SPECTRA TECH LTD

THE ACOUSTICAL ENVIRONMENT

in the

Open-Plan Office

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Acoustical Environment in the Open-Plan Office

The modern open-plan or "landscaped" office has become an accepted means of accommodating large office areas. As with any departure from familiar techniques, however, problems arise that are not everywhere understood or solved. It is the purpose of this paper to describe the acoustics of the open-plan office in a way that clarifies the principles that designers and architects use to achieve an acceptable and flexible environment.

An open-plan office may be broadly defined as a space in which individuals and work zones are not separated by ceiling-high barriers. Instead, free-standing barriers or screens that do not extend to the ceiling are used to provide a measure of privacy. Even these may be dispensed with in some cases. This definition, then, applies to the traditional "bull-pen" type of office as well as to the more modern approach, which is sometimes called the "landscaped office" because of the liberal use of soft furnishing, plants, art work, and color.

The prime advantage of an open-plan office is its flexibility. Organizational changes can be implemented with minor effort and at a cost lower than in the conventional office. Properly planned, the work flow determines layout, and function becomes a primary consideration. Where visual amenities are used, these may be enjoyed by the entire staff, not just those in upper echelons, thus contributing to greater employee satisfaction.

The key to achieving a successful open-plan office lies in a thorough systems approach. In particular, one must consider the interface and interaction between subsystems when examining any individual component. The primary problem faced in open-plan office design is the achievement of acoustical privacy for individual work stations while maintaining the featured flexibility, economy, and openness.

Theory

The ideal open-plan office acoustical environment would permit any occupant to talk easily with a visitor or on a telephone without distracting or being understood by other occupants. The best way to design such an environment is to look at that office as a man-machine system. This system may be considered in three principle parts:

- Noise sources, including people who talk and move about, office machines, and anything else that is likely to make annoying noises.
- **Noise transmission elements,** which constitute the bulk of the architecture of the office, such as ceilings, walls, floors, office screens, office layout, and anything that influences the amount of speech or noise reaching the receiver (for example, transmission paths involving ceilings, walls, floors, screens, and other items of furniture).
- **Noise receivers,** who are predominantly people with a common, but not completely singular, sensitivity to these noises. Their sensitivity may be modified by adding masking sound, which does not annoy them, to their environment.

It is the responsibility of the system designer or open-plan office planner to provide the proper environment by confining those sources under his or her control, achieving the best attenuation along noise transmission paths, and understanding the sensitivity of the people-receivers. The bulk of quantitative knowledge developed to date centers on the second item—ceiling, screen, and masking subsystems. Not much has been quantified on receiver sensitivity in the open-plan office context. At office locations acoustically separated from high-level noise sources (high-speed printing machines, for example), the acoustical conditions normally encountered are not presently considered damaging to human hearing, so one ends up dealing on a subjective plane.

Privacy Criteria

At the onset of the design process, it is important to determine the need for privacy since measures necessary to provide acoustic privacy can be expensive. The privacy criterion for a given function depends on that function. Executive and sensitive areas require confidential privacy, defined as "zero phrase intelligibility with some remaining isolated word intelligibility" [*1*]. Other areas may require minimal privacy, such as secretarial pools. To date it has been customary to relate privacy requirements to speech communication as discussed in the following sections.

Speech Sounds in the Open-Plan Office

Average male conversational speech at a distance of 1 m (3 ft) has a broad band level of 60 to 65 dB. The dynamic range of component levels is 30 dB across the frequency range from 200 to 5000 Hz. These limits are not firm. It is usually accepted that the middle frequency components are more important for communications than the low and high frequencies. For 100% intelligibility, the full 30-dB dynamic range of the complex frequency spectrum should lie above the prevailing background noise. Intelligibility of speech is a function of the signal-to-noise ratio. This can be used to arrive at a quantitative calculation of probable intelligibility known as the articulation index (AI) [*2*]. This is a formal index derived from a procedure that takes into account the contribution of different frequency bands to the intelligibility of speech and that can be related to the fraction of speech sounds intelligible above the background noise.

Apart from the dynamic range of 30 dB, the mean value of a normal voice sound has a range of 20 dB from "quiet" through "normal" to "raised," depending on the amount of speech effort applied. Merely raising one's voice may destroy the state of acoustical privacy at nearby work stations. This is perhaps the most irritating human disturbance in the open-plan office. Fortunately the higher absorptive surroundings in the open-plan office appear to induce lower voice levels.

