ACOUSTIC SCREENS EFFECT ON THE ACOUSTIC PROPERTIES OF OPEN PLAN OFFICES – A CASE STUDY BASED ON COMPUTATIONAL RESEARCH

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Open plan offices require special acoustic properties. The requirements for them are given in EN ISO 3382-3:2012. These requirements are determined by the speech transmission index STI (distraction distance and privacy distance) and the A-weighted sound pressure level of speech (A-weighted sound pressure level of speech at a distance of 4 m and the spatial decay rate of speech). In order to obtain the required acoustic properties of open plan offices, it is necessary to apply technical solutions affecting the reverberation and speech sound propagation in the room. Technical solutions having the greatest impact on the fulfillment of the above the requirements are: sound-absorbing materials (applied on the walls and floor of the room and used in suspended ceilings), acoustic screens and sound-masking systems. Until now, most open plan offices do not meet the requirements of EN ISO 3382-3:2012. The article presents research results regarding the acoustic screens effect on the acoustic properties of an open plan office. The research was carried out in a room with typical dimensions for open plan offices with sound absorption that meets the requirements of the Polish standard PN-B-02151-4:2015 (sound absorption of the room relative to 1 m² of the floor it should be equal to or larger than 1.1 m²). Acoustic screens with different heights, different sound absorption coefficients and different location in the room have been taken into account. The analysis was carried out with the calculation method using the ODEON software.

Keywords: open plan offices, acoustic screens, speech transmission index

1. Introduction

Open plan offices require special acoustic properties in comparison to traditional office spaces where several people can work. Their requirements in Poland are set out in the Polish standard PN-B-02151-4 [1] and in the international standard EN ISO 3382-3:2012 [2]. The requirements specified in these standards take the form of criteria that define the physical parameters which characterise the acoustic properties of these rooms and the permissible values of these parameters which include sound absorption of the room (according to PN-B-02151-4 [1]), distraction distance \( r_D \) and privacy distance \( r_P \) (according to EN ISO 3382-3[2]), as well as the A-weighted sound pressure level at a distance of 4 m \( L_{p,A,S,4m} \) and the reference spatial decay rate of speech \( D_{2,S} \) (according to EN ISO 3382-3[2]). In Poland, the criterion provided in accordance with PN-B-02151-4:2015[1] is mandatory from 2018, while the criteria provided in accordance with EN ISO 3382-3 [2] are regarded as recommendations (good practice). This article considers all of them to be mandatory. In order to obtain the required acoustic proper-
ties of open plan offices, it is necessary to apply technical solutions which affect the reverberation and speech sound propagation in the room. The most significant technical solutions to meet the above requirements include sound-absorbing materials (applied to the walls and floor of the room, as well as to suspended ceilings), acoustic screens and sound-masking systems. In Poland, in most new open space offices, sound-absorbing suspended ceilings are used, whereas in most cases acoustic screens are not used (acoustic screens are only used in call center rooms). This article presents the results of a computational analysis of the effect of acoustic screens on the acoustic properties of a typical room.

2. A preliminary analysis of the possibility of obtaining acoustic properties of open plan offices in compliance with PN-B-02151-4 and EN ISO 3382-3

The parameters which characterise the acoustic properties of open plan offices include:

- sound absorption of the room \( A \) and sound absorption of the room relative to 1 m\(^2\) of the floor plan area \( A_{1/1m^2} \) \( (A_{1/1m^2} = A/S_p; S_p - \text{floor area}) \); the minimum permissible value \( A_{1/1m^2} \) according to PN-B-02151-4 \[1\] amounts to 1.1 m\(^2\); the calculation method is provided in the standard PN-B-02151-4 \[1\];
- A-weighted sound pressure level at a distance of 4 m from the speech source \( L_{p,A,S,4m} \); its maximum permissible value for so-called good acoustic properties of the rooms concerned, according to EN ISO 3382-3 \[2\], amounts to 48 dB; the determination method is provided in EN ISO 3382-3 \[2\];
- spatial decay rate of speech \( D_{2,S} \); its maximum permissible value for so-called good acoustic properties of the rooms concerned, according to EN ISO 3382-3-2012, amounts to 7 dB; the determination method is provided in EN ISO 3382-3 \[2\];
- distraction distance \( r_D \); its maximum permissible value for so-called good acoustic properties of the rooms concerned, according to EN ISO 3382-3 \[2\], amounts to 5 m; the determination method is provided in EN ISO 3382-3 \[2\];
- privacy distance \( r_P \); no permissible value according to EN ISO 3382-3 \[2\] has been specified; the determination method is provided in EN ISO 3382-3 \[2\]; since no criteria values for the privacy distance \( r_P \) are specified, it will no longer be taken into account.

