The Impact of Screen Design Parameters on the Reduction of Noise Levels in Multi-Functional Spaces

K. Şaher, L. Nijs. and M. van der Voorden

Delft University of Technology, Faculty of Architecture, Building Physics Group, *Berlageweg 1, CR 2628, Delft, Netherlands,* [*k.saher;l.nijs;m.van der voorden]@bk.tudelft.nl*]

ABSTRACT: Reducing sound pressure levels (SPL) from a noise source for improved acoustical quality in terms of speech intelligibility is the principal goal in multi-functional spaces. Speech intelligibility index (STI) calculated in noise is 'STI in noise', which is a quality indicator in multi-functional rooms. Screens blocking the direct sound from the noise source provides a good improvement in 'STI in noise' by reducing noise levels . This paper discusses the impact of design parameters of screens to reduce noise levels. The parameters effecting the acoustical performance of screens are discussed together with the architectural constraints. Screen parameters such as position, height, bottom gaps, absorption capacity, depth, width are investigated together with the space parameters such as absorptive ceiling and floor.

The results indicate that to position screens closer to the sound source gives better acoustical improvement. Higher screens are more effective, however, the difference between a ceiling high screen and less high screen is not so large. Bottom gaps are possible and they do not effect the acoustical performance negatively. Absorption is more effective when a depth factor is introduced. Ceiling absorption is necessary for the acoustical performance of the screens. All improvements are more effective in high frequencies. The calculations are based on a computer model in a ray-tracing software which is calibrated according to measurement values.

1. INTRODUCTION

Our research focuses on the prediction of acoustical quality in living rooms in institutions for mentally challenged people (MCP) since there are many complaints about the acoustical environment in these spaces from staff members. Mentioned spaces have to be regarded as "multi-functional spaces" since different activities occur simultaneously [1].

One of the main activities occurring in these spaces is conversation by many speakers at the same time and sometimes together with a television set. It is crucial to figure out the speech intelligibility in these rooms. Houtgast and Steeneken defined the Speech Transmission Index (STI) to measure and predict this intelligibility. It combines the effects of room acoustics and the signal to noise ratio (S/N) into a single quantity [2].

Our previous research showed that *STI in noise*, which is a measure for evaluation of speech under a variety of combinations of speech and noise levels [3], is a good quality indicator in "multi-functional spaces" [1]. The noise source decreases the *STI in noise* by decreasing the S/N. This means the difference between sound pressure level (SPL) caused by the target source and noise source at the receiver position have small difference. Our previous research showed that screens may be useful to decrease the SPL values of the noise source.

The acoustical performance of screens have been long a discussion subject in open-plan office acoustics. However, there is a little information about the effect of screens as a means to reduce SPL caused by noise source(s) in a multi functional space and its effect on *STI in noise*. Thus, it is important to determine the factors effecting screen design in a room from both the acoustical and the architectural point of view. This paper focuses on the impact of these screen design factors on reduction of SPL caused by the noise source.

2 FACTORS EFFECTING SCREEN DESIGN

To achieve accurate architectural-acoustical screen designs, it is necessary to have an insight in the factors effecting screen design in literature. The existing knowledge in the field is usually from the applications in open-plan offices and this knowledge can be useful for our purpose. Thus, we figured out the important parameters in the following sub-titles (Table 1):

Table 1 - *Factors effecting the screen design*

FACTORS EFFECTING SCREEN DESIGN			
PARAMETERS	**Screen**	**PARAMETERS EFFECTING THE ACOUSTICAL PERFORMANCE OF SCREENS**	**ARCHITECTURAL CONSTRAINTS**
		Position of a screen in relation to receiver and source	Visual aspects
		Height of a screen in relation to the ceiling	Influence of occupancy density on sound level
		Bottom gap of a screen	Difficulties in definition of source and receiver positions
		Absorption capacity of a screen	
		Depth of a screen	
		Width of a screen	Necessity for cleanable/ economical materials
	Space	Impact of absorptive ceiling and floor	

2.1 Parameters Effecting the Acoustical Performance of Screens

2.1.1 Screen parameters

(a) Position of a screen in relation to receiver and source

Whether sufficient noise reduction is achieved depends primarily on the position of the screen. There are three possible locations for a screen which are a) closest to the source, b) closest to the receiver and c) in-between. However, the location of the screen is a parameter much dominated by the architectural constraints.

(b) Height of a screen

The screen must be high enough to block the direct path of the noise sound [4]. 'The Standard Guide for Open Office Acoustics and Applicable ASTM Standards' states that screens lower than 1.5 m do not provide adequate speech privacy, however, screens higher than 2m offer smaller improvements [5, 6]. Besides, high screens create lighting and visual problems.