Interfering Sounds

An additional factor to be considered in an open-plan office is the interference and annoyance caused by common office equipment and ventilation systems. The most irritating mechanical disturber in this office area is the standard electric

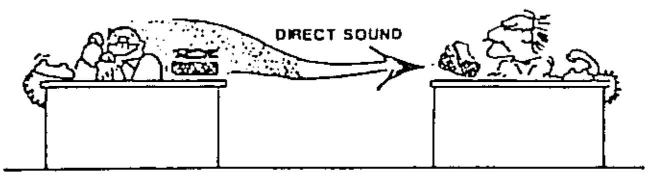

FIG. 1—*Annoyance in the absence of screens.*

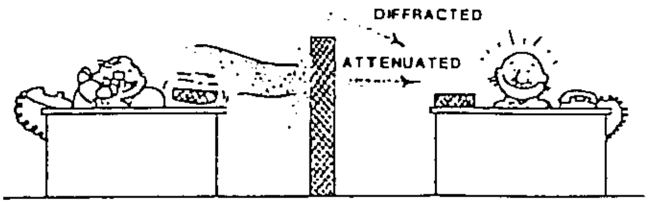

FIG. 2—*Screens reduce intruding speech sounds to acceptable levels.*

typewriter. This is followed and occasionally surpassed by the clamoring telephone bell. Other machines, such as copiers, tend to be less numerous and may be given special treatment or placement to minimize their annoyance. Other sources of mechanical noise, such as ventilation systems, should be kept below noise criteria curve 35 (NC35) (or approximately 45 dB A) throughout the office. This is not a stringent requirement and is usually not a problem. Noise control procedures are generally most effective when applied directly to the source. Thus, the strident telephone bell should be banned and replaced with, for example, a quiet tone, flashing light, or both.

The planner should impress on his or her client the need for the quietest typing system feasible. Private secretaries perforce must be situated close to their immediate superiors. If their work load includes extensive typing and telephone communications, their station should be isolated from the adjacent work areas with larger than normal screens. On the other hand, secretarial pools merit special consideration. Typists in such pools usually prefer not to be isolated from each other by screens. It is cautioned that a large typing pool or word processing center (WPC) will produce ambient noises up to 80 dB A so that special isolation measures are required to shield the surrounding work areas from annoyance. This could be best accomplished by removing them to another location or erecting a ceiling-high enclosure about their station. If these steps are not feasible, then their work station placement should include a peripheral buffer zone of lesser sensitivity, such as walkways or reproduction facilities.

The Attainment of Acoustical Privacy

The main means of sound control in the open-plan office plan is pathway attenuation. Since the work stations in an open-plan office plan are not separated by walls, occupants can be disturbed by intruding sounds, human or mechanical, from other parts of the office.

In a normal reverberant field room where sound undergoes many reflections, the sound field caused by any single source reaches a more or less uniform level at some distance from the source. This remote sound level does not then change appreciably from one part of the room to another. On the other hand, sounds created out-of-doors or in a large open space decrease in level by 6 dB each time the distance from the source is doubled. A well-designed open-plan office approaches this condition. This is achieved by treating reflecting surfaces, especially the ceiling and walls, with absorbing materials to reduce sound reflections to negligible values in the speech frequency range.

In a typical open-plan layout, the average distance between individuals is about 4 m (13 ft). This dimension varies, being affected by the degree of privacy required, function, and economics. Such a layout may be rendered acoustically private by carefully designing and interfacing the acoustical components: (1) partial-height acoustical barriers (screens), (2) sound-absorbing ceilings and walls, and (3) background masking sound system. Experience has shown that all three elements are usually required to achieve acceptable privacy. The interrelationship between speech privacy and these components may be described as follows:

An individual speaker in an average office or work area will normally modulate his voice so that his listener will enjoy a nearly 20-dB signal-to-noise ratio at his listening distance, typically 1.2 m (4 ft), thus:

(1) The designer provides a screen that will reduce the speech level intruding into adjacent work stations as much as is considered feasible within aesthetic and economic limits.

(2) The designer also provides an absorbent ceiling that approaches an "open sky" condition as nearly as possible. Absorbent walls and carpeted flooring are usually included in this step.

