Open-office acoustics: history, projects, and standards

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Historically, open-plan offices were the realm of clerical workers. In the 1960s upgraded open-office environments were introduced for mid-level office workers. Employees in these early open offices were bothered by noise and poor speech privacy. Starting in 1969, I became involved with finding acoustical solutions. This article explains the acoustical challenges with many of the first open-office projects, looks at the acoustical systems modified, and discusses acoustical standards developed by ASTM Committee E33 concerning open-office acoustics. This is an expanded version of a paper given at InterNoise 2012.

INTRODUCTION

In the 1960s, the Quickborner Team of Hamburg, Germany brought their management concepts to North America. They introduced office landscape, an open-office concept based on free-form, non-rectangular open-office layouts that employed freestanding curved barriers with freestanding desks. This concept was described as achieving non-hierarchical and collaborative environments. I had the good fortune or luck to provide acoustical consultation on many of the original office landscapes for organizations such as Eastman Kodak and the Port Authority of New York and New Jersey (World Trade Center). Following these, I consulted on numerous open-office projects including many for Fortune 500 Companies both on a new design and remedial basis.

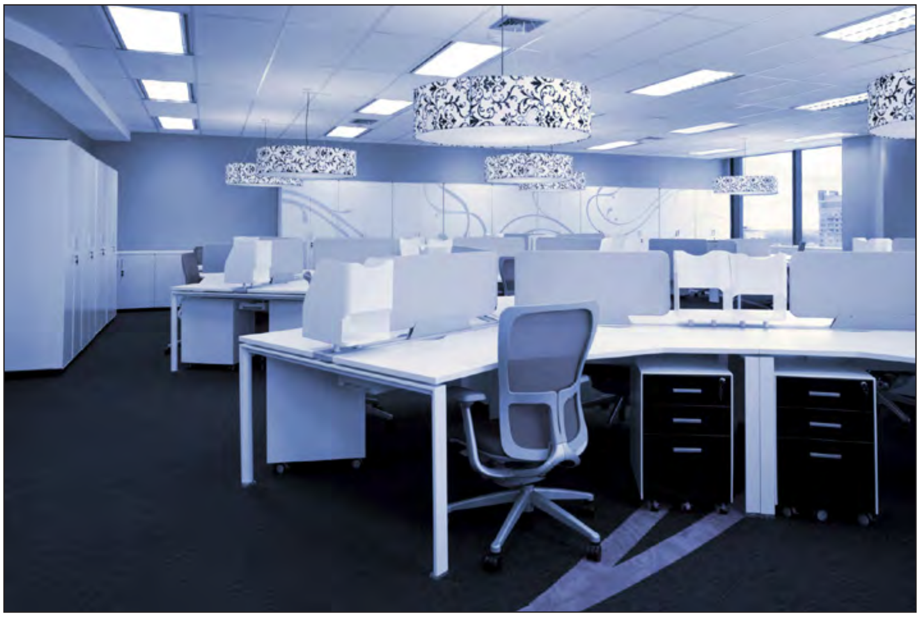
This paper discusses some early projects and acoustical solutions that were used, the development of test methods and standards relating to open plan offices by ASTM International Technical Committee E33 on Building and Environmental Acoustics, the acoustical elements that influence open office acoustical environments, and how these can be manipulated for improved conditions.

EARLY OPEN OFFICE CONSULTATIONS

Eastman Kodak was one of the first adapters of the office landscape concept. A pilot installation was built at their headquarters in Rochester, New York. It was well-received by employees, with one exception: noise/speech privacy was a problem. Kodak had done what many organizations continue to do: they took their normal office constructions, removed the walls, and installed an office landscape layout.

Kodak's normal office construction consisted of luminous ceilings comprising open egg-crate lay-in ceilings (Circlegrid), suspended below a white-painted slab with strip fluorescent lighting fixtures. There was no ceiling sound absorption to control privacy-reducing reflections off ceiling surfaces, and no masking sound system to obscure intruding speech sounds. I was not involved with the initial corrective modifications. These were engineered by a colleague at Goodfriend-Ostergaard Associates. One modification included sound-absorbent baffles suspended below and in-line with the ceiling grid. These units, manufactured by MBI, consisted of glass-fiber batts encased in white muslin. A rudimentary masking sound system was installed using a mixer modified to incorporate a noise source. Loudspeakers in metal enclosures were suspended on chains above the Circlegrid ceiling. Human resources surveys of the employees indicated that there was a perceived improvement.

