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Acoustical Design for Open-Plan Offices

by J.S. Bradley

This Update discusses how to achieve acceptable acoustical privacy in open-plan offices. The information is derived from current best practice and the results of research carried out by NRC's Institute for Research in Construction.

This Update expands on Update No. 60, which summarized the findings of the Cost-effective Open-Plan Environments (COPE) project. IRC's partners in COPE were: Public Works and Government Services Canada, the Building Technology Transfer Forum, USG Corporation, Ontario Realty Corporation, British Columbia Buildings Corporation, Steelcase Incorporated, and Natural Resources Canada. For more information on COPE, see http://irc.nrc-cnrc.gc.ca/ie/cope. Three related Updates address workstation design, lighting, and ventilation and air quality.

The open-plan office has become the predominant type of office space for a wide range of work-related activities. Older designs with stand-alone panels and furniture have typically been replaced by modular workstations, frequently referred to as cubicles. This type of office is considered to be cheaper to construct and reconfigure than other types. However, there are factors, such as the lack of privacy and increased noise, that have negative effects on office workers and that need to be mitigated by appropriate design to obtain an acceptable level of acoustical privacy.

Not all types of work need the same degree of acoustical privacy. For tasks that require concentration or confidentiality, open-plan offices may not be suitable. They can, however, provide an acceptable level of acoustical privacy for many tasks, but only if they are carefully designed as a complete system, ensuring that adjacent work functions are compatible and that there is sufficient space between workstations.

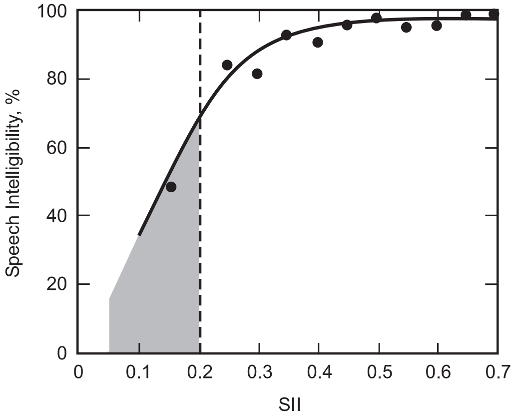

Figure 1. Speech intelligibility score relative to Speech Intelligibility Index (SII). Shaded area indicates acceptable or normal speech privacy (SII≤0.20).

If any aspect of the system is neglected, acceptable acoustical privacy will not be achieved.

Acoustical privacy is often referred to as speech privacy because intruding speech sounds are typically the most disturbing. Speech privacy is related to the level of unwanted speech sounds from adjacent workstations relative to the level of more constant ambient noise. Reducing intruding speech sounds or increasing background noise levels can both improve speech privacy, although at some point the noise level may itself become a problem.

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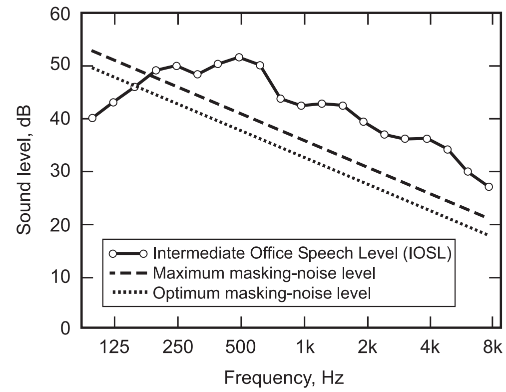

Figure 2. Intermediate Office Speech Level (IOSL) for speech privacy calculation, and optimum and maximum ambient noise spectra

Definitions

Speech Intelligibility Index (*SII*) is a measure derived from the signal-to-noise level differences in each frequency band, where the differences are weighted according to their relative importance to the intelligibility of speech. These weighted signal-to-noise level differences are summed to obtain the *SII* value between 0 and 1. This measure indicates the expected speech intelligibility in particular conditions: An *SII* of 1 indicates conditions in which near perfect speech intelligibility is expected, whereas an *SII* close to 0 indicates conditions in which near perfect speech privacy is expected. *SII* has replaced the Articulation Index (*AI*) and has values that are approximately 0.05 larger than corresponding *AI* values.