(c) Bottom gap of a screen

It is often speculated that gaps under screens may reduce their effectiveness as sound barriers, however, small gaps up to 5 cm under screens have small effect, when there is an absorptive ceiling and floor [7].

(d) Absorption capacity of a screen

The screen itself is a free-standing surface, which can act as a reflector in the room so it may help to have absorptive screens, however, the difference between typical medium and higher absorptive screen is small [4]. In offices, for speech the suggested noise reduction coefficient (NRC) of the screen material is 0.80 [5, 8]. Moreover, covering screen edges with absorptive material to attenuate some diffracted and reflected sound is also recommended [6].

2.1.2 Space Parameters

(a) Effect of an absorptive ceiling and floor
The effect of absorptive ceiling and floor is important for the performance of the screens [9]. The ceiling absorption is the most important since it is the largest surface to which absorption can easily be applied in the room. The NRC of the ceiling material should be between 0.80 and 0.85 for open-plan offices[8, 10].

2.2 Architectural constraints

(a) Visual aspects: The staff members need to observe the MCP so it is not desirable to have high screens which block the sight of eye in the room. Glass screens may be a solution for that, however, the glass itself is a bad sound absorber.
(b) The influence of occupation density on sound levels: This is noticeable as there is a tendency of people to raise their voices when the room is noisy or reverberant, so the noise levels become higher and are difficult to be controlled and fixed as constant levels.
(c) Difficulties in the definition of source and receiver position: It is impossible to block all direct, reflection, diffraction paths since occupants move around changing conditions constantly so the source and receiver positions are not strictly fixed. It is most effective to define some activity zones.
(d) Necessity for cleanable/ economical materials: There is a necessity for cleanable, cheap and flexible materials which are usually poor absorbers in the room.

3 MEASUREMENTS & COMPUTER SIMULATIONS

In order to figure out the impact of screen design parameters, we made several measurements and computer simulations. In this paper, one of the investigated cases is taken as an example. Measurements were carried out in a L-shaped room, which is used as a library and meeting room. The volume of the room is 158 m^3. The floor is covered by linoleum; walls are painted and the room has an absorptive ceiling. Figure 1 shows a floor plan plus a cross section.
The same situation was used in a ray-tracing computer model. We calibrated this computer model based on the measured values by estimating absorption and diffusion coefficients of all materials. The dimensions and the materials match with the situation in a living room of MCP. Thus, only the interior design of the room has been changed in the computer model to simulate the case in a living room of MCP.
According to the geometry of the room, 3 activity zones were defined, which are called *Region 1*, *Region 2* and *Region3* (see Figure 1). In all three regions, the activities are defined as conversations. All sources are supposed equally loud. Then we assume that a conversation is going on in *Region 2*. It has a “target source” that need to be understood by one receiver at the other side of the table. The sources in regions 1 and 3 produce “noise” for this conversation. From our previous research, we know that it is important to determine the main noise source for receivers. In that situation, noise source located in *Region 1* acts as the main noise source. Thus, our aim is to reduce SPL caused by that noise source in *Region 2*.

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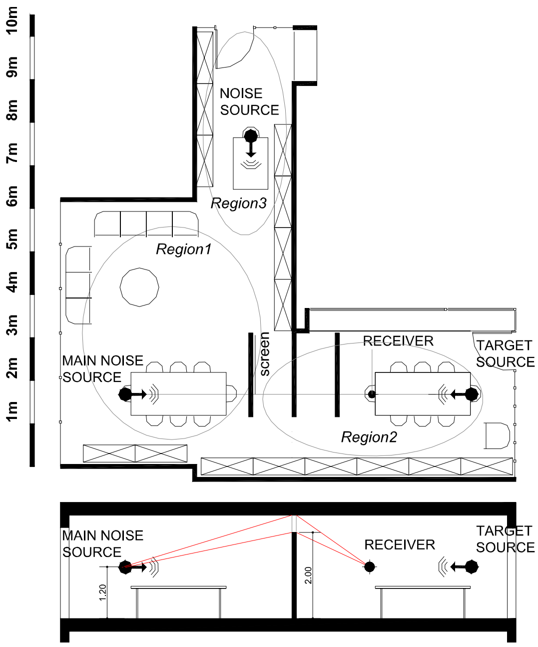

Figure 1 - *Ground floor and section of the room (ceiling height is 2.7 m)*

As mentioned earlier, sound sources and receivers constantly change positions, so for our simulations we decided to simulate the worst case that could happen. The source in *Region 1* is directed towards *Region 2* and in *Region 2*, the receiver position is in the position closest to the noise source and far away from the target source. Figure 1 shows the configuration of sound sources and receiver. Figure 1 also shows three different locations for screens between regions 1 and 2, at 3, 4 and 5 m respectively from the noise source in *Region 1*. The height of the noise source, target noise and receiver are 1.2 m.

