.19	.14	.17	.16
Shelf	.30	.40	.40	.30	.20	.20
Acoustic screen (absorber)	.49	.99	.99	.99	.99	.99
Acoustic screen (glass sheet)	.20	.15	.10	.05	.03	.02
Concrete columns	.02	.02	.03	.04	.05	.05
Ceiling tiles (cooling ceiling)	.54	.49	.67	.87	.79	.58
Mineral ceiling tiles	.55	.85	.99	.95	.99	.99

**Table 1.** Overview of the used sound absorption coefficients.

the spatial decay rate  $D_{2,S}$  and average SPL at 4 m distance  $L_{p,A,S,4m}$ . The reverberation time  $T_{20}$  (125–4,000 Hz) is also determined. In the following, horizontal bars above the parameters indicate that the parameters were derived from the source-receiver matrix, and were not determined on measurement paths according to ISO 3382-3 [15]

### 3. RESULTS

Fig. 2(a) and Fig. 2(b) show the SPL and STI values for all source-receiver combinations for the design with 1.5 m high screens and a ceiling with integrated cooling system, and Fig. 3(a) and Fig. 3(b) show the SPL and STI values for the design with 1.5 m high screens and absorbing ceiling (mineral ceiling tiles). Based on such matrices, possible areas with high disturbance can be identified and optimized. The estimated distraction distance  $\bar{r}_D$ , spatial decay rate  $\bar{D}_{2,S}$  and average SPL at 4 m distance  $\bar{L}_{p,A,S,4m}$  are estimated from logarithmic regression of all values and summarized in Tab. 3 for the five acoustic designs.

#### 3.1 Screen Height

As expected, the screen height affects the reverberation time  $\bar{T}_{20}$ , SPL at 4 m distance  $\bar{L}_{p,A,S,4m}$ , spatial decay

rate  $\bar{D}_{2,S}$  and distraction distance  $\bar{r}_D$ . Adding screens with 1.5 m height decreases the reverberation time from 0.5 s to 0.4 s, and increasing the screen height to 3.0 m reduces the reverberation time to 0.3 s. As a consequence, the SPL at 4 m distance reduces from 46 dB to 41 dB while the spatial decay rate increases with increasing screen height (from 4 dB to 7 dB), and the distraction distance reduces with increasing screen height (3 m c. t. 5 m).

#### 3.2 Ceiling Absorption

Increasing the ceiling absorption affects the sound attenuation at medium and large distances and the speech privacy: the SPL at 4 m distance  $\bar{L}_{p,A,S,4m}$  decreases from 46 dB to 40 dB and the spatial decay rate  $\bar{D}_{2,S}$  increases from 4 dB to 5 dB. The distraction distance  $\bar{r}_D$  reduces from 5 m to 3 m. At constant background noise SPL, improving the ceiling absorption does not increase the STI values even though the reverberation time  $\bar{T}_{20}$  decreases slightly.

#### 3.3 Wall Absorption

Reducing the wall absorption and absorption of the acoustic screens (with 3 m height) increases the reverberation time, and it increases the SPL at 4 m distance  $\bar{L}_{p,A,S,4m}$

Aspect \. Design	No screens	Half screens	Half screens, absorbing ceiling	High screens, reflecting screens/walls	High screens
Sound screens	none	1.5 m	1.5 m	3.0 m (only glass)	3.0 m
Wall absorbers	yes	yes	yes	none	yes
Cooling ceiling	yes	yes	none	yes	yes
Background noise SPL	38.3 dB(A)				
Speaker SPL	59.5 dB(A)				
Source directivity	directional				

**Table 2.** Overview of the evaluated acoustic designs.

(a)