Sound Absorption Average (*SAA*) is an average of the absorption coefficients in the 1/3-octave frequency bands from 250 Hz to 2.5 kHz. It replaces the older Noise Reduction Coefficient *(NRC)* measure and has similar values for the same material.

A-weighted sound level (*dBA*) is a simple measure that weights and sums the contributions of sounds at different frequencies to approximate the total loudness experienced by listeners.

Sound Transmission Class (*STC*) is a single number rating of the sound transmission characteristics of panels. Higher numbers indicate greater attenuation of the transmitted sound.

There is a reciprocal relationship between speech privacy and speech intelligibility—the lower the speech intelligibility the greater the speech privacy. To achieve adequate speech privacy from intruding speech sounds, speech intelligibility scores must be low. Speech privacy and speech intelligibility are both related to the loudness of the speech compared to that of the ambient noise and both use measures of the signal-to-noise level difference, where intruding speech is the “signal” and the general ambient noise is the “noise.”

Speech Privacy Rating

The Speech Intelligibility Index, or SII, is a measure of the signal-to-noise level difference (see box above); it indicates the expected speech intelligibility in particular conditions.[1] SII can vary between 0 and 1, with a high SII indicating conditions that correspond to a high degree of speech intelligibility and low values indicating those that relate to a high degree of speech privacy. SII is widely used as a measure of speech privacy. An SII ≤ 0.20 is considered to provide normal or acceptable speech privacy in open-plan office situations.[2]

The results of extensive tests in which subjects rated the intelligibility of speech sounds in open-office situations show that speech intelligibility increases as SII increases, to a point, and then it levels off (Figure 1). These results confirm that an SII ≤ 0.20 (indicated by the shaded area) represents conditions in which speech intelligibility is substantially reduced relative to conditions on the right hand side of this graph. An SII ≤ 0.20 is achievable if all aspects of the acoustical design are carefully considered.

Speech and Noise Levels

Since speech privacy is related to the speech-to-noise level difference, reducing speech levels in the open-plan office can improve speech privacy. Office etiquette that encourages occupants to keep their voices down is an essential starting point. Relocating prolonged or animated discussions to closed meeting rooms is also desirable.

Measurements of speech levels in open-plan offices indicate that occupants generally talk more quietly in these settings than in most others. The Intermediate Office Speech Level (IOSL) is representative of louder than average speech sounds found in typical open-plan offices and is recommended for use in design calculations (see Figure 2).[3]

It is difficult to obtain acceptable speech privacy if the general ambient noise level is too low. On the other hand, if the ambient noise level is too high, it can be annoying and cause people to talk more loudly. There is a narrow range of ambient noise levels that can mask intruding speech sounds from adjacent workstations without being disturbing. For this reason, successful open-plan office designs typically use electronic masking-sound systems.

Masking-Sound Systems

Electronic masking-sound systems can be designed to provide close-to-ideal noise levels to mask speech sounds and enhance privacy, without being disturbing. The masking noise should be adjusted to sound like ventilation-system noise and it should be evenly distributed throughout the office

