Guidelines for Design of an Office with Good Acoustics

A means for prospective owners, architects, and interior designers to provide good acoustics in open and closed offices

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Chapter 1: Privacy Concepts

Acoustical Needs of Employees in Offices

There is a spectrum of needs for employees in offices (Figure 1). A good acoustical design takes these factors into account.

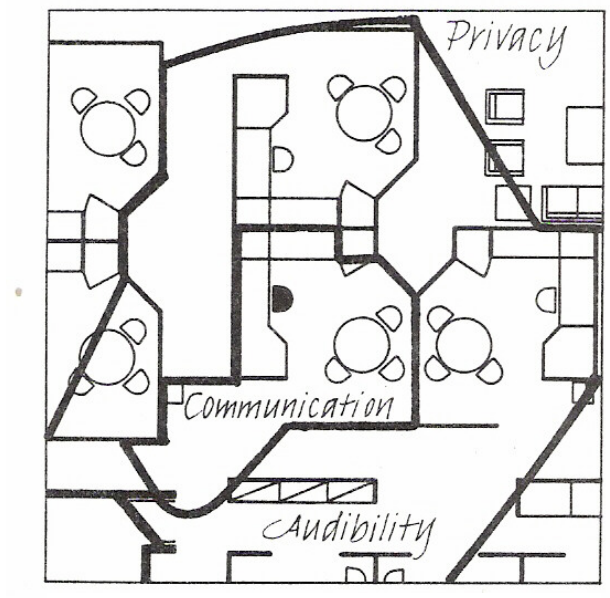

Figure 1

Communication

There is little value in an office where ideas cannot be communicated, and since most of that communication is in the form of speech, the design of an office must not inhibit speech where and when it is needed. Similarly, *over communication* must be avoided. Persons for whom the speech was *not* intended should not be bothered by it.

Privacy

There are two degrees of privacy needed in an office. The most restrictive is confidentiality to protect sensitive conversations. Closed rooms are required to achieve confidentiality. The second is to reduce the distractions of casual listeners. It applies to both closed and open offices. When distractions accumulate productivity decreases, annoyance is created, followed by complaints.

Community

People need to feel a part of their organization. Sound is one means of keeping in touch with other people in the office. When workers hear the low-level activity sounds of others, it enhances their sense of community. People want privacy, but not isolation, from their community of fellow workers.

Two Characteristics of Office Noise

To improve office acoustics, noise (unwanted sound) needs to be reduced. The noise can be divided into two types. The first is that from transient sounds, such as conversation, paging, interior machine sounds and exterior sounds such as aircraft and road traffic. The other is that from steady sounds such as air conditioning equipment or light fixtures. Good acoustical design reduces both.

Transient Sounds

A transient sound is short term; it generally distracts a person's attention if the level is high relative to the steady sound level (a rise of about 10 dB is a common criterion). The distraction is further strengthened if the sound has high information content, such as conversation. People conversing with each other typically create transient sound levels of 70 dB(A) in the immediate vicinity. The letter **A** appended to the levels denotes an adjustment of the sound spectrum to weight the sound as a person would hear it. Paging creates higher levels and alarms may run as high as 90 dB(A). Exterior sounds, such as traffic noise, also may contribute but generally at lower levels. Since these sounds are short term and not excessively high (except alarms), the major concern is about distraction and annoyance.

Steady Sounds

Steady sounds are the background sounds; continuous, generally unvarying, and long term. In offices, they are mostly composed of sounds from the air handling system or light fixtures. Good mechanical and electrical design keeps such levels below 40 dB(A). Steady sounds can be tonal or random. Light fixtures are primarily tonal while air handling noise is random (it consists of many frequencies). A general observation is that continuous random sound becomes "normal" to the listener after a time because it is unchanging and conveys no information. In most cases it is less noticeable and less distracting than a transient sound. Tonal sounds are more likely to elicit negative responses based on the listener's evaluation of the sound's utility. Lighting fixture hum in the office often generates complaints.