It was at about this time (1970) that I took over Kodak as a client and over the subsequent two decades consulted on many new Kodak open-office projects. We started with the features of the modified pilot installation and progressively introduced acoustical improvements.



Many of these installations were at the Corporate Headquarters in Rochester as well as Kodak international offices in Madrid, London, Caracas, and Bogotá.

Looking at the modified pilot installation, the concepts were right but the specific solutions could be better. The masking system electronics were difficult to adjust or tune to achieve an optimum masking spectrum. We were essentially dealing with tone controls.

The downward-facing loudspeaker enclosures had round, solid baffles mounted on stand-offs. This arrangement was thought to direct sound horizontally in an omnidirectional pattern for more uniform coverage. This was a pipe dream. In fact the round plate acted like an acoustic lens that produced 800 Hz lobes below each enclosure. Because the ceiling was sound transparent, these lobes were quite audible. For subsequent installations we added white cellulose-spray on the overhead slab and eliminated the ceiling-mounted baffles. For later installations, we moved to glass-fiber lay-in ceilings and aimed the loudspeakers horizontally. Better masking control was developed through the use of one-third octave band equalizers. Analog noise sources were replaced with digital.

Quickborner originally used a concept that employed curved furniture screens that were thought to reflect sound back at a talker for better privacy. It did not work. We developed furniture barriers with sound-absorbent faces and centerline septums to block sound penetration.

The Port Authority of New York and New Jersey planned on moving the majority of their offices to their new development in lower Manhattan. Because they were interested in employing the office landscape concept, Goodfriend-Ostergaard Associates services were retained and I became the project manager. The Port Authority had developed a pilot office landscape in their building at 18th Street and 8th Avenue and were planning new offices to occupy the 56th through 73rd floors at One World Trade Center. About this time I joined Paul Ostergaard at Ostergaard Acoustical Associates.

The World Trade Center was being designed by Minoru Yamasaki on a 1-meter (40-inch) module so that three column bays would facilitate a 3-meter (10-foot) office. The project-standard ceiling boards comprised Armstrong Travertone tiles of custom size, 50-cm (20-inches) square, two per building module. With a noise-reduction coefficient (NRC) of 0.70, these were not sufficiently sound absorbent for the planned Port Authority open offices. As a consequence, we suggested two alternatives, supplemental acoustical baffles below the ceilings or use of nubby glass-cloth-faced glass fiber lay-in ceiling panels.

DEVELOPMENT OF THE ARTICULATION-INDEX TEST METHOD

As part of our consulting on open-office acoustics, I felt that there was a need to be able to test speech privacy in completed installations as well as in mock-ups of open offices prior to construction. I developed a procedure for measuring the noise reduction between open offices and then calculating the articulation-index values for different speech efforts. The method was based on the concepts and one-third octave weighting factors given in ANSI S3.5-1969, *"Method for the Calculation of Articulation Index."* For speech levels, we used the male voice spectrum developed by Bolt Beranek and Newman and documented in the U.S. Department of Commerce Report PB-270053, May 1977. The male voice spectrum was selected because the results were more conservative than for the female voice. Although the test method was relatively straightforward, a number of challenges had to be solved to achieve reliable results.

The procedure called for the measurement of noise reduction between two locations, typically in adjacent workstations. However, the source levels could not be measured in the test environment. This was because path phenomena, such as sound reflected off a desk, would skew the source sound levels. The solution was to pre-measure source levels off-site in an anechoic or acoustically similar environment. Assuming no damage to the loudspeaker source, the amplifier output voltage could be measured, prior to testing, to verify the reliability of the source levels.

Since we wanted to replicate a human talker, a speech-directional loudspeaker was needed. For this, I was helped by Radio Speakers of Canada. They developed a small cabinet with two 4-inch loudspeakers aimed about 30˚ horizontally from the centerline.

