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Acoustical Design of Open-Planned Offices

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Please note

The open-planned office is not new in concept, having been for many years the most direct approach to the accommodation of large groups of routine workers. Recent demands for greater organizational flexibility and improved interpersonal communication have brought about, however, a radical change in its application. To distinguish it from the older form its German originators gave it the name 'Burolandschaft' (landscaped office).

This approach requires that all levels of staff and a multiplicity of activities be accommodated in one large space. The use of colour and soft furnishings, carpeted floors and moulded ceilings to satisfy acoustical, comfort, and aesthetic requirements have resulted in a greatly improved physical environment, and general acceptance has been echoed in a number of user surveys. The diversity of activities, however, results at best in acoustically marginal solutions and the most consistent complaint cited by users is annoyance caused by intrusive noise, particularly speech.

This Digest examines the acoustical environment of an open office plan, and discusses its problems and the elements that can be utilised to obtain acceptable results. A design procedure follows that allows the condition at any point within an open office to be determined at the planning stage.

Speech Communication vs Privacy

The ideal office environment would permit any occupant to talk easily with a visitor or on a telephone without distracting other occupants of the office. Thus the acoustics of the open office is tied up in two ways with the properties of the speech communication process.

Normal speech has a dynamic range of some 30 dB and a frequency content from 250 to 6000 Hz. The middle frequency components are more important than the extreme high and low frequencies, but for 100 per cent intelligibility the full 30 dB range of the speech signal across the complete frequency spectrum should lie above the prevailing background noise.

Intelligibility of speech, then, is a function of the *signal to noise ratio*, and this is used to arrive at a quantitative measure of intelligibility known as the *Articulation Index* (AI), i.e. the fraction of speech sounds perceived above background noise, weighted to take into account the contribution of different frequency bands to the intelligibility of the speech signal. The delicate task in an open office is to adjust the signal-to-noise ratio so as to permit adequate local communication together with adequate privacy in relation to points nearby.

The articulation index ranges in value from zero, for zero communication/perfect privacy, to unity, for perfect communication/zero privacy (see Table I). The articulation index is influenced significantly by the following six variables.

Table I. Relation Between AI and Subjective Impression

<table>
<tr><th>AI</th><th>Speech Privacy Conditions</th><th>Communication Condition</th></tr>
<tr><td>1.0</td><td rowspan="5">Nil</td><td rowspan="4">Excellent</td></tr>
<tr><td>0.9</td></tr>
<tr><td>0.8</td></tr>
<tr><td>0.7</td></tr>
<tr><td>0.6</td><td>Good</td></tr>
<tr><td>0.5</td><td rowspan="2">Very Poor</td><td rowspan="2">Fair</td></tr>
<tr><td>0.4</td></tr>
<tr><td>0.3</td><td rowspan="2">Poor</td><td rowspan="2">Poor</td></tr>
<tr><td>0.2</td></tr>
<tr><td>0.1</td><td>Acceptable</td><td>Very Poor</td></tr>
<tr><td>0</td><td>Excellent</td><td>Nil</td></tr>
</table>

1. *The nature of the sound field*. In a normal, reverberant room the sound field created by a noise source reaches a more or less constant level that does not change appreciably with distance from the source. Noise created out-of-doors where there are no reflecting surfaces decreases in intensity as a function of the distance from source to receiver at a rate of 6 dB per doubling of distance. Measurements made in the sound absorbing environment of well-designed, open-planned offices show that a decrease in sound intensity with distance approaches the free field situation, with a reduction of 4 to 5 dB per doubling of distance.

   In order to reduce the propagation of sound within the open-planned office and provide maximum acoustic privacy it is necessary to simulate the anechoic conditions of outdoors by eliminating reflected sound. This requires that major vertical surfaces such as walls be sufficiently removed from each other (60-ft minimum recommended) and sufficiently sound absorbing to avoid the setting up of a reverberant sound field. A floor area of 10,000 ft^2 is desirable and 4,000 ft^2 is considered the absolute minimum for a successful open-office installation. Screens may be used to intercept direct sound but care must be taken to position minor vertical surfaces so that they do not reduce the effect of the screens by reflecting sound energy around them. The ceiling, which ordinarily constitutes the major reflecting path, should be surfaced with a highly efficient sound absorbing material (Noise Reduction Coefficient (NRC) = 0.8 or greater), especially if it is a plane, unbroken surface. A slightly less efficient material may, however, be effective if the surface is broken up with coffers or baffles. Reflections via the floor are usually interrupted by furniture, but the floor should nevertheless be carpeted.

- *Prevailing background noise*. It is a common experience that for effective communication in a noisy environment the speaker must reduce the distance between himself and the listener or increase the level of his voice to maintain a sufficient signal to noise ratio and thus a sufficient degree of speech intelligibility. Obviously there is an acceptable limit beyond which the increased levels of speech add to the over-all noise level, culminating in the well known "cocktail party" effect. It is this problem that underlies the success or failure of the open-office concept. A decrease in background noise level of 5 dBA, all else being equal, results in an increase of 0.17 in the Articulation Index. Conversely an unobtrusive level of background noise with an appropriate spectral shape is a useful tool in increasing speech privacy and thus reducing annoyance.