The General Effects of Noise on People in Offices

Noise is defined as unwanted sound. Noise can be interpreted as anything from a dripping faucet at home to an exceedingly loud workplace. This range of sound levels runs from those that cause only annoyance to those that do physical damage. Managers of businesses always have had a concern about the effect of the office environment on the health and productivity of their employees; noise is one such concern. To get an appreciation of the relative magnitude of the sounds, we must resort to the standard unit, the decibel (dB). It ranges from very low levels, such as 0 in a very quiet room, to very high levels, such as 170 near a rocket launch. Every time the sound level *increases* by 10 dB, the sound energy *multiplies* by 10. If the sound level is 45 and is raised to 75, the sound energy increases by 30 dB; by 10xl0xl0 or 1000 times. Depending on the degree of occupancy and the distance from sound sources, levels can range from 35 dB(A) to 75 dB(A).

There are three classes of effects of sound on the human being: physical, physiological, and psychological.

Physical

These are mechanical changes in a person, such as heating of the skin, rupture of the eardrum, or vibration of the eyeballs or internal organs. The continuous levels required to cause these changes are above 140 dB and it takes a very special situation such as rocket noise to cause this effect. The energy associated with physical effects is often about ten million times more than that found in the office. Physical effects on the human body should be of no concern in the office.

Physiological

These are biological changes in a person, such as elevation of blood pressure, hearing loss, or stress. The Occupational Safety and Health Administration (OSHA) considers that levels in the workplace of 80 dB(A), or more, during 8 hours per day over a working lifetime of exposure puts people *at risk* for moderate hearing loss. This is a very high level and long term exposure that does not occur in the typical office. The lowest level at which a physiological effect was near 70 dB; a barely detectable dilation of the pupils of the eye and small changes in galvanic skin response with no permanent result. Although minor physiological effects may occur, they should be of no concern in the office. Claims by employees are often in this category, but there is little evidence that they are valid.

Psychological

These effects are mental changes in a person due to exposure to noise, manifested most often by annoyance. Such effects can occur at any sound level. Dripping faucets in the home may create annoyance at sound levels of 25 dB, while sound levels of 120 dB caused by a passing ambulance may elicit the same response. The response is totally *subjective*, based on factors such as the person's evaluation of the necessity of the noise, or whether it can be controlled, or whether it is normal for the environment. Since psychological effects can occur at any level, they are a concern in the office.

Studies of Noise in the Office Environment

Many cognitive psychology studies have been made relating specifically to the office environment. It was found in one study that there was a modest stress (physiological) increase and diminished motivation caused by typical office noises, including speech. This study recommended the use of sound masking under the control of the worker. It was suggested in another study that changes in sound level are an important factor, but that habituation to the noise can occur. Habituation in the office environment can be interpreted to mean "I've grown used to the noise and it no longer distracts me" or "Since I cannot do anything about it, I will have to live with it". Speech and non-verbal intrusive noises caused significant performance decreases for arithmetic tasks. Speech caused a greater performance decrease than nonverbal noises for "prose tasks". Another study found that "during a serial recall task, the accuracy of report decreases 30 to 50%." When the intrusive speech was increasingly filtered to a meaningless mumble, there was a monotonic increase in performance. The author of that study stated: "Perhaps the single feature that makes the irrelevant speech phenomena so fascinating is that the processing of sound is *obligatory*; it appears beyond the individual's control".

The Fallacious Quest for Quiet

When people are annoyed by activity sounds around them (noise), they futilely search for "quiet." Since noise is unwanted sound, "quiet" is often considered the absence of sound. The word "unwanted" implies a subjective human response. Not everyone will agree that a given sound is, or is not, noise. Most people think of noise as a distracting or interfering sound, which usually causes annoyance and complaints. Most people believe that "quiet" is a desirable condition of low background sound level, but what they are really searching for is freedom from acoustical distractions ultimately causing annoyance. There is a difference. Distractions are caused by unwanted *transient* sounds, such as speech, that rise above the background level and are noticeable. Thus, a better definition of "quiet" is the absence of those distracting sounds, not an absence of all sound. The only way to achieve the former definition of "quiet" is to maintain a low background sound level with *no* transient sounds; a condition that requires complete *isolation* from all activity sounds.