Source Receiver	Parameter	A0	A1	A2	A3	A4	A5	B0	B1	B2	B3	B4	B5	C0	C1	C2	C3	C4
R00	Lp,A (dBA)	x	46.2	42.1	41.2	38.6	37.5	50.8	49.8	43.5	40.9	39.6	35.7	44.4	42.5	43.1	40.9	36.9
R01	Lp,A (dBA)	45.2	x	46.2	41.3	39.7	39.8	48.7	49.7	48.8	43.2	39.9	39.0	41.5	42.1	46.5	39.7	37.4
R02	Lp,A (dBA)	42.1	46.5	x	44.9	40.9	42.8	43.0	48.4	50.8	48.4	43.2	41.1	40.7	43.9	41.0	40.8	37.8
R03	Lp,A (dBA)	40.3	41.1	43.1	x	52.5	43.7	39.2	38.6	47.1	49.6	50.1	46.4	37.3	39.8	41.0	41.3	42.0
R04	Lp,A (dBA)	38.6	39.5	42.2	52.4	x	46.1	37.8	38.9	41.5	50.1	49.6	49.0	37.6	36.5	40.7	40.7	41.6
R05	Lp,A (dBA)	36.7	37.9	43.8	42.0	45.9	x	37.2	38.4	39.8	45.9	49.3	51.5	34.4	38.2	40.6	41.7	43.9
R10	Lp,A (dBA)	50.8	49.2	42.3	40.2	37.4	36.5	x	44.9	41.4	41.3	38.1	34.3	45.0	43.4	41.3	39.5	36.3
R11	Lp,A (dBA)	48.6	49.6	47.3	42.1	40.8	40.2	43.6	x	49.1	40.9	37.4	38.4	41.9	45.0	48.8	42.4	39.4
R12	Lp,A (dBA)	44.4	48.8	50.1	47.0	39.3	39.6	41.6	48.8	x	42.6	38.7	38.6	41.4	47.7	44.8	41.1	38.3
R13	Lp,A (dBA)	39.3	41.8	48.2	49.8	50.0	47.4	39.9	38.4	42.5	x	50.7	42.4	37.1	40.0	42.0	42.9	42.1
R14	Lp,A (dBA)	40.4	41.7	47.0	49.2	49.6	48.8	38.8	36.7	40.5	50.2	x	43.7	38.7	36.7	41.2	43.4	42.9
R15	Lp,A (dBA)	35.8	38.3	42.2	44.6	48.9	51.0	35.6	37.3	40.2	41.4	43.8	x	34.6	38.9	39.2	40.9	44.9
R20	Lp,A (dBA)	43.5	43.4	39.6	38.1	35.7	33.7	43.7	42.7	39.7	38.2	37.5	34.0	x	43.9	41.2	38.2	32.6
R21	Lp,A (dBA)	42.0	41.7	45.7	41.8	36.6	37.8	42.3	45.4	48.4	41.5	37.5	39.9	43.3	x	51.2	43.2	36.8
R22	Lp,A (dBA)	44.8	46.9	40.2	41.1	39.5	39.3	42.3	48.5	45.1	41.9	39.4	38.1	42.1	49.5	x	43.0	36.6
R23	Lp,A (dBA)	39.8	38.3	41.1	40.9	40.7	41.5	39.9	40.0	41.3	42.1	42.8	42.6	37.5	40.2	41.9	x	44.8
R24	Lp,A (dBA)	35.9	36.0	38.5	40.4	42.1	43.9	36.1	39.0	39.2	40.7	42.7	45.0	32.9	35.1	39.0	42.5	x

(b)