The calculation method, based on ODEON software \[3\], used in further analysis enables more accurate results to be obtained for reverberation time \( RT \) than for the sound absorption of the room. Therefore, instead of the criterion of sound absorption of the room relative to 1 m\(^2\) of the floor plan area \( A_{1/1m^2} \) according to PN-B-02151-4: 2015 (the minimum permissible value of 1.1 m\(^2\)), this article will use the criterion relative to the reverberation time \( RT \) (then, the maximum value calculated from the Sabine’s formula is equal to 0.51 s; Eq. (10)) in frequency bands of 0.5, 1 and 2 kHz. A method for determining the reverberation time \( RT \) is described in PN-EN ISO 3382-2 \[4\].

An analysis of the possibility of ensuring adequate sound absorption of the room

Sound absorption of the room is determined by the following formula \[1\]:

\[
A = A_{room} + A_{equipment} + A_{air} = A_{ceiling} + A_{floor} + A_{walls} + A_{equipment} + A_{air} \quad (1)
\]

where:
- \( A_{room} \) – sound absorption of the room surfaces (ceiling \( A_{ceiling} \), floor \( A_{floor} \), and walls \( A_{walls} \)), in m\(^2\);
- \( A_{equipment} \) – sound absorption of particular pieces of equipment (e.g. desks, cabinets, acoustic screens), in m\(^2\);
- \( A_{air} \) – sound absorption due to the absorption of sound in the air, in m\(^2\).
In this case, the condition for obtaining minimum sound absorption of the room is determined by the following relationship:

\[ A_{\text{ceiling}} + A_{\text{floor}} + A_{\text{equipment}} + A_{\text{air}} \geq S_{\text{floor}} \cdot 1.1 m^2 \]  

(2)

where:

- \( S_{\text{floor}} \) – the floor area, in \( m^2 \);
- 1.1 \( m^2 \) – sound absorption of the room relative to 1 \( m^2 \) of the floor plan area \( A_{\text{1/1m2}} \) according to PN-B-02151-4:2015 [1].

Assuming that the ceiling and floor areas are the same, their sound absorption is the quotient of the sum of their surfaces and the sound absorption coefficient of their surfaces. In this case, the above condition takes the following form:

\[ (\alpha_{\text{ceiling}} + \alpha_{\text{floor}}) \cdot S_{\text{floor}} + A_{\text{walls}} + A_{\text{equipment}} + A_{\text{air}} \geq S_{\text{floor}} \cdot 1.1 \]  

(3)

after conversion:

\[ \alpha_{\text{ceiling}} + \alpha_{\text{floor}} \geq 1.1 \cdot \frac{A_{\text{walls}}}{S_{\text{floor}}} + \frac{A_{\text{equipment}}}{S_{\text{floor}}} - \frac{A_{\text{air}}}{S_{\text{floor}}} \]  

(4)

Since the component \( \frac{A_{\text{air}}}{S_{\text{floor}}} \) is negligible, the equation takes the following form:

\[ \alpha_{\text{ceiling}} + \alpha_{\text{floor}} \geq 1.1 \cdot \frac{A_{\text{walls}}}{S_{\text{floor}}} - \frac{A_{\text{equipment}}}{S_{\text{floor}}} \]  

(5)

The relationship shows that the condition is met where the total of sound absorption coefficients values for the floor \( \alpha_{\text{floor}} \) and the ceiling \( \alpha_{\text{ceiling}} \) is even lower than 1.1 \( m^2 \). Under real-life conditions, the use of a sound-absorbing material on the room’s ceiling (with the sound absorption coefficient \( \alpha \) of 0.8-1) and a sound-absorbing flooring (with the sound absorption coefficient of 0.15-0.2) result in these criteria being met (which is due to the fact that the components \( \frac{A_{\text{walls}}}{S_{\text{floor}}} \) and \( \frac{A_{\text{equipment}}}{S_{\text{floor}}} \) in Eq. (5) have values significantly higher than 0). This was proven by several examples [5-9].