4 RESULTS & DISCUSSION

4.1 Relation between 'STI in noise' and SPL

Table 2 shows the STI values, when there is no noise source for the receiver and then *STI in noise* values, when the noise source is active. STI values decrease by the 25% and *STI in noise* values are very low. Then SPL values of the target and noise sources at the receiver position are checked (Table 3) and the SPL values caused by the noise source at receiver position are very high. The aim is to reduce the SPL values caused by the noise source. From the calculations it is observed that:
1dB decrease = 0.03 increase in 'STI in noise' = noticeable improvement
2dB decrease = 0.06 increase in 'STI in noise' = fair improvement
3dB decrease = 0.08 increase in 'STI in noise' = improvement
>3dB= good improvement

Table 2 - *STI at receiver's position when there is no noise source and 'STI in noise' at receiver's position without any screen*

	125	250	500	1000	2000	4000
STI	0.80	0.84	0.91	0.94	0.95	0.94
STI in noise	0.63	0.66	0.72	0.69	0.71	0.68

Table 3 - *SPL values for Noise and Target sources at Receiver's position*

SOURCES	125	250	500	1000	2000	4000
Target	67.7	66.1	67.3	65.7	63.4	60.2
Noise	61.5	59.2	59.9	58.8	56.0	53.5

We discuss the results of the computer simulations based on our previous classification on factors effecting screen design. Besides the defined parameters in the literature, simulations for screen depth and width as parameters effecting the acoustical performance were done. For simplicity, SPL reduction values of 500 Hz band are compared.

4.2 Discussion of screen parameters effecting the acoustical performance

(a) Position of a screen in relation to receiver and source

Figure 2 shows the effect of the distance of a screen from the sound source. SPL (in the 500 Hz band) equals 60 dB. Introducing the screen decreases SPL by about 6 dB. The position close to the source (at 3 m) gives a slightly higher reduction than the positions at 4 and 5 m.

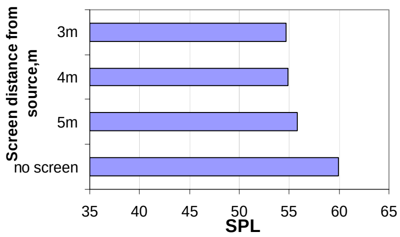

Figure 2 - *Effect of position of screen (2x2 m screen)*

Positioning the screen close to the sound source, appears the best solution. However, this is not always possible since the location of a screen is also based on architectural parameters such as existing walls, furniture and geometry of the room. In this room the most appropriate location for the screen is 4 m from the source, since it provides a continuity with the existing wall of the room and cupboards.

(b) Height of the screen in relation to ceiling height Figure 3 (left) gives the influence of screen height. The influence is considerably, since each increase by 50 cm causes about 2 dB decrease in SPL. However the difference between a ceiling-high-screen (2.7 m) and the 2.5 m high screen is only 1 dB. From the architectural viewpoint a 2 m high screen is most practical in these spaces since it provides visual comfort and contributes to a flexible design in the room.

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(c) Bottom gaps of the screen

Bottom gaps up to 10 cm do not effect the performance of the screen negatively. Only in high frequencies an increase around 1dB is observed (Figure 3, right). Bottom gaps can be an important part of the screen design. They can be helpful for making the screens mobile (installation of rollers), flexible and are beneficial for cleaning reasons.

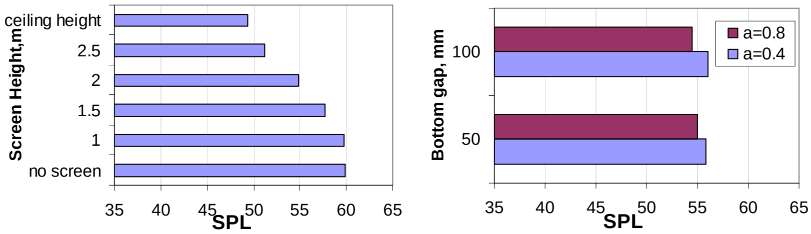

Figure 3 - *Effect of screen height on SPL and effect of bottom gaps (2x2 m screen)*

(d) Absorption capacity of the screen

Figure 4 (left) shows the calculated effects of varying sound absorption on screens. The differences in SPL appear very small. A high absorption values increases the total amount of absorbing surface in the room, however, since the screen surface is only small, that absorbing increase, and hence the SPL-decrease is only marginally

(e) Depth of the screen

Until now the screen was considered is a thin plate. Figure 4 (right) shows the effect if a "depth factor" is introduced to the screen. The results show that introducing a depth up to 60 cm does not reduce SPL values, however, with increasing depth absorption of whole screen is more efficient, especially in the high frequencies (2-3dB). This can be due to the prevention of diffraction by the absorption.