(3) In most offices, Steps 1 and 2 above result in an extremely quiet environment so that "normal" speech and activities cause sound levels in adjacent work stations far in excess of this quiet environmental background noise. As a consequence, it becomes necessary to introduce controlled masking sound throughout the area so that these spill-over sounds are not noticed or are at least unintelligible.

Open-Plan Office Components

Screens

The free-standing screen, or partial-height acoustical barrier, is one of the basic elements of the open-plan office. It serves as both a sound attenuator and a sound absorber. It usually has an impervious central septum covered on both sides with a sound-absorbing layer and then finished with an attractive fabric. This unit provides visual privacy for the occupants and when used with an appropriately absorbing ceiling system and background masking sound system can effect speech privacy between adjacent work stations.

The screen functions in the following way: If there were no barrier between work stations, only distance would reduce the amplitude of speech sounds between stations (see Fig. 1). A screen placed between the stations has the effect of attenuating direct sound waves that now must either pass through it or bend around its edges (see Fig. 2). Sound-wave bending is called "diffraction." The heavier the septum material, the greater the transmission loss for sounds attempting to pass through it (assuming no penetrations or leaks). In practice, this transmission loss need only be sufficient to reduce the level of transmitted sounds to be below that of the diffracted sounds. Common rectangular screens may have diffraction occurring around all four edges. Finite screen width and height must be accepted in practice, but diffraction and reflection under the bottom edge of the screen can be blocked by resting that edge directly on the floor.

The diffracted sounds reaching the listener's ears are reduced in amplitude by an amount dependent on geometry. In general, greater attenuation results for larger bending angles and higher audio frequencies. The larger the screen and the closer it is to the speaker or listener, the lessen the transmission due to diffraction. Thus increasing the height of the screen usually increases privacy as does increasing the width of the screen. This principle cannot be carried to extremes since there is no point, for example, in using a screen 3 m (10 ft) high which is only 2 m (7 ft) wide.

Screens are often curved for aesthetic purposes. The acoustical performance of such screens is not usually affected by this curvature, provided their faces are highly sound absorbing.

Occupant Orientation

Along with screen placement, occupant orientation plays a role in determining the degree of privacy that is achieved. As a human speaker turns away from a listener, the received speech level decreases. Each 30 deg of rotation away from the straight-ahead position results in a 1.5-dB decrease in speech energy so that a maximum decrease of 9 dB occurs when the speaker turns his back to the listener (see Fig. 3). This fact can be used to some advantage in planning, but a design relying on this phenomenon will be successful only if it is absolutely certain that desks and screens will not be disturbed from their acoustically prescribed positions. In addition, this directivity applies to a free field condition of maximum absorption which may not exist in a typical office.

Human nature being what it is, it is better to plan for a worst-case acceptable design so that positional requirements are not so stringent. Also, a rigid design (no orientation alternatives) reduces the flexibility and ease of change, which is one of the major benefits of the open-plan office, not to mention the fact that rigidity often necessitates acoustical counseling for each organizational change.

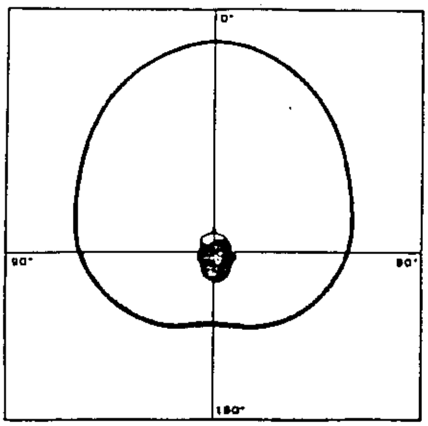

FIG. 3—*Decrease in speech energy with respect to speaker orientation (approximately 1.5 dB per 30 deg).*

The Ceiling

In addition to transmission through or diffraction about a screen, intruding sounds may reach the listener by bouncing from nearby flat surfaces, as shown in Fig. 4. This process is termed "specular reflection" and is analogous to the bounce of a billiard ball from a cushion or the reflection of light by a mirror. The amplitude of this reflected sound depends on the reflective properties of the surface. Reflectivity is not always predictable by the noise reduction coefficient (NRC) of the surface, primarily because NRC averages absorptivity at all angles of incident sound [3].

The largest surface available for specular reflection of sound in the open-plan office is the ceiling. For that reason, much attention is paid to its acoustical properties. The ceiling surface must be highly sound absorbent, especially at angles of incidence of 45 to 60 deg for a flat ceiling, lest reflections greatly reduce screen effectiveness.