An analysis of the possibility of ensuring appropriate acoustic conditions specified by the A-weighted sound pressure level at a distance of 4 m from the speech source \( L_{p,A,S,4m} \)

The criterion based on the A-weighted sound pressure level at a distance of 4 m from the speech source \( L_{p,A,S,4m} \) takes the following form:

\[ L_{p,A,S,4m} \leq 48 dB \]  

(6)

At the same time, it is known (EN ISO 3382-3 [2]), that the A-weighted sound pressure level at a distance from the speech source \( L_{p,A,S,1m} = 57.4 dB \), which results from the reference sound source data. In this case, the condition takes the following form:

\[ L_{p,A,S,1m} \cdot L_{p,A,S,4m} \geq 9.4 dB \]  

(7)

In simpler terms (simplification results from the fact that the A-weighted sound pressure level at a distance of 4 m from the speech source is determined from the logarithm line approximating the A-weighted sound pressure level values as a function of the distance from the reference sound source [2]), meeting this condition with no acoustic screen between the reference sound source and the nearest workstation would be extremely difficult. This is due to the fact that it would then be necessary to ensure that the sound pressure level in the room decreases at a rate greater than 4.7 dB per doubling of distance. This would result in the need to obtain (apply) an extremely high sound absorption \( A \) of the room of approx. 750 \( m^2 \) (which results from the estimation conducted near the boundary distance of the room \( r_g = 0.14 \cdot \sqrt{A} \)). However, the above criterion could also be met by applying another technical solution involving the use of an acoustic screen and the sound absorption \( A \) of the room (200-300 \( m^2 \)). This will be a combined effect of acoustic screening and reducing the A-weighted sound pressure level.
as a function of the distance from the source (for the boundary distance of the room $r_g = 2 \text{ m}$ and the sound absorption of the room of approx. $200 \text{ m}^2$).

**An analysis of the possibility of ensuring appropriate acoustic conditions specified by the spatial decay rate of speech $D_{2,S}$**

The criterion condition for the spatial decay rate of speech $D_{2,S}$ takes the following form:

$$D_{2,S} = L_{p,A,S,1m} - L_{p,A,S,2m} \geq 7 \text{ dB} \tag{8}$$

In simpler terms (simplification results from the fact that it is determined from the logarithmic line approximating the A-weighted sound pressure level values as a function of the distance from the reference sound source [2]), this difference needs to be greater than for the point source in a free field (i.e. 6 dB). It follows therefore that it is impossible to obtain it without an acoustic screen.

**An analysis of the possibility of ensuring appropriate acoustic conditions specified by the distraction distance $r_D$**

The condition for the distraction distance $r_D$ takes the following form:

$$r_D \leq 5 \text{ m} \tag{9}$$

In simpler terms (simplification is due to the fact that the distraction distance $r_D$ is determined from the line approximating the speech transmission index STI values as a function of the distance from the reference sound source [2]), it means that at a distance of 5 m from the source, the speech transmission index STI value should not be greater than 0.5. This value can be obtained either where the sound absorption of the room is low (which is contrary to other conditions provided above), or where the sound absorption of the room is high and a small difference is obtained between the values of the A-weighted sound pressure level for the reference sound source and the A-weighted background noise level. In order to meet this condition, it is necessary to reduce the A-weighted sound pressure level for the source (at a distance of 5 m from it) by the use of an acoustic screen and/or increase the A-weighted background noise level (sound-masking system).

It follows from the preliminary analysis presented above that in order to obtain appropriate acoustic conditions in open plan offices, it is necessary to use effective acoustic screens and sound-absorbing materials on the ceiling (and the floor). Since acoustic screens must improve the acoustic properties assessed according to the above-mentioned criteria [1,2] irrespective of the location of the sound source (irrespective of the workstation where the source is located), it follows that acoustic screens should be located between all workstations.

### 3. An analysis of the possibility of obtaining acoustic properties of open plan offices in compliance with PN-B-02151-4 and EN ISO 3382-3 – a case study

The analysis will be carried out computationally on a selected case using an ODEON software program for acoustic field simulation [3].

Since the reverberation time RT in this program is determined more accurately than the sound absorption of the room, the reverberation time for the room will be taken into account instead of the sound absorption of the room.
Assuming that the relationship between the sound absorption of the room and the reverberation time for the room is described by the Sabine’s formula, and taking into account the minimum sound absorption value provided above, the maximum reverberation time $RT_{\text{max,per}}$ for the room, expressed in seconds, can be calculated for the rooms concerned using the following formula:

$$RT_{\text{max,per}} = \frac{0.161V}{A_{\text{min,per}}} = \frac{0.161V}{S_{\text{floor}}A_{\text{min,per,1m}^2}} = \frac{0.161V}{S_{\text{floor}}V^{1/4}} = 0.146 \cdot H \quad (10)$$

where:

- $V$ – room volume, in m$^3$;
- $A_{\text{min,per}}$ – minimum permissible sound absorption, in m$^2$;
- $A_{\text{min,per,1m}^2}$ – minimum permissible sound absorption of the room relative to 1 m$^2$ of the floor plan area, in m$^2$;
- $S_{\text{floor}}$ – the floor area, in m$^2$;
- $H$ – the room height, in metres.