There are three ways to reduce the magnitude of transient sounds. First, one may use the age-old technique, once employed by librarians, of simply asking persons not to talk. Administrative controls, such as these, are generally ineffective. The second way is to physically isolate people from sources of sound by putting them behind sound attenuating structures, such as enclosed offices. One favorite method is to add materials that are highly sound absorbing. Unfortunately, absorbing materials cannot decipher "wanted" from "unwanted" sounds so the distraction merely occurs at a lower level. This is not to imply that sound absorbing materials are ineffective, but rather that they may not be sufficient by themselves. Another method is to increase the amount of materials between the listener and the source of the sound, to block transmission of the transient sounds. Both methods can be expensive and, as will be shown later, may, or may not, be adequate to achieve the desired freedom from distraction. The third way is to alter the background sound level so that the transient sounds do not penetrate significantly above the ambient level at the listener. Persons not familiar with this method ask "How can you make it 'quiet' by adding noise?" Hopefully, this document will convince the reader that, if done properly, adding sound masking will make it possible to achieve the new definition of "quiet." By implementing this technique, it is possible to achieve a level of background sound that is socially acceptable. Low levels are required for bedrooms, yet when most people are questioned about aircraft sounds, they do not object to the level of "noise" despite the fact that the sound energy is thousands of times greater than that in a typical masked office. Acceptance depends on the context.

Common Opinions about Sound

> *The following is not an attempt at "pop" psychology, but was deduced from employee comments about their office environment. These are questions the listeners implicitly ask themselves to determine their response to their environment. The design of good office acoustics should take these opinions into account.*

Is the sound made by me or made on my behalf?
Noise is often described as the sound made by other people. Our own sounds are always more acceptable. For example, a manager in an office may complain about the noise created by another manager's secretary, but not that of his own. Employees must be convinced that any change in their acoustical environment is made on their behalf. The desire to have personal control over that environment is implied.

Is the sound "normal" for this environment?
When all encounters with a situation are the same, people grow to accept it. When there is a crowd or an abundance of human activity (e.g., a football game) or when there is mechanical power or machinery (e.g., an auto race), most people will accept the sounds as normal. When there are rapid changes in the office environment, an employee's sense of normalcy is dislocated. For example, in the classic change from closed offices to "cubicles," there is often a strong negative response. It takes time for "normal" to occur.

Is the sound necessary and can anything he done to control it?
Even though a sound may not be normal, it may be accepted if the listener believes that nothing *should* be done about it. For example, police or ambulance sirens are accepted because they are believed necessary. A negative response often occurs when a person believes nothing *can* be done to prevent an unnecessary sound.

Does the sound have meaning?
Extraneous sounds with high information content are more likely to be unacceptable than sounds that mean nothing. The brain diverts attention to meaningful sounds. Because speech is rich in information, speech sounds are significant in the office.

Is the sound frightening?
Sounds that change abruptly startle listeners, particularly if they are at higher levels. Responses of fear and concern make a sound more unacceptable. Generally, this is not an issue in the office.

Will the sound have an adverse effect on my health?
The regulations against very high noise levels in the workplace have created concern that office noise can adversely affect a person's health. Typical health complaints are headaches, dizziness, nausea and even disruptions of biological functions. While the manifestations may be real, it is not clear that eliminating the "noise" would solve the problem. There is no evidence that typical office sounds cause health problems other than through a stress response to chronic annoyance. Offices with good acoustical design generally have no health complaints related to noise.

What is the pitch of the sound?
Sound with a great deal of bass (low frequency) is normally associated with something large and powerful. Sound with a great deal of treble (high frequency) is associated with small or delicate objects. Generally, high pitched sounds cause more annoyance than low pitched ones at the same level. Experience has shown that there is a "preferred" spectrum (frequency distribution of levels) of sound in the office.