We were able to use this method to evaluate mock-up offices for the Decker Engineering Building at Corning Glass Works and the T. Easton offices in Toronto, and for evaluating existing installations at Eastman Kodak, IBM, and John Hancock. The paper "Use of the Articulation Index to Evaluate Acoustic Privacy in the Open Office" was published in the September-October 1978 issue of Noise Control Engineering. It described the test method and was later used to develop ASTM E1130 "Standard Test Method for Objective Measurement of Speech Privacy in Open-Plan Spaces Using Articulation Index. "

Articulation Index (AI) is a measure of speech intelligibility that is equivalent to a percentage scale. In open offices, the goal is speech privacy, or low AI values. A paper prepared by W. J. Cavanaugh, W. R. Farrell, P. W. Hirtle, and B. G. Waters, "Speech Privacy in Buildings", documents that confidential privacy occurs with AI values of 0.05 and lower. A confidential privacy condition exists when so few words can be understood that a listener cannot determine what is being said.

Since confidential privacy is seldom feasible between adjacent workstations in open offices, and not necessarily needed, two other privacy ranges were developed: normal privacy and minimal privacy. I describe normal privacy, which covers the AI range between 0.05 and 0.20, as providing a high degree of speech privacy and control of intruding noise. However, under a normal privacy condition, with concentration, a listener can understand intruding speech. Minimal privacy only reduces the audibility of intruding noise.

Even today, some acousticians and most facilities managers are surprised to learn that the degree of speech privacy available in an open-office can be predicted or measured.

ASTM COMMITTEE E33

ASTM International is a standards-writing organization. It has been serving government and industry with the development of consensus standards for over a century. In the 1970s, ASTM Technical Committee E33 on acoustics started an effort concerning open-plan office acoustics. The initial effort was the preparation of a white paper "Acoustical Environment in the Open-Plan Office" which was published in ASTM Standardization News in 1976. The white paper was prepared by an ASTM Task Group headed by David A. Harris and included Steven M. Brown, Angelo J. Campanella, Richard N. Hamme, A.C.C. Warnock, and others. The white paper sparked my interest in participating in E33 activities and I became a member. As I remember it, there were three task groups developing two separate standards for laboratory measurement of ceilings and screens/wall panels, as well as a standard guide that would further develop the kinds of educational materials in the white paper. This would eventually become E1374 "Standard Guide for Open Office Acoustics and Applicable ASTM Standards."

Since the open-plan office acoustics activity in E33 was spread out over a number of subcommittees, consolidation seemed logical. In 1984 I went to the E33 Executive Committee and requested that a new subcommittee be authorized to consolidate open-office efforts. ASTM Subcommittee E33.02 on Open-Plan Spaces was created and, since no good deed goes unpunished, I was made the Chairman. One of my first acts was to appoint a new task group chairman, Howard Kingsbury of Penn State, to foster the Open Office Guide into final form. It was completed in 1990 and became Standard Guide E1374.

I was interested in having the method I developed for measuring articulation index in open offices converted into a standard test method. With the help of my partner, Edward M. Clark, we drafted "Standard Test Method for Objective Measurement of Speech Privacy in Open Plan Spaces Using Articulation Index" which was ratified in 1986 and designated ASTM E1130.

In 2006, I moved to Chairman of the main E33 committee and stayed for the maximum of six years. I then returned to chairing E33.02 in 2012. While I was

Chairman of E33, Robert Hallman of Armstrong World Industries ably chaired Sub-Committee 02. Bob is currently the Chairman of E33. At my suggestion, E33 modified the name of Subcommittee E33.02 from "Open-Plan Spaces" to "Speech Privacy." The reason for the name change was that new standards were under development that address closed-plan offices. These standards-writing efforts belong under the 02 umbrella because these relate to speech privacy. An example is Test Method E2638 to measure speech privacy between closed rooms.

A SYSTEMATIC LOOK AT OPEN-OFFICE ACOUSTICS

Open-office acoustical design is much more challenging than closed-office design. The primary reason is that it is not feasible to achieve a high degree of sound isolation between workstations since speech sounds refract over and around furniture barriers and reflect off walls and ceilings. Despite these limitations, it is feasible to improve sound isolation between workstations with effective furniture barriers, acoustically sensitive workstation layouts, and sound-absorbent wall and ceiling finishes that reduce the transfer of reflected speech energy between workstations. The audibility of intruding sounds is strongly affected by the masking provided by background sound.

The acoustical system of open-office environments is best viewed using the classic SOURCE-PATH-RECEIVER model. The primary sources are people talking. If lower voice effort can be encouraged, the occupants of nearby workstations will experience better privacy and less intrusive noise. Although there are limited ways to reduce speech effort, there is evidence that reduced lighting levels results in lower voice effort. Also, because speech is directional, the furniture layout may be useful in orienting talkers away from nearby listeners for a perception of better privacy. Modifications to the path and the receiver are the most powerful tools. The concept is to reduce the level of speech sounds reaching listeners. First, block the direct path between the sources (talkers) and the receivers (listeners). Second, sound reflections off ceiling, floor, wall, and furniture surfaces need to be controlled with sound absorption or some method of diffusion.