For the study, the room presented in Fig. 1 was selected, with the dimensions of 22 x 10 x 3.5 m, cubic volume $V = 770$ m$^3$, total room surface area $S_v = 630$ m$^2$, and a floor area $S_{\text{floor}}$ of 220 m$^2$. The maximum reverberation time $RT_{\text{max,per}}$ amounts to approx. 0.51 s.

A sound-absorbing suspended ceiling with a weighted sound absorption coefficient $\alpha_w = 0.6$, sound-absorbing materials on four walls with a weighted sound absorption coefficient $\alpha_w = 0.9$ and a carpet flooring with a weighted sound absorption coefficient $\alpha_w = 0.25$ were used in the room.

![Figure 1: The room considered in the example (image generated by ODEON software).](image)

The A-weighted background noise level $L_{p,A,B}$ of 35 dB was assumed to be permissible for the technical equipment of the building [10]. The sound source and observers were at a height of 1.2 m from the floor.

The tested parameters included various heights of acoustic screens (height $h$, counted from the floor, of 0.9, 1.1, 1.3, 1.5, 1.7, and 1.9 m) and various weighted sound absorption coefficients $\alpha$ for the screen (0.25, 0.5, 0.9; Table 1). (The workstation desktop was located at a height of 0.75 m).

<table>
<thead>
<tr>
<th>Weighted sound absorption coefficient $\alpha_w$</th>
<th>Sound absorption coefficient $\alpha$ for the following frequencies, in Hz:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>63  125  250  500  1000  2000  4000  8000</td>
</tr>
<tr>
<td>0.5</td>
<td>0.05 0.05 0.1 0.15 0.25 0.3 0.3 0.3</td>
</tr>
<tr>
<td>0.9</td>
<td>0.02 0.02 0.2 0.7 1 0.9 0.7 0.7</td>
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<tr>
<td></td>
<td>0.05 0.15 0.6 1 1 1 0.8 0.8</td>
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</table>

Study results are provided in Table 2 and in Figs 2 and 3.
Table 2: Results of calculations for various heights and various sound-absorbing materials on the surfaces of acoustic screens ($L_{p,A,B} = 35$ dB)

<table>
<thead>
<tr>
<th>Item</th>
<th>Weighted sound absorption coefficient $\alpha_w$ of the acoustic screen surface</th>
<th>Screen height</th>
<th>Reverberation time RT, in seconds, for the following frequencies, in Hz:</th>
<th>$L_{p,A,S,4m}$, dB</th>
<th>$D_{2,S}$, dB</th>
<th>$r_D$, m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>1000</td>
<td>2000</td>
<td></td>
</tr>
<tr>
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<td>-</td>
<td>-</td>
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<td>0,23</td>
<td>0,23</td>
<td>48,5</td>
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<tr>
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<td>0,9</td>
<td>0,16</td>
<td>0,10</td>
<td>0,12</td>
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<td>3</td>
<td>0,25</td>
<td>1,1</td>
<td>0,23</td>
<td>0,23</td>
<td>0,23</td>
<td>47,7</td>
</tr>
<tr>
<td>4</td>
<td>0,25</td>
<td>1,3</td>
<td>0,23</td>
<td>0,19</td>
<td>0,20</td>
<td>42,4</td>
</tr>
<tr>
<td>5</td>
<td>0,25</td>
<td>1,5</td>
<td>0,24</td>
<td>0,19</td>
<td>0,20</td>
<td>41,1</td>
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<tr>
<td>6</td>
<td>0,25</td>
<td>1,7</td>
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<td>0,21</td>
<td>0,20</td>
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<tr>
<td>7</td>
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<td>1,1</td>
<td>0,23</td>
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<td>17</td>
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<td>38,3</td>
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<tr>
<td>18</td>
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<td>0,21</td>
<td>0,20</td>
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<tr>
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<td>1,9</td>
<td>0,21</td>
<td>0,19</td>
<td>0,19</td>
<td>35,0</td>
</tr>
</tbody>
</table>

Legend:
- $RT$ – reverberation time, in seconds;
- $L_{p,A,S,4m}$ – $A$-weighted sound pressure level of speech at a distance of 4 m from the source, in dB;
- $D_{2,S}$ – spatial decay rate of speech, in dB;
- $r_D$ – distraction distance, in metres.

A red background indicates non-compliance with the requirements, while a green background indicates compliance.