Source Receiver	Parameter	A0	A1	A2	A3	A4	A5	B0	B1	B2	B3	B4	B5	C0	C1	C2	C3	C4
R00	STI (-)	x	0.63	0.46	0.48	0.37	0.33	0.75	0.73	0.5	0.46	0.36	0.25	0.55	0.52	0.51	0.48	0.32
R01	STI (-)	0.57	x	0.58	0.46	0.35	0.43	0.7	0.73	0.67	0.55	0.36	0.4	0.49	0.48	0.61	0.42	0.35
R02	STI (-)	0.5	0.61	x	0.57	0.4	0.53	0.54	0.66	0.76	0.69	0.49	0.45	0.46	0.54	0.45	0.44	0.35
R03	STI (-)	0.44	0.42	0.5	x	0.7	0.54	0.4	0.32	0.65	0.72	0.68	0.64	0.35	0.38	0.46	0.46	0.49
R04	STI (-)	0.4	0.36	0.5	0.71	x	0.61	0.37	0.33	0.49	0.7	0.72	0.7	0.38	0.27	0.45	0.43	0.49
R05	STI (-)	0.3	0.34	0.56	0.45	0.61	x	0.33	0.31	0.43	0.57	0.71	0.76	0.24	0.36	0.46	0.43	0.54
R10	STI (-)	0.75	0.72	0.46	0.45	0.33	0.3	x	0.59	0.44	0.5	0.33	0.23	0.59	0.56	0.43	0.43	0.3
R11	STI (-)	0.69	0.73	0.61	0.48	0.4	0.42	0.53	x	0.64	0.47	0.3	0.39	0.49	0.54	0.67	0.49	0.43
R12	STI (-)	0.55	0.67	0.71	0.65	0.36	0.42	0.5	0.63	x	0.52	0.33	0.4	0.49	0.63	0.55	0.42	0.39
R13	STI (-)	0.41	0.45	0.68	0.71	0.69	0.65	0.46	0.34	0.52	x	0.7	0.5	0.35	0.38	0.49	0.51	0.49
R14	STI (-)	0.43	0.45	0.65	0.67	0.72	0.7	0.4	0.27	0.45	0.67	x	0.55	0.41	0.27	0.46	0.48	0.51
R15	STI (-)	0.27	0.35	0.49	0.55	0.7	0.74	0.27	0.29	0.45	0.42	0.55	x	0.27	0.4	0.42	0.41	0.55
R20	STI (-)	0.54	0.56	0.39	0.37	0.28	0.23	0.53	0.53	0.39	0.39	0.33	0.25	x	0.58	0.44	0.39	0.16
R21	STI (-)	0.48	0.47	0.59	0.46	0.29	0.35	0.5	0.56	0.67	0.49	0.31	0.45	0.55	x	0.79	0.53	0.33
R22	STI (-)	0.6	0.63	0.41	0.44	0.38	0.4	0.51	0.65	0.57	0.49	0.36	0.37	0.52	0.68	x	0.53	0.34
R23	STI (-)	0.44	0.35	0.44	0.42	0.44	0.46	0.44	0.39	0.46	0.45	0.49	0.52	0.38	0.4	0.51	x	0.58
R24	STI (-)	0.28	0.27	0.36	0.4	0.49	0.53	0.3	0.38	0.43	0.4	0.51	0.56	0.19	0.22	0.4	0.46	x

**Figure 2.** (a) SPL  $L_{p,A}$  of design "Half screens". (b) STI values of design "Half screens".

Metric \ . Design	No screens	Half screens	Half screens, absorbing ceiling	High screens, reflecting screens/walls	High screens
$T_{20}$	0.5 s	0.4 s	0.4 s	0.5 s	0.3 s
$L_{p,A,S,4m}$	49 dB	46 dB	40 dB	46 dB	41 dB
$D_{2,S}$	3 dB	4 dB	5 dB	6 dB	7 dB
$r_D$	18 m	5 m	3 m	5 m	3 m

**Table 3.** Results of the evaluated room acoustic parameters.

(a)