It has been shown that most people are unaware of broad-band, steady-state sound levels below 35 dBA and will accept levels up to approximately 45 dBA. Although higher levels do occur, there is evidence that levels above 50 dBA are generally unacceptable. Continuous background noise has been provided by air-conditioning systems with varying degrees of success owing to the difficulty of generating the right amount of noise with the right frequency spectrum. Electronic noise generators have proved more successful because of the degree of control available. It is important that noise be uniformly distributed over the area so that the source is not obvious. The normal activities of an office produce noise levels typified by Table II. Because of their intermittent character, however, they cannot be relied upon to provide adequate masking.

Table II. Typical Background Noise For Various Environments

(These levels should be considered to range ±5 dB about quoted mean.)

Environment	Typical Background Noise	
Professional/Clerical (No machines)	35 dB (A)	V. Quiet
Professional/Clerical (Some machines)	40 dB (A)	Quiet
Small Drawing Office	40 dB (A)	Quiet
Clerical + Numerous Machines	45 dB (A)	Acceptable
Large Clerical + Numerous Machines)	50 dB (A)	Noisy

- *Speech level.* Apart from the dynamic range of 30 dB previously mentioned, the mean value of a normal voice has a range of approximately 20 dB from quiet to raised, depending on the speech effort applied. Simplifying this range to discrete steps of quiet, normal and raised, each step of 10 dB results in a change in Articulation Index of 0.34. Merely raising ones voice may therefore destroy the state of acoustical privacy at nearby work locations and the more demonstrative speaker would cause the AI to fluctuate by 0.6, thus spanning the range from confidential privacy to excellent communication. Fortunately the open-office concept appears to have the effect of reducing conversational levels.
- *Speaker to receiver orientation.* As the speaker turns from the receiver, the received speech level decreases, assuming the absorptive environment described in (1). Considering the receiver as a non-directional point, each 90 deg change in speaker orientation results in a decrease in AI of approximately 0.15, so that a maximum decrease of 0.3 may be obtained when the change in orientation is 180 deg, i.e. when speakers back is to the receiver. At worst, this would span the range from acceptable to zero privacy.
- *Speaker to receiver distance.* In the absorptive environment described in (1) the doubling of distance from speaker to receiver can result in a reduction in Articulation Index of 0.15. Thus, if good communication exists at a certain close range (say 3 ft), then without the use of screens a separation of some 20 ft would be required before a condition of acceptable privacy is reached.
- *Attenuation provided by screens.* The effectiveness of partial height barriers or screens as commonly used in open office planning is generally over-rated. The maximum reduction that can be expected from the insertion of a well-designed screen between speaker and listener is approximately 10 dB at the important speech frequencies. Even this reduction is possible only if it is thoughtfully located and there are no flanking paths to reflect sound around it. A well-designed screen must be sufficiently opaque to sound to provide less transmission through it than around it, but this requires only that there be an impermeable barrier weighing at least ¼ lb per sq ft. It is desirable that the absorptive surface covering the barrier have a noise reduction coefficient of at least 0.8.

The insertion of such a screen will provide a maximum reduction in AI of 0.3. This will improve an already reasonable situation but will not provide acceptable conditions if the AI is initially high.

Machine Noise

Both the level and intermittent character of machine noise can cause annoyance. Where noisy, fluctuating sources (typewriters, business machines, etc.) are unavoidable, there is some benefit to be gained in grouping them together so that they act as a single relatively continuous source. Such devices as stenographic machines and telephone buzzers must be set to operate at an effective but unobtrusive level.

A Design Guide

Table III, together with Tables I and II and Figures 1 and 2, sets out a procedure whereby the privacy condition at any point in an open-office plan can be established with respect to any speaker position. The procedure, which is applicable only to the type of environment outlined in Section (1), allows for the prevailing speech level, background noise, speaker-to-receiver distance and orientation, and the insertion of partial barriers. As individual reactions to noise vary, the objective/subjective relations presented in Table I must be considered only as a guide. By way of illustration, the method is applied to several locations in the open plan segment shown in Figure 2. The procedures outlined in Table III have been combined to form the "ready reckoner" shown in Figure 3.

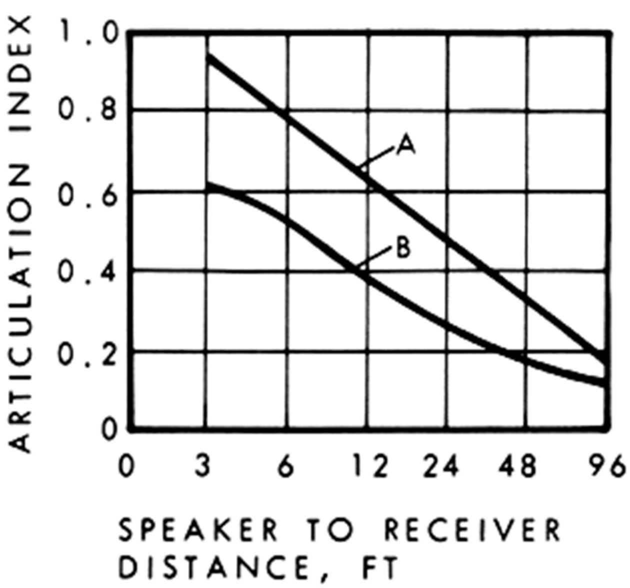

Figure 1. Articulation Index as a function of speaker-to-receiver distance (for S/N ratio = 15dB).