The results show that without the use of acoustic screens, despite the high acoustic absorption of the room (reverberation time of 0.23 s with a maximum permissible value of 0.51 s), there is no guarantee that the appropriate conditions specified by the remaining parameters will be obtained (Table 2, item 1). Through the use of acoustic screens with a height of 0.9 m and higher above the floor (i.e. 0.15 m and higher above the desktops at workstations but below the level of employees’ heads), the $A$-weighted sound pressure level of speech at a distance of 4 m meets the requirements (Table 2 items 2-19). When considering the minimum height of acoustic screens at which the remaining criteria will be met (for spatial decay rate of speech and distraction distance), it can be observed that the criteria are only met for the height of 1.7 m (irrespective of the acoustic properties of the sound absorbing materials covering the screens; Table 2, items 6, 12, and 18). This demonstrates that acoustic screen height is of critical importance in the process of ensuring appropriate acoustic properties of open plan offices. However, Figs. 3 and 4 show that the sound-absorbing properties of screens also affect the spatial decay rate of speech and the distraction distance, particularly where the material is highly sound-absorbing. This is also shown in Table 2, item 17: weighted sound absorption coefficient $\alpha_w = 0.9$ for which only the spatial decay rate of speech $D_{2,S}$ fails to meet the criteria but only by 0.3 m (for weighted sound absorption coefficients $\alpha_w$ of 0.5 and 0.25, the difference amounts to 1.2-1.3 m).
Increasing the sound absorption of acoustic screens causes an increase in spatial decay rate of speech $D_{2,S}$ when the sound absorption factor increases from 0.5 to 0.9, while distraction distance $r_D$ decreases when the sound absorption coefficient increases from 0.25 to 0.5. The first one is the result of the fact that the considered room has a high acoustic absorption, so only acoustic screens with high sound absorption affect its increase, and thus reduce the sound pressure level and increase spatial decay rate of speech $D_{2,S}$. The second effect is the result of the fact that the small increase in the sound absorption of the screens reduces the ratio of sound speech to background noise, which results in a decrease in the speech transmission index STI and the reduction of the distraction distance.

It can therefore be concluded that an effective acoustic screen covered with a sound-absorbing material, with a weighted sound absorption coefficient $\alpha_w = 0.9$ can be lower by several centimetres than an acoustic screen with a weighted sound absorption coefficient $\alpha_w$ of 0.5 and less.

![Figure 2: Spatial decay rate of speech $D_{2,S}$ for materials covering acoustic screens with weighted sound absorption coefficients of 0.25, 0.5 and 0.9.](image)

![Figure 3: Distraction distance $r_D$ for materials covering acoustic screens with weighted sound absorption coefficients of 0.25, 0.5 and 0.9.](image)
4. Summary and conclusions

The article provides criteria for the assessment of acoustic properties of open plan offices. The result of general considerations concerning the possibilities for obtaining appropriate acoustic properties of the rooms concerned is provided. The results of the preliminary analysis demonstrated that it is possible to obtain appropriate acoustic conditions in rooms where, at the same time, appropriate sound absorption is ensured (using sound-absorbing materials), the workstations are acoustically separated (using acoustic screens), and the work-disturbing sounds are masked (using masking system generating the acoustic background). In the selected example, based on the computational analysis conducted, the effects of the height and acoustic properties of sound-absorbing materials used on the acoustic screen surfaces were examined. The case analysis results indicated that obtaining the required sound absorption (characterised by the reverberation time RT of approx. 0.2–0.25 s; a maximum permissible value of approx. 0.51 s) in a room with a cubic volume of 770 m³, and the use of acoustic screens with a height of 1.7 m, with the A-weighted background noise level of 35 dB, made it possible to meet all criteria of assessment of the acoustic properties of open plan offices. In the examined case, the use of an acoustic screen with a height of 1.7 m: A-weighted sound pressure level of speech at a distance of 4 m from the source $L_{PA,S,4m}$ amounted to 36.1–40.5 dB (a maximum permissible value of 48 dB), the spatial decay rate of speech $D_{2,8}$ amounted to 7.0–8.5 dB (a minimum value of 7 dB), and the distraction distance $r_D$ amounted to 2.8–4.7 m (a maximum permissible value of 5 m). According to the author, in order to ensure appropriate acoustic conditions in an open plan office room (proper noise separation between workstations), it is necessary to obtain a high sound absorption of the room (sound-absorbing materials on all surfaces of the room, particularly on the ceiling), to use acoustic screens with a minimum height of 1.5 m and to use masking sources to increase sound pressure level of background noise.

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