How reverberant is the room?
People will judge how reverberant (live) a room is, based on how they hear the echoes of voices or footsteps. Generally, a reverberant room is considered more "noisy", and therefore less acceptable than a "quiet" room. Subjectively, people interpret a "quiet" room as "plush", "expensive" or "important." Sound absorbing materials are desirable in the office environment.

Complaints about Noise

As examples of psychological responses, some employees cite the occurrence of headaches, nausea, dizziness, and disturbance of biological functions caused by excessive "noise." A classic work on the effect of noise on people had this to say:

> "*The general finding that the performance of the more anxious personality types is more affected by noise than that of nonanxious types would attest to the existence of a stimulus-contingency factor. In terms of learning or conditioning, the task becomes disliked and is performed relatively poorly because it is related to or contingent upon the aversive noise.*"

> "*A possible teaching of much of the data presented in this book is that, other than as a damaging agent to the ear and as a masker of auditory information, noise will not harm the organism or interfere with mental or motor performance.*"

It appears that many office complaints of the type noted above are associated with anxious personalities, and complaints about noise, (along with drafts, temperature, or lighting) are the manifestation of that anxiety. In conclusion, there does not appear to be evidence that office noise causes the adverse effects noted above. In fact, in earlier offices with vinyl floors, metal furniture, and gypsum board ceilings, the ambient and activity levels were considerably higher than those in modern offices.

Chapter 2: Speech Privacy

To design an office with good acoustics, the concept of privacy needs to be addressed. The most important type of privacy in the office is that from speech. Often when speech privacy is achieved, privacy from non-speech sounds is also achieved.

Types of Speech Privacy

When it is possible to provide privacy from all surrounding persons, we call it ***Universal Privacy***. It can be achieved in both open and closed offices with proper design. There are occasions when it is not economically feasible or socially acceptable to provide privacy from everyone else; call centers are but one example. In this case, good design provides privacy from *most* people, but not all. This type of privacy is called ***Partial Privacy**.* In an open office, there is a distance beyond which the inadvertent listeners have privacy from the person talking. Those inside that distance have reduced privacy. To help owners understand the value of the distance concept, we use a rating called ***Radius of Distraction**.* These two types describe how many persons have privacy, but not how much; that is covered next.

Degrees of Speech Privacy

The degree of privacy defines how much privacy a listener has from a person talking. It varies from complete privacy to none. Below is a list of the degrees and typical applications for them.

Secret Privacy

When people have Secret Privacy, their conversations cannot be intelligible to others even when *deliberate* attempts to listen are made using sensing devices. This degree of privacy is more difficult to achieve than other degrees. Typical applications are:

- Classified Conversations
- Corporate Boardrooms
- Critical Legal Conversations
- Corporate Planning Rooms

Confidential Privacy

When people have Confidential Privacy, their conversations are unintelligible to *casual* listeners. The conversations may, or may not, be audible. Persons outside the room cannot converse with, or understand, the person inside. Confidential or sensitive conversations are possible. The room occupants have no distractions. Most often this degree of privacy can be achieved only in closed offices. Typical applications are:

- High Level Management
- Labor Negotiators
- Contract Negotiators
- Personnel Interviewers
- High Level Legal Staff

- High Level Financial Staff
- Medical Counselors
- Conflict Resolution Situations

Normal Privacy

When two people have Normal Privacy from each other, their conversations do not distract each other. Their speech will be audible and partially intelligible. The choice of the word "normal" is based on its use in standards; a better descriptor might have been "acceptable". This degree of privacy can be achieved in open offices with good design. Very few complaints are expected. Typical applications are:

- Middle Level Management
- Computer Programmers
- Researchers and Engineers
- Persons doing mathematical tasks
- Persons reading or writing difficult material
- Self-learning situations

Transitional Privacy

When two people have Transitional Privacy from each other, their conversations may distract each other occasionally. Their speech will be audible and partially intelligible. This degree of privacy often is achieved in a room when no attention is paid to acoustical design. Complaints are expected by persons that wish more privacy. Typical applications are:

- Sales Staff
- Purchasing Staff
- Administrative Assistants
- Executive Secretaries
- Draftsmen
- Customer Service Staff (telephone use)
- Secretarial Staff
- Clerical Staff
- Order Processing Staff

No Privacy

When two people have No Privacy from each other, their conversations are clearly intelligible and completely distracting. This degree is achieved by design *within* a closed room, such as a closed office, conference room, and reception area, and elsewhere by no design. Typical applications are:

- Receptionists
- Customer Service Staff (face-to-face)
- Staff handling customers or visitors
- Conference, lectures, or seminars

Degree of Privacy	None	Transitional	Normal	Confidential
Area	Communication	Audibility	Audibility	Privacy
Intelligibility	Clear	Partial	Partial	None
Distractions	Total	Many	Few	None

Table 2-1

Objective Rating of Speech Privacy

Speech privacy is not totally subjective. There have been enough studies to develop methods for objectively rating the degrees of speech privacy. There are several equivalent ratings in use for speech privacy.

Articulation Index (AI)
The initial interest was in speech communication so a rating for speech intelligibility was developed; called AI. It takes into account three relevant factors: the speech spectrum (level of speech at each frequency), the sound attenuation spectrum between talker and listener, and the background or masking spectrum at the listener. It presumes the listener has normal hearing. It is an older rating but is still being used successfully. The rating ranges from 0 where nothing can be understood to 1 where everything can be understood.

Privacy Index (PI)
Numerical values of AI have little meaning for office owners, so AI was reversed to put emphasis on privacy. When AI is 0, PI is 100, and when AI is 1, PI is 0. It is preferred by CCR ASSOCIATES because this rating has a close relationship to the more familiar rating of school grades as shown in the table below. The degrees of privacy can be grouped as a range of Privacy Index as shown below.

Speech Privacy	Privacy Index	Grade
Confidential	95-100	A
Normal	80-95	B
Transitional	60-80	C
None	<60	F

Table 2-2

The Most Important Concept in Achieving Speech Privacy

The relationship between a person's sense of privacy and the objective measure of it is not a straight line. It is vital that an office designer be aware of this. Figure 2 shows this relationship graphically.

In a completely *open office*, the Privacy Index between two people may be as low as 10, on the lower left of the chart. When furniture panels are added, a very large change in the Privacy Index can occur. Depending on panel height, the Privacy Index will jump to between 50 and 65. What do