Curve A -- No screen between speaker and receiver
Curve B -- Screen between speaker and receiver

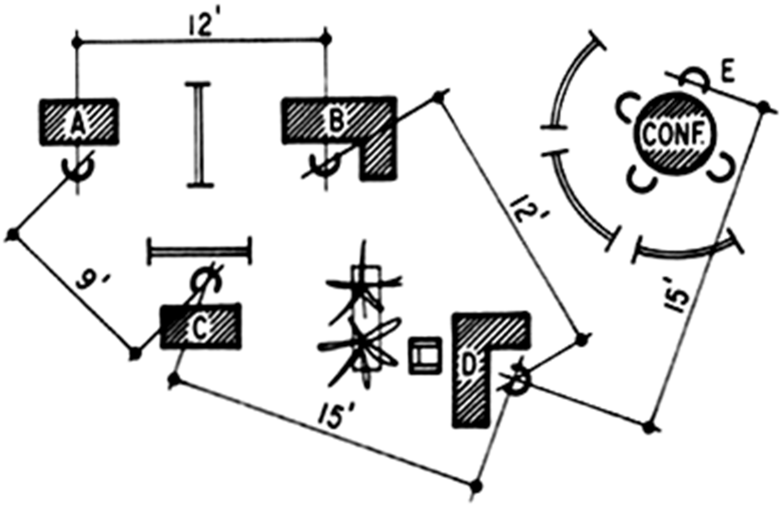

Figure 2. Open plan segment.

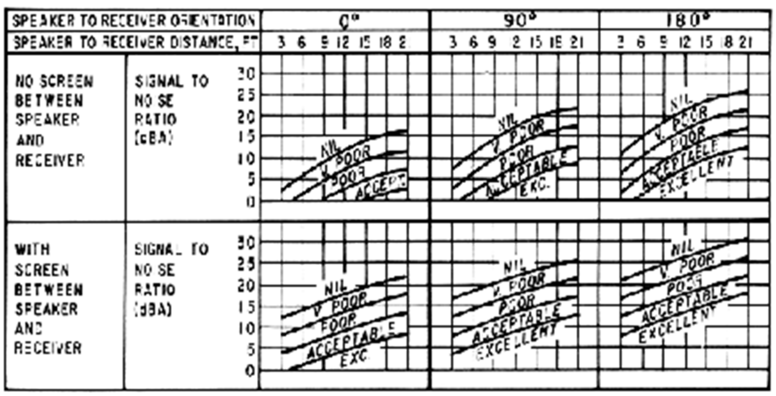

Figure 3. Design guide based on Table III.

Method of Use:

a. Establish signal/noise ratio (Table III, steps 1 to 4)

b. From proposed layout determine speaker-to-speaker-to-receiver distance and orientation.

c. Using above data enter Figure 3 for "no screen" or "with screen" case and read privacy condition.

Table III. Procedure For Determining The Privacy Condition At Any Position In An Open Planned Office

Step		Reference		Example (See Fig. 2)						
1.	Location	Design Drawings		A to B	A to C	C to D	D to C	D to E	E to D	D to B
2.	Assumed or Measured Speech Levels at 3 ft from Speaker	Quiet Normal (conversation) Raised (conference)	50 dBA 60dBA 70dBA	60	60	60	60	60	70	60
3.	Assumed or Measured Background Noise Level	Table II		45	45	45	45	45	45	45
4.	Signal/Noise Ratio at a Distance of 3 ft	(Step 3 minus step 2)		15	15	15	15	15	25	15
5.	Articulation Index at Required Distance from	Figure 1		0.38	0.44	0.57	0.57	0.34	0.34	0.62

	Speaker									
6.	Correction For Signal/Noise Ratio	S/N Ratio 25 20 15 10	Correction +0.34 +0.17 0.00 -0.17	0	0	0	0	0	0.34	0
7.	Correction For Speaker Orientation re Receiver	0° 90° 180°	0. -0.15 -0.30	- 0.15	-0.30	- 0.15	0	-0.15	0	0
8.	Correction Articulation Index at Receiver	(Step 5 plus 6 plus 7)		0.23	0.14	0.42	0.57	0.19	68	0.62
9.	Privacy Condition	Table I		Poor	Accept	V. Poor	Nil	Accept	Nil	Nil

It should be noted that even in a highly absorptive environment the over-all effect can be seriously degraded if all aspects are not properly considered. If used properly, they are complementary and additive in their effect, but incorrect use of one or more can negate the effect of the others. *(Corrected Sept. 1971)*