This information can be useful that the cupboards can be used as partition elements. 60 cm is a possible depth for a cupboard. If the side surfaces of the cupboards are closed by an absorptive material, this can provide an improvement.

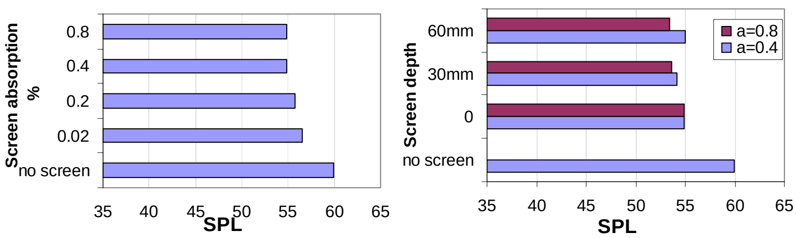

Figure 4 - *Effect of absorption on screen and effect of depth (2x2 m screen)*

(f) Width of the screen

The three screens drawn in Figure 1 are 2 m wide. They are 2 m high, so there is a 70 cm gap above the screen. When it is built from wall to wall (keeping that same gap), the difference in

SPL between these two situations is not as high as expected (1.5dB). It is known that if there was a partition wall between two regions, then the SPL decrease is around 20 dB. Thus, it is observed that when there is upper gap, the acoustical performance of the screen is low. Figure 5 (right) shows the level of decreases obtained by the addition of each piece in the screen.

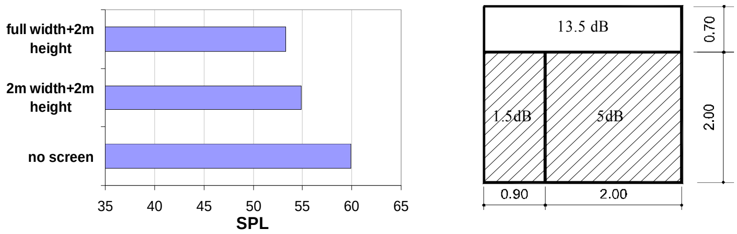

Figure 5 - *Effect of screen width and graphical representation of the screen and SPL decreases caused by each piece.*

4.2 Discussion of space parameters as parameters effecting the acoustical performance

(a)Impact of absorptive ceiling and floor

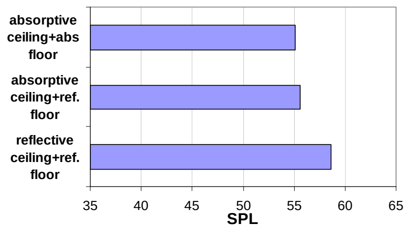

Figure 6 - *Effect of absorptive ceiling and floor (2x2 m screen)*

The effect of an absorptive ceiling for the performance of the screen is very essential (4dB) since it is the most important free surface in the room and the reflections from the ceiling are very important (Figure 6). On the other hand, when we introduce an absorptive floor in addition to an absorptive ceiling, the impact is not very noticeable (1dB). This may be due to the fact that the reflections from the floor usually absorbed and diffused by furniture. This information is important since it is difficult to place sound absorbing materials on the floor due to cleaning reasons and higher costs.

5 CONCLUSIONS

1. Acoustically the best place to place the screen is closer to the sound source to block the direct sound, however, architecturally it is not always possible. Besides, the differences between a very near location and relatively far distance is not very large.
2. The screen should be at least high enough to block the direct sound path. Higher screens are more effective, however, the difference between a ceiling high screen and less high

screen is not so large. High screens are not practical visually in such small spaces. Bottom gaps are possible in screens and they do not effect the performance of screens negatively.

3. The depth factor of a screen (a cupboard) is more effective when absorption is introduced.
4. Increasing the width of a screen does not make a substantial impact, if there is a gap between 50-60 cm under the ceiling. However, having a partition wall in the room is not architecturally suitable. In this respect, design research for flexible partition walls is necessary, especially when there is a very noisy environment.
5. For better performance of a screen, absorptive ceiling as a space parameter is always necessary, however, the effect of floor absorption is not as much as expected and it can be compensated by furniture.

Table 4 - *The chart shows the maximum amount of SPL decrease and the architectural constraint related to the screen design parameters (2x2 m screen)*

	position	**height**	**bottom gaps**	**absorption**	**depth**	**depth + absorption**	**full width**	**absorptive ceiling**
SPL decrease	1 dB	5 dB	negligible	negligible	negligible	1.5 dB	1.5 dB	4 dB
STI in noise improvement	noticeable	good	x	x	x	fair	fair	good
Architectural constraints	geometry	visual aspects	cleaning aspects	economical aspects	x	x	visual aspects	x

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