Source Receiver	Parameter	A0	A1	A2	A3	A4	A5	B0	B1	B2	B3	B4	B5	C0	C1	C2	C3	C4
R00	Lp,A (dBA)	x	39.3	37.9	33.7	36.0	31.6	49.9	48.1	38.2	34.4	32.0	28.8	40.4	36.8	40.6	36.5	30.8
R01	Lp,A (dBA)	38.0	x	45.2	33.0	31.1	35.1	47.4	48.7	47.5	40.4	36.2	33.6	36.4	35.2	45.3	31.4	30.2
R02	Lp,A (dBA)	35.2	45.6	x	39.1	34.6	39.2	40.1	47.2	49.9	47.3	41.8	33.8	35.5	42.0	34.0	34.8	29.9
R03	Lp,A (dBA)	32.6	32.5	35.5	x	51.9	37.5	33.5	34.1	44.9	48.7	49.4	43.7	28.1	31.4	34.0	33.6	34.5
R04	Lp,A (dBA)	31.4	31.6	34.7	52.2	x	38.7	32.1	34.9	35.9	49.4	48.7	47.3	28.6	28.2	33.1	32.6	33.4
R05	Lp,A (dBA)	29.9	35.1	39.6	35.2	38.7	x	33.4	33.5	32.9	43.2	47.7	50.5	28.0	30.9	32.4	34.2	39.2
R10	Lp,A (dBA)	49.8	47.5	40.1	33.2	31.8	31.1	x	39.4	34.7	37.5	32.4	28.5	41.8	37.0	36.0	31.2	28.6
R11	Lp,A (dBA)	47.2	48.7	45.9	36.8	36.1	32.4	39.7	x	48.1	36.8	32.4	31.7	34.7	41.3	47.9	36.6	31.7
R12	Lp,A (dBA)	40.4	47.4	49.3	45.0	32.7	32.7	37.0	47.7	x	37.2	32.1	31.6	37.1	46.4	40.4	34.0	30.2
R13	Lp,A (dBA)	33.4	37.5	46.7	49.0	49.2	45.6	37.4	34.3	36.1	x	49.8	37.0	28.3	32.8	34.0	35.0	34.3
R14	Lp,A (dBA)	32.4	38.2	45.7	48.3	48.6	47.2	33.7	32.0	33.9	49.4	x	38.3	29.3	28.7	32.9	36.2	35.4
R15	Lp,A (dBA)	29.4	34.2	33.3	43.3	47.2	50.0	28.3	31.9	33.1	36.2	40.3	x	26.2	31.0	32.5	33.8	41.0
R20	Lp,A (dBA)	40.4	40.0	35.2	28.4	28.7	26.9	39.3	34.6	34.6	30.0	29.4	27.3	x	38.2	36.8	29.8	25.0
R21	Lp,A (dBA)	36.4	36.3	44.4	33.2	29.1	30.4	36.6	42.0	47.5	35.4	29.3	31.8	38.8	x	50.7	39.7	30.3
R22	Lp,A (dBA)	42.8	45.5	35.0	33.0	31.6	33.1	36.3	47.3	42.1	33.7	31.3	30.9	37.2	48.76	x	39.7	30.5
R23	Lp,A (dBA)	34.8	32.5	34.4	32.7	32.8	33.8	31.9	34.6	33.7	33.9	35.1	34.0	29.0	37.61	37.9	x	41.0
R24	Lp,A (dBA)	29.2	30.5	30.7	34.5	36.3	41.2	29.0	31.6	31.3	32.7	36.0	41.4	25.0	29.48	32.3	38.4	x

(b)

Source Receiver	Parameter	A0	A1	A2	A3	A4	A5	B0	B1	B2	B3	B4	B5	C0	C1	C2	C3	C4
R00	STI (-)	x	0.24	0.37	0.24	0.48	0.17	0.74	0.69	0.34	0.24	0.18	0.10	0.41	0.32	0.45	0.35	0.16
R01	STI (-)	0.30	x	0.55	0.18	0.12	0.28	0.67	0.72	0.64	0.46	0.28	0.19	0.29	0.24	0.58	0.15	0.13
R02	STI (-)	0.25	0.18	x	0.43	0.39	0.43	0.45	0.64	0.75	0.67	0.45	0.22	0.28	0.48	0.25	0.27	0.11
R03	STI (-)	0.18	0.43	0.25	x	0.84	0.33	0.20	0.20	0.60	0.71	0.67	0.58	0.08	0.13	0.24	0.19	0.23
R04	STI (-)	0.15	0.71	0.24	0.71	x	0.36	0.17	0.23	0.31	0.69	0.71	0.67	0.09	0.08	0.21	0.16	0.19
R05	STI (-)	0.12	0.25	0.44	0.25	0.58	x	0.24	0.21	0.19	0.51	0.68	0.75	0.09	0.14	19%	0.21	0.39
R10	STI (-)	0.74	0.21	0.40	0.21	0.24	0.18	x	0.40	0.25	0.37	0.19	0.11	0.51	0.32	0.30	0.14	0.09
R11	STI (-)	0.67	0.32	0.58	0.32	0.45	0.17	0.38	x	0.61	0.34	0.19	0.16	0.20	0.39	0.66	0.33	0.16
R12	STI (-)	0.40	0.61	0.69	0.61	0.28	0.20	0.33	0.59	x	0.29	0.17	0.16	0.33	0.60	0.43	0.19	0.11
R13	STI (-)	0.22	0.72	0.65	0.72	0.83	0.60	0.36	0.27	0.28	x	0.68	0.32	0.08	0.18	0.19	0.19	0.19
R14	STI (-)	0.17	0.65	0.61	0.65	0.85	0.66	0.25	0.18	0.23	0.66	x	0.36	0.10	0.08	0.17	0.24	0.24
R15	STI (-)	0.11	0.55	0.18	0.55	0.82	0.73	0.10	0.18	0.22	0.32	0.43	x	0.05	0.14	0.20	0.17	0.40
R20	STI (-)	0.43	0.09	0.27	0.09	0.00	0.06	0.37	0.24	0.22	0.11	0.11	0.07	x	0.36	0.33	0.13	0.03
R21	STI (-)	0.29	0.21	0.55	0.21	0.00	0.13	0.28	0.42	0.66	0.29	0.09	0.16	0.39	x	0.79	0.44	0.14
R22	STI (-)	0.54	0.19	0.26	0.19	0.19	0.21	0.29	0.63	0.50	0.18	0.12	0.14	0.32	0.63	x	0.44	0.14
R23	STI (-)	0.29	0.17	0.26	0.17	0.22	0.21	0.16	0.24	0.19	0.17	0.20	0.20	0.10	0.35	0.38	x	0.44
R24	STI (-)	0.12	0.24	0.14	0.24	0.50	0.47	0.10	0.15	0.17	0.16	0.29	0.43	0.04	0.11	0.19	0.36	x