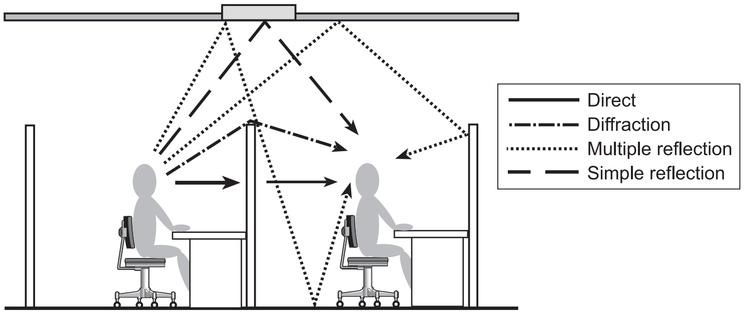

Figure 3. Sound paths between workstations

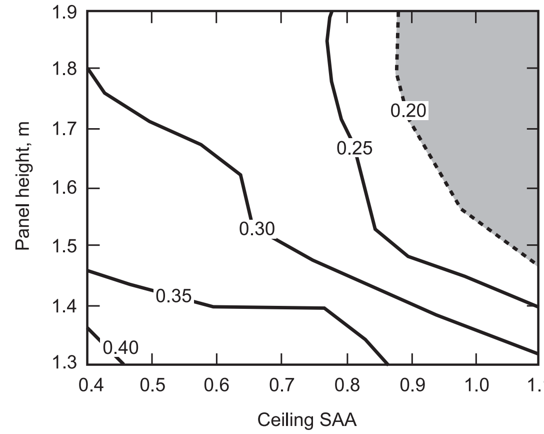

Figure 4. Shaded area shows combinations of workstation panel height and ceiling absorption (SAA) that can provide acceptable speech privacy corresponding to SII≤0.20 for a 3 m by 3 m workstation.

(variations should be less than 3 dBA). A masking-noise level of 45 dBA is judged to be optimal, with a level of 48 dBA considered the maximum acceptable level.[4] These levels roughly correspond to ventilation noise ratings, commonly used by heating and ventilation engineers, of NC or RC 38 (optimal) and 41 (maximum). These two ambient noise spectra (shown in Figure 2) indicate the narrow range of masking noises that can provide acceptable speech privacy.

Masking-sound systems include those with centrally located electronics and those with distributed units. Manufacturers of both types claim various practical advantages. Although the sound propagated into the ceiling void (the space between the suspended ceiling and the structural floor) may aid the even distribution of the masking sound in the office itself, it gets modified when transmitted through the ceiling tiles and lighting fixtures. This can lead to localized areas of higher sound levels in the office space.

More recently, masking-sound systems with loudspeakers mounted in the ceiling tiles and on workstation panels have been proposed in order to provide better control over the masking sound. The installation of masking-sound systems is best left to experienced professionals.

Reducing Speech Propagation

The acoustical design of an open-plan office can be complex because of the many different sound paths that need to be considered (see Figure 3). Mainly, sound can be reflected from the ceiling, diffracted (or bent) over the top of a separating panel, or transmitted through the panel. One can conveniently calculate the effect of these various sound paths using acoustical design software[5] that is based on a complex mathematical model[6,7] of sound propagation between adjacent workstations.

Ceiling Absorption and Panel Height. Such calculations show that the most significant paths are those that reflect sound from the ceiling and diffract sound over the separating panel. It is therefore essential that the combination of ceiling absorption and separating panel height be adequate. The shaded area in Figure 4 indicates combinations of average ceiling absorption (SAA, see sidebar) and separating panel height that can provide an acceptable level of speech privacy for a 3 m by 3 m workstation.

Two combinations that just meet the SII ≤ 0.20 criterion are:

- a ceiling with an SAA=0.90 combined with a panel height of at least 1.7 m, and
- a ceiling with an SAA=0.95 combined with a panel height of at least 1.6 m.

If the particular combination of ceiling absorption and panel height does not fall within the shaded area, it is not possible to achieve adequate speech privacy by making changes to other office design parameters. (See also examples in Table 1 below.)

Ceiling absorption with SAA > 0.90 is usually only possible with high density glass-fibre-based ceiling tiles. Mineral fibre tiles usually have an SAA<0.60.

Workstation Size. The size of the workstation is also important for achieving adequate speech privacy. If the workstation referred to in Figure 4 is reduced in size from 3 m by 3 m to 2 m by 2 m, the speech privacy is also reduced (corresponding to an increase in the SII rating of 0.05). To achieve acceptable privacy in a workstation that is so much smaller, it is necessary to increase the ceiling absorption and separating panel height to the maximum possible. Workstations smaller than 2 m by 2 m cannot provide acceptable speech privacy.

Other Factors Affecting Speech Propagation

Many other design parameters influence the level of speech privacy in an office but to a lesser degree than those mentioned previously. Still, it is important to consider them, because it is usually only possible to achieve acceptable speech privacy when all aspects of the design are close to ideal.