All paths need to be controlled because the sounds that reach the receiver via a variety of paths merge to make one coherent sound image. The path that allows the most speech energy to pass often controls the degree of privacy. Consequently, it is important in designing an open-office environment that upgrading one element, say the ceiling, while allowing low screens, may help with the general noise level, but does little to improve privacy between adjacent workstations.

Since the very openness of open-office environments limits path noise reduction, it is important to reduce the audibility of intruding speech sounds for listeners. This is achieved with background sound tailored to improve privacy, while being neither an annoyance nor inducing talkers to elevate their voice level. If done properly, artificially-generated background sound can significantly contribute to privacy. I will discuss each of these tools.

Ceilings

Ceilings are the most acoustically-critical surfaces in open offices because of their potential to reflect source sounds to all adjacent workstations. Ceiling characteristics that can reduce the detrimental impact of these reflections include sound absorption, diffusion, and increased height.

Richard Hamme of Geiger and Hamme developed a number of open-office acoustical metrics and test methods for the United States General Services Administration. Hamme's laboratory test environment included a ceiling, walls, and a furniture barrier. All of these constructions were made highly sound absorbent except for the test specimen, which might be a ceiling, furniture barrier, or wall finish. ASTM E33.02 members were also interested in developing test methods to evaluate these open-office components. It was thought that Hamme's test environment, which mimicked an open office, was the correct approach. However, a different single-number metric was developed by E33 and called articulation class (AC), which is an AI-weighted noise-reduction value. It is based on the work of A. C. C. Warnock at the National Research Council of Canada. The interzone attenuation is the noise reduction between a source and a receiver location on either side of a furniture barrier. Values are measured over the 200-to-5,000 Hz one-third octave band range.

The initial component test method developed by E33 was E1111, "Standard Test Method for Measuring the Interzone Attenuation of Ceiling Systems." Also developed were E1375, "Standard Test Method for Measuring the Interzone Attenuation of Furniture Panels used as Acoustical Barriers," and E1376, "Standard Test Method for Measuring the Interzone Attenuation of Sound Reflected by Wall Finishes and Furniture Panels." In 2004 the three test methods, which had many characteristics in common, were combined into E1111 and the standard's name was changed to "Standard Test Method for Measuring the Interzone Attenuation of Open Office Components."

For the specifics of the test configurations please look at the standards. They have in common that the source loudspeaker is located 1.83 meters (6 feet) from the barrier. Levels on the receiving side are measured on a survey line perpendicular to the barrier starting 0.30 meters (12 inches) from the receiver side of the barrier. Receiver levels are measured at 30.5 centimeters (12 inch) intervals. Articulation class, the single number classification, is calculated according to E1110 for each receiver distance. First, interzone attenuation values are calculated for each receiver position. What are called nominal interzone attenuation values are calculated by averaging the values at each position with the values to either side. The nominal interzone attenuation values are then weighted according to the tabulated values given in E1110 and summed.

If you review the published AC values for high-performance ceilings, you will find that these range between 180 and 220. The final zero was added over concern that there might be confusion with Hamme's "NIC Prime" metric that he developed for the GSA. If you remove the zero, you will have the AI-weighted noise reduction in decibels.

One of the serious challenges in achieving a consistent degree of open-office speech privacy is sound reflecting from ceiling light fixtures. Although ceiling reflections can be controlled with highly sound absorbent finishes, such as certain glass fiber boards, the acrylic-lensed fluorescent fixtures, commonly used in the 1970s, provided mirror-like reflections that significantly reduced privacy, especially when located in the "offending region" midway between workstations. We carried out AI testing in office mockups to evaluate methods to control these reflections. Approaches tested included perforated fixture lenses and use of sound-absorbent baffles. Deep-cell parabolic light fixtures subsequently became available, which provided better light quality, required less power, and minimized sound reflection problems. More recently a range of pendant light fixtures have become popular. Using perforations or convex faces, these fixtures produce few detrimental sound reflections and allow virtually the entire ceiling surface to be sound absorbent.