A variety of ceiling products and configurations is available to reduce ceiling reflections. They range from flat absorbing panels to coffered systems and baffles.

Accessory installations in the ceiling also can cause sound reflections. Flat, hard surfaces, such as light fixture shielding media, are generally unsatisfactory when located uniformly throughout the ceiling area. An exception to this rule can occur with task-oriented lighting. The concept of task-oriented lighting generally means the provision of adequate lighting at work stations without uniformly illuminating that space to the level of the most difficult seeing task. These lights must be moved as the work station moves. In this arrangement, the fixture is located directly over the speaker and listener; thus, the intelligibility of their conversation is improved, if anything, while the privacy of other stations is not impaired. It is usual to evaluate the privacy of the ceiling and lighting system together along a survey line which produces the lowest rating. The method of test is outlined later.

Walls

Where work stations requiring speech privacy are located near hard vertical surfaces such as cabinets, columns, perimeter, and core walls, these surfaces should be covered with sound-absorbing panels to minimize reflections. As a minimum, such absorptive treatment should be applied to the region from 0.6 m (2 ft) to 1.8 m (6 ft) from the floor. Carpeting and drapes, although aesthetically pleasing and durable, may not be sufficiently sound absorbing unless extremely thick. Also, they may not have proper fire resistance. It is suggested that acoustically absorptive panels specifically designed for this application be utilized.

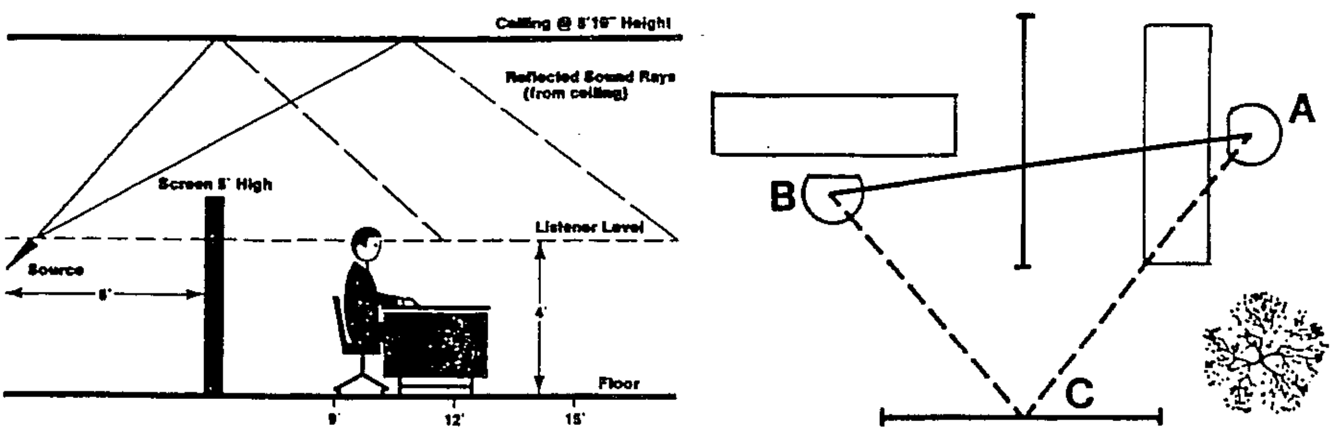

FIG. 4—*Specular reflection via ceiling (left) and specular reflection between work stations via Vertical Surface C (right).*

Sound reflected below the panels sometimes will be absorbed or diffused by the furniture, screens, and carpet. Sound reflected above this strip is usually absorbed by the ceiling. Where the finish surface of the columns is circular in cross section and less than 0.46 m (1.5 ft) in diameter, no treatment is necessary. This is because objects of this size or smaller serve as convenient sound scatterers or diffusers.

Windows around the perimeter of the office present a problem since most acoustical absorbers will impair vision. Draperies do not provide enough sound absorption unless they are of heavy textile material, fuller than usual, and closed. One possible solution is to tilt the window glass out of the vertical plane, thus deflecting the unwanted sound reflections to the ceiling or floor. Acceptable results may also be obtained by using vertical louvers that do not seriously impede vision but adequately diffuse the otherwise specular reflections.

The screens themselves might be reflectors, but most commercially available units are faced with absorbing materials and do not cause problems unless used as pin boards—a use that should be discouraged.