Panel Characteristics. To control speech sound transmission through workstation panels, the panels must have an STC rating (see box, p. 2) of at least 20. Partial height workstation panels should all have an SAA≥0.70, to minimize reflections from their surfaces. If the workstation panel absorption were changed from an SAA=0.90 to an SAA of 0.60, the SII would increase by 0.02. While this may seem to be a small degradation in the overall performance, it is important to remember that, at best, most designs barely provide acceptable speech privacy.

Even small improvements can help to meet the SII ≤ 0.20 criterion. However, if the panels are not reasonably absorptive (i.e., if SAA<0.60), there will be a significant increase in the resulting SII and a corresponding reduction in privacy. For example, if one uses non-absorptive panels in an otherwise ideal workstation design, the SII can increase from 0.2 to 0.3.

Wall Treatment. Similarly, where there are large areas of wall, they too should be treated with sound-absorbent material with an SAA≥0.70.

Floor Treatment. Floor absorption and ceiling height generally have very small effects on SII. In most cases, varying these parameters changes SII by no more than 0.01. However, floors should be carpeted, to minimize activity noises and sound propagation through gaps at the bottom of workstation panels. When the floor is carpeted, gaps of up to 25 mm have negligible effects on sound propagation between workstations.

Light Fixture Selection. Lighting fixtures in the ceiling can degrade the speech privacy of the open-plan office. The magnitude of the effect depends on the type and location of lighting units. Lights with a flat plastic or glass surface produce strong unwanted acoustic reflections and are most troublesome when located directly above the separating panel between two workstations. The change in SII is greatest when these lights are installed in a highly absorptive ceiling. The evaluation of several types and locations of lighting fixtures has shown that, for a ceiling with an SAA=0.90, the SII can increase by up to 0.08. The use of parabolic louvre (open-grill) lighting fixtures has a less negative impact on speech privacy, but still reduces the effectiveness of a highly absorptive ceiling.

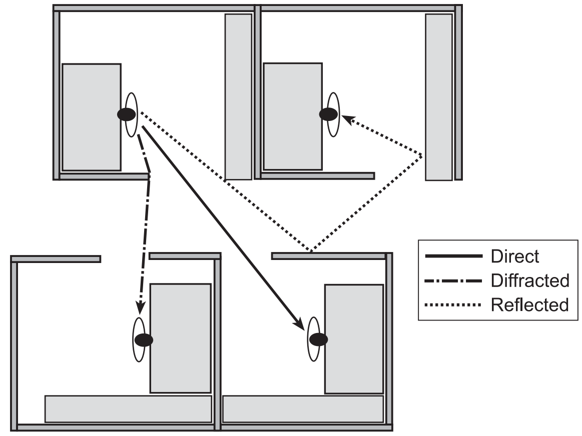

Figure 5. Examples of direct, diffracted and reflected sound paths between workstations

Workstation Layout. It is also important to consider the layout of the nearby workstations. Sound paths in both horizontal and vertical planes should be examined to identify possible direct or reflected paths between workstations. Examples of the problems that may arise are shown in Figure 5. Vertical surfaces outside individual workstations should be made sound absorbent to prevent strong sound reflections between workstations. Where there is a direct line of sight between two nearby occupants, the layout should be changed to eliminate the direct sound path.

Window/Panel Interface. When workstations are located next to windows, it is often difficult to avoid having gaps between the panels and the window. Such gaps can allow for strong sound reflections between workstations, greatly reducing speech privacy. Efforts should be made to completely fill such gaps.

Team-Style Work Spaces

Team-style open office spaces usually resemble a large cubicle with multiple occupants. Achieving acceptable privacy between such spaces is the same problem as between individual cubicles. Although intended to provide easy communication between team members, it is at times desirable to have some speech privacy between occupants of the team-style space. Of course, it is much more difficult to achieve speech privacy between office workers within a team-style space. Encouraging an office etiquette that includes the use of low voice levels is even more important in this type of office. While panels generally do not exist, it is particularly important that the ceiling be as highly absorptive as possible. Team-style spaces are not suitable for individual work requiring concentration but are most suitable where the work involves considerable interaction throughout the day.

Figure 6 gives an example of a team-style work area. There are essentially no barriers between occupants of the work area, but there are barriers or panels separating them from adjacent work spaces. In this type of space, the occupants are in full view of each other, and clear speech communication between occupants can occur if they desire it. Although it may not be possible to change the basic concept, some details of the design can help to improve acoustical conditions.