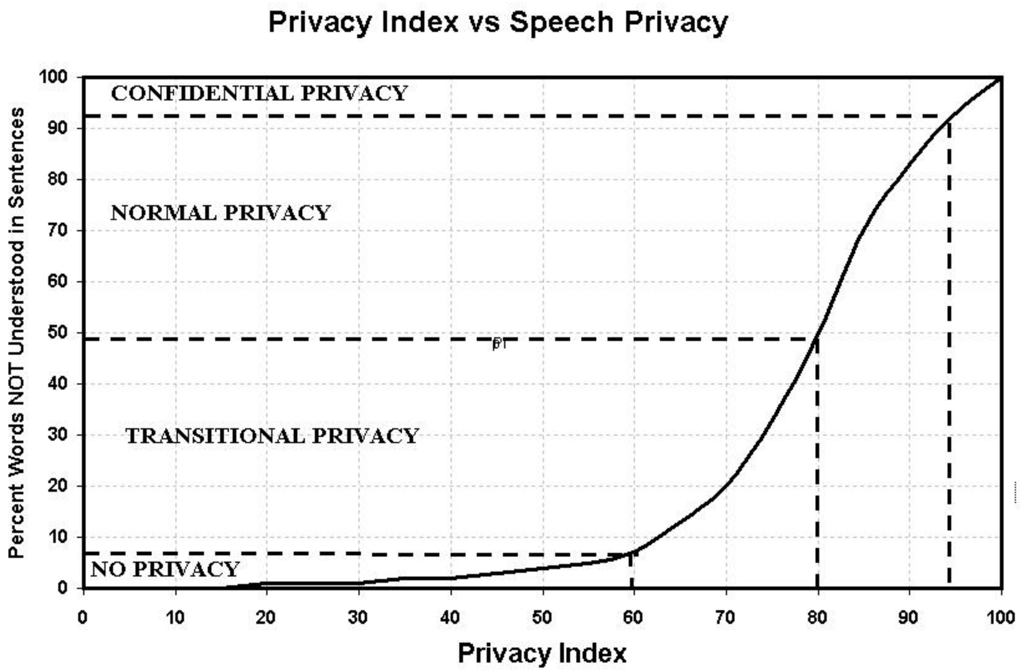

Figure 2-1

employees think of that improvement? The figure shows that privacy at a PI of 60 will block only a few percent of sentences. Perhaps a good ceiling is added and the privacy moves up to 60 or 75. Again, according to the figure, there is an improvement of privacy, but it is not enough so employees consider the privacy still to be poor. When sound masking is added, privacy moves into the acceptable range (Normal Privacy PI=80).

The sequence of additions above generally follows that during the design stages of an office. If the steps are reversed, it will show that sound masking without the other two factors simply puts noise in the office. There are two important rules:

> *Over eighty percent of the cost in improving privacy is in setting the pre-conditions for it, the remainder is spent in achieving it.*
>
> *Good design balances the three important factors (shown below), overkill on any one factor wastes money and achieves little.*

Three Factors that Determine Speech Privacy

There are three important factors that determine the acoustical privacy a person can have in an office environment. They are:

SOUND SOURCE (TALKER VOICE LEVEL)
MINUS
SOUND ATTENUATION (VOICE LEVEL REDUCTION)
MINUS
BACKGROUND (SOUND MASKING LEVEL)
=
SPEECH INFORMATION

Sound Source (Talker Voice Level)

Although managers have tried in vain to control levels of speech administratively, they are fortunate that most employees regulate their voices in a responsible manner. Most persons speak in what is now called a normal voice level and this level is well documented in standards publications for use in our privacy calculations. The louder people talk, of course, the less privacy others have. The designer should consider a closed room instead of an open office when there are situations where people speak louder, such as in conflict resolution situations. One important aspect of speech related to office design is the direction of the talker relative to the listener. Speech is highly directional and dynamic (time varying).

Sound Attenuation (Voice Level Reduction)

The nearby level of a talker's voice is attenuated as it travels to a listener. There are a number of paths, depending on whether the talker is in an open or closed office. There is the natural spreading, blockage by intermediate objects such as panels or walls, and reflection from nearby surfaces such as ceilings. This factor is static (not time varying); once the office design is completed the attenuation remains the same, so privacy cannot be adjusted after completion.

Background (Sound Masking Level)

The ability for a person to understand the attenuated speech that reaches him is determined by its level relative to the ambient or background sound level. The higher the background level, the lower the intelligibility. Electronically enhanced background sound is called *sound masking.* Sound masking has one distinct, but generally unappreciated, advantage. It can be adjusted after the office design is completed to achieve the speech privacy desired.

Balancing the Factors

It is not possible for an office designer to balance each of these factors for each situation to maximize privacy performance and minimize expense. The most important factor is sound attenuation. There are a number of paths of speech from the talker to the listener, and the critical path (the least sound attenuating) is the one that needs attention. The only way to know which path is critical is to model the office on a computer. Chapter 7 addresses how CCR ASSOCIATES models offices. The frequency distribution of speech is very important to understanding, but standard ratings such as Sound Transmission Class or Noise Reduction Class are inadequate to the task. CCR ASSOCIATES uses a new rating called **Speech Weighted Loss** which combines all sound paths and then weights the result based on how people hear speech.

Chapter 3: Achieving Acoustical Privacy in Open Offices

To determine the proper design of an open office three major factors must be taken into account and they must be properly balanced both with respect to cost and performance.