Floors

The acoustical efficiency of carpeted floors for reduction of impact sounds is well known and highly desirable. The sound absorption of carpeting is of limited value for open-plan office applications. Since sounds reflected from carpeted floors are easily absorbed by the ceiling system and otherwise broadly diffused by the screens and furniture, no great problems result.

Masking Sound

It was brought out earlier that the intelligibility of received speech depends on the level of the accompanying background noise. Ambient levels in open-plan offices tend to be very low because of the absorptive environment; thus the anomaly occurs that in this quieted office voices and noises from the adjacent work stations are audible and distracting. It is common, therefore, to use electronic random noise generators feeding loudspeakers hidden in the ceiling plenum to raise the level of the background. The spectrum of this sound is shaped to effectively mask speech with the least distraction. Figure 5 is a block diagram of an electronic masking sound and paging system. Signals from the sound generator are shaped with narrow band filters (for example, one-third or one-half octave) into the spectrum (as heard by the listener) that is considered optimum. Figure 6 shows a range of spectrum shapes that have been found to be acceptable.

Continuous background noises provided by air conditioning systems, though an attractive expedient, have not been generally successful because of the difficulty in generating the right level with the preferred spectrum. Electronic generators are more flexible. Likewise, music alone is unacceptable because it has pure tone components and transient level characteristics; however, music has been successfully introduced as a supplement to a properly adjusted masking system.

The masking sound field produced in the office must be uniform in space and time [*1,4*] to avoid occupant complaints or detection of the masking system. The uniformity of the sound field is governed by the spacing and orientation of loudspeakers, transmission characteristics of ceiling systems, reflective properties of the plenum surfaces, and openings in the ceiling such as plenum air return slots and light fixtures.

A common arrangement is to distribute individual loudspeakers in a square or triangular array with approximately 3 to 6-m (10 to 20-ft) spacing between units. The exact distribution will be influenced by plenum depth, obstructions, ceiling tile properties, and speaker radiation patterns. Ceiling materials that are relatively transparent to sound sometimes use an impervious layer on the back side to diffuse the sound and produce a uniform sound field in the listener areas. Another approach is to mount the speakers over fairly large baffles, about 1.25 m (4 ft) square, so that the sound must reflect and diffract around them, producing a more uniform field.

The monitoring and adjustments are carried out in the fully furnished office area minus staff. The level chosen for this background sound will depend on the degree of privacy required and on the physical properties of the screens and ceiling, although there is an upper limit. Clearly, the introduction of masking sound must not arouse hostility or adverse reactions in the office. Although various occupants have different reactions, most people seem to accept broad band, steady state sounds having A-weighted levels up to 52 dB A. Higher levels may be found unacceptable. It appears that talkers tend to raise their speech level to compensate for the further increased background level, thus defeating the system. It is better to increase interzone attenuation through better ceiling, screen, and wall design, or greater station separation.

It is best not to have other areas in the building quieter than the open-plan office, lest occupants become aware that their work area is not as quiet as it might be. This suggests the use of masking sound throughout the building. Some work areas require more masking sound level than others, however, and a compromise must be found. One successful technique is a gradual transition zone between levels.

A side benefit of the electronic masking system is that its amplifiers and loudspeakers can be used for public address announcements, life safety programs, or emergency paging. However, it should be stressed that the masking sound becomes a permanent part of the office environment and must never be turned off or muted for paging while the office is occupied. For paging, the power amplifiers and loudspeakers should have reserve power capacity to produce adequate voice signal-to-noise ratio in the office. Also a voice filter circuit, usually a tone control, will be necessary to compensate for frequency response modification of the ceiling structure.

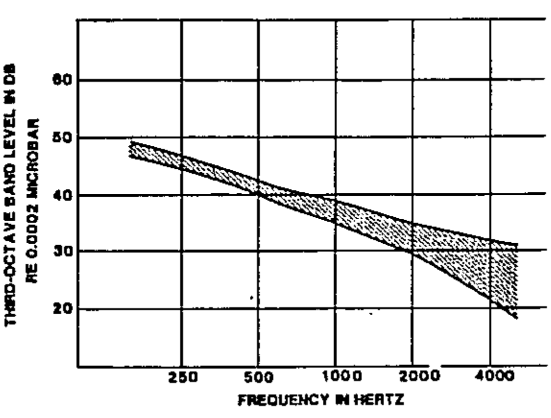

FIG. 6—*Range of typical masking sound spectra.*