When testing a ceiling assembly, diffraction over the 1.5 meter (60-inch) barrier has an influence on the outcome. Consequently, I suggested adding another barrier height to the standard, which was done. I am unaware of tests using the higher barrier being carried out.

Vertical Building Surfaces

Wall and window surfaces, like ceilings, can be a source of privacy-reducing reflections. Reflections from blank walls are readily controlled with sound absorbent wall panels covering the surface. Whether or not such acoustical treatments are required depends on the needed degree of privacy and whether the surface will provide direct reflections between adjacent workstations.

Glazed exterior walls are a bit more challenging since, not surprisingly, workers object to having their views obstructed. Depending on the project, we developed a number of project-specific controls for window reflections.

Sheer glass curtains that could be extended by individuals were used at Educational Testing Services. The choice was between reduced privacy or vision.

For the John Hancock Tower in Boston we were retained to evaluate their very real privacy concerns. We developed baffles that were perpendicular to the glass and in-line with mullions. The baffles, which filled the gap above low perimeter induction units, were a continuation of the furniture barriers between workstations. The baffles were constructed to have sound-absorbent surfaces and act as acoustical barriers.

For the Port Authority floors in the World Trade Center the 1 meter (40-inch) column spacing allowed furniture barriers to abut the columns. Sound-absorbent panels were placed on the column faces and glass curtains were also provided.

Laboratory testing of the effectiveness of vertical surface treatments is covered in ASTM E1111.

Furniture Barriers

Various forms of furniture barriers are needed to block line-of-sight between personnel in adjacent workstations. Such barriers should provide reasonable insertion-loss values in the primary speech frequency range. These constructions also need to absorb surface sound reflections in a similar fashion to wall surfaces. Laboratory testing of the effectiveness of furniture barriers is covered in ASTM E1111.

Masking Sound

Providing controlled background sound to mask intruding speech sounds is a critical element for achieving acoustical comfort in most open-plan offices. Exceptions might be installations with very high ceilings where the ceiling reflections are significantly dissipated by distance before reaching ears far from the source, while also blending together to provide some masking sound. Installations with high ceilings were built in Sweden and are reported to be acoustically acceptable. In North America, where ceilings are lower, artificially-produced background sound is an essential element of good open-plan office acoustics.

There is an inherent conflict between the desire for better privacy through higher masking levels and the need to minimize annoyance from overly-intrusive masking sound. To reduce this conflict, masking sound should be spatially uniform in level, have a spectrum that is suited to the specific acoustical environment, and have a very smooth frequency spectrum. In the early Eastman Kodak installation, with sound-transparent ceilings, we used a spectrum that descended 7 dB per octave above 250 Hz. Later, with more conventional lay-in ceilings, and looking at AI-weighting factors, 5 dB per octave was found to be more appropriate.

Generally the acceptable level of masking sound is between 45 and 48 dB(A). When tuning the early Kodak installations in the evening, I would think, "How can the employees stand this 48 dB(A) level?" When returning the next morning, I was amazed to find that the masking sound seemed barely audible. The presence of a moderate amount of activity noise made all the difference. In later installations we specified systems where the masking level was gradually reduced for the evening hours so it was less apparent during periods of reduced occupancy.

Electronically-generated random noise is more detectable when all loudspeakers are sent the same signal. Consequently we switched in later installations to a two-channel approach. Alternate loudspeakers were sent the signal from one of the two channels. The spectrums were identical and could be adjusted from a central location.

The tuning processes we employed remained somewhat arduous. It involved capturing the masking spectrum in one-third octave bands in a sufficient number of representative locations and then using a carefully selected "tuning location" where we established the offset in each band from the mean measured levels. We were able to adjust the spectrum at the tuning location while being assured that the target spectrum would be achieved on average.

CONCLUSIONS

- Today there is no excuse for repeating the missteps made in early open-office installations since acoustical solutions are available to office design teams. Speech privacy goals can be established and new offices can be designed to meet these goals.
- ASTM test methods are available for evaluating open-office components and systems as well as for measuring privacy in open-office mock-ups or completed installations.
- A high degree of normal privacy is achievable in an acoustically well-designed open-office where attention is paid to layout, sound-absorptive finishes, effective furniture barriers, and correctly-tailored masking sound.
- The aid of an experienced acoustical consulting team is invaluable in achieving the acoustical goals for an office installation, whether for new construction or on a corrective basis.

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