**Figure 3.** (a) SPL  $L_{p,A}$  of design "Half screens, absorbing ceiling". (b) STI values of design "Half screens, absorbing ceiling".

and distraction distance  $\bar{r}_D$  to a similar level as the design with 1.5 m high screens. Despite the increased reverberation time (0.5 s c. t. 0.3 s) the STI values increase because the speech SPL and background noise SPL have a larger impact on STI than reverberation time in this range (0.3–0.5 s). As a consequence, the distraction distance increases from 3 m to 5 m.

The spatial decay rate  $\bar{D}_{2,S}$  stays at a similar level due to the unchanged screen height (6 dB c. t. 7 dB). Such a layout would result in a higher speech intelligibility at close distances.

### 3.4 Summary

High acoustic screens reduce the SPL at 4 m distance on an average by 8 dB and increase the spatial decay rate by 4 dB in comparison to an office design without screens. The distraction distance may be as low as 3 m (depending on the background noise SPL). In this example, screens with 1.5 m height reduce the SPL at 4 m distance by 3 dB, whereas the spatial decay rate only increases by 1 dB in comparison to an office design without screens. Moreover, the distraction distance may decrease from 18 m to 5 m. These results indicate that  $\bar{D}_{2,S}$  cannot alone predict the acoustic quality of open-plan offices.

The consideration of 1.5 m high screens in combination with mineral ceiling tiles with high sound absorption results in similar SPLs at 4 m distance and distraction distances as the use of 3 m high screens with a cooling ceiling. However, the spatial decay rate  $\bar{D}_{2,S}$  is only predicted at 4 dB in comparison to 7 dB for the design with 3 m high screens.

## 4. DISCUSSION

The results of this study imply that reducing the reverberation time from 0.5 s to 0.4 s or 0.3 s does not predict an increase in speech intelligibility and distraction distance  $\bar{r}_D$  under constant background noise SPL, while on the other hand the SPL of speech at 4 m distance  $\bar{L}_{p,A,S,4m}$  is reduced with increasing absorption. As expected, the use of sound screens particularly reduces the SPLs of speech at larger distances and the distraction distance, whereas an increase of the ceiling absorption in combination with 1.5 m high screens has a more pronounced effect at the speech SPLs at 4 m distance.

The German guideline VDI 2569 [14] requires measurements of the spatial decay rate  $D_{2,S}$  and SPL at 4 m distance  $\bar{L}_{p,A,S,4m}$  to characterize the sound propagation in open-plan offices. The determined values vary depending on the selected measurement paths and locations. Moreover, *Haapakangas et al.* [1] pointed out that there is no significant relationship between  $D_{2,S}$  and the percentage that are highly disturbed by speech or by noise in general. It is highly recommended to consider additional parameters besides reverberation time,  $D_{2,S}$  and  $\bar{L}_{p,A,S,4m}$  in the acoustical design of offices. Absolute SPL parameters, such as A-weighted SPLs of speech at distances of 4 m  $\bar{L}_{p,A,S,4m}$ , 8 m  $\bar{L}_{p,A,S,8m}$ , and 16 m  $\bar{L}_{p,A,S,16m}$  may

be more meaningful.

Analyzing all possible source-receiver combinations is expected to improve the reproducibility and may involve acceptable measurement effort for small to medium-sized open-plan offices.

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