This relates open offices where furniture panels are used to define workstations. The purpose of this chapter is to provide the prospective designer or owner with some guidelines for choosing the materials and products to be used in the office. This chapter provides information on common privacy errors which should be avoided. Many of the examples in this section are for the "***worst case situation***," i.e., where a seated talker, speaking horizontally, faces a seated listener, each being three feet from a separating panel. The sound attenuation for such an arrangement is the minimum and more speech is transmitted to a listener than for any other arrangement.

Two factors play an important role in reducing speech transmitted to a listener, they are: (1) the talker's voice characteristics, and (2) the amount of speech that is lost enroute to the listener (sound attenuation).

Talker's Voice Characteristics

This factor is *dynamic* and is determined by:

1. The gender of the person speaking.
2. The amplitude and frequency characteristics of their voice.
3. The direction in which they are speaking.

Gender
The casual voice spectra of men and women are well known. Although the female voice has less bass, the intelligibility is not too greatly different. The particular characteristics of a person's voice seems to be more significant than gender. This makes analysis of office design simpler since the gender of a future occupant is generally not known.

Voice Level
The level of a talker's voice has significant influence on the level of speech received by a listener. Standards societies have defined two levels of speech useful for analysis: *normal* and *raised*. The most common level found in open offices is the "normal" voice. Occasionally a raised voice occurs during heated discussions. It is important for a prospective end user to identify for the person doing the analysis which persons are considered *loud talkers* and to identify any rooms used for *conflict resolution* where the raised voice level is more applicable.

Orientation

The human voice is very directional. How persons are situated in an open office workstation relative to others around them is determined by the layout. Designers seldom take advantage of this fact to enhance privacy. Figure 3-1 shows the loss of intelligible speech (Speech Weighted Loss) for two people separated by 6 feet in an office *without* any separating panels. Obviously, there is great benefit in orienting people so they do *not* face each other. Even a 90 degree turn creates about an 8 dB improvement in privacy. An example of a workstation layout that takes advantage of talker orientation is shown in Figure 3-2. The employees are either facing away from neighbors or at right angles to them.

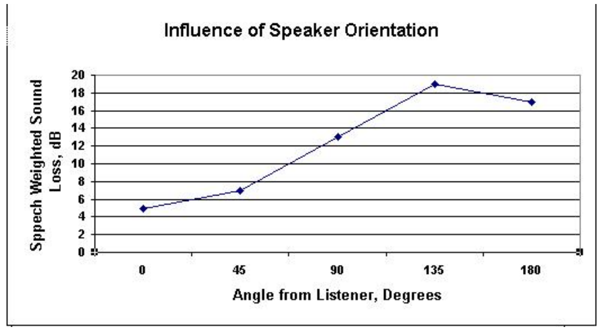

Figure 3-1

There are a number of workstation layouts where employee direction is set beneficially. For workstations in a row, seating the employees facing at right angles to each other gives a significant improvement in privacy. Figure 3-2 shows a workstation arrangement that takes advantage of voice directivity.

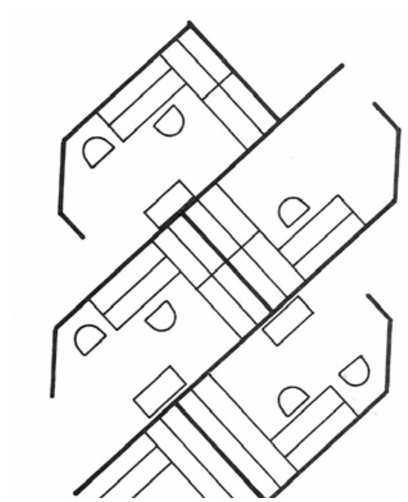

Figure 3-2

Sound Attenuation

The second factor is *static* and is controlled by the building structure. There are two types of paths for speech: the open-air path and the path through a solid object.

There are several open-air paths and several loss mechanisms: loss due to distance, loss due to reflection from a surface, and loss due to bending (diffraction) around a solid object. Some of these paths for an open office are:

1. Single or multiple reflections from the ceiling.
2. Single or multiple reflections from the floor.
3. Single