- All panels and other large surfaces should be sound absorptive (SAA≥0.70).
- Small, low barriers can be used to break the line-of-sight between adjacent occupants and to improve speech privacy without detracting from the open feeling of the workspace (see Figure 6).

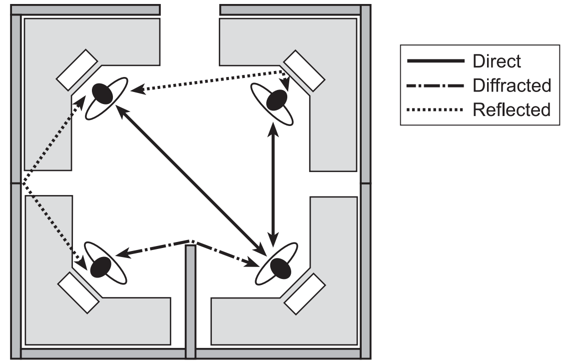

Figure 6. Examples of direct, diffracted and reflected sound paths between occupants of team-style office space

- Occupants should be oriented so that, when working independently, they are facing away from each other.
- The ceiling should be highly sound-absorbent (SAA≥0.95).
- Maximize the distance between occupants.

Design Examples

Table 1 shows four different designs for open-plan offices that achieve the SII≤0.20 criterion. These examples show various combinations of parameters that provide acceptable designs.

Example A achieves the design criterion (i.e., SII≤0.20) using the lowest possible panel and ceiling absorption values with a relatively high panel (1.7 m). The other three designs are variations of Example A.

Example B has a lower panel (1.6 m) and compensates for this with increased ceiling absorption values.

Table 1. Design examples that just meet the SII≤0.20 criterion. Shaded cells indicate parameters have been changed relative to those for Example A. All results used a speech level (measured 1 m from the speaker) of 53.2 dBA (IOSL) and an ambient noise level of 45 dBA (optimum ventilation noise) as shown in Figure 2.

Office Design Parameter	**A**	**B**	**C**	**D**
Ceiling SAA	0.90	0.95	0.97	0.95
Panel height	1.7 m	1.6 m	1.7 m	1.7 m
Panel SAA	0.70	0.70	0.70	0.80
Workstation size	3 m x 3 m	3 m x 3 m	3 m x 3 m	2.5 x 2.5 m
Floor SAA	0.20	0.20	0.20	0.20
Panel *STC*	21	21	21	21
Ceiling height	2.7 m	2.7 m	2.7 m	2.7 m
Light fixtures	None	None	Parabolic louvre	None
SII	**0.20**	**0.20**	**0.19**	**0.20**

Example C adds a parabolic louvre (open-grill) type of light fixture to the centre of the ceiling of each workstation. To compensate for this, the ceiling absorption is increased.

Example D is a smaller workstation (2.5 m by 2.5 m). To compensate for its smaller size, the ceiling and panel absorption are increased.

By increasing the absorption of the ceiling or the partial-height panels, or by increasing the height of these panels, one can further improve each of the designs and achieve a lower SII value; e.g., if Example A is modified so that the ceiling absorption is increased to SAA=1.03, and the panel absorption to SAA=0.90, the SII is reduced to 0.11, providing excellent speech privacy.

These design examples should be used only as a guide. The actual SII depends on how the sound absorption of each product varies with frequency.

Summary Recommendations

Where detailed calculations are not possible, follow these recommendations for conventional open-plan office designs:

- Choose a combination of ceiling absorption and panel height from the shaded area of Figure 4.
- Make the workstation as large as possible; a minimum of 2.5 m by 2.5 m is preferred.
- Select workstation panels that have an SAA≥0.70 and treat all large vertical surfaces with similarly absorbent material.
- Use carpet on floors.
- Do not use flat-lens light fixtures in the office ceiling.
- Encourage office workers to lower their voices.
- Add masking sound with a 45-dBA level evenly distributed throughout the office.
- Ensure that all noise sources (e.g., ventilation systems, office equipment and water coolers) do not exceed 40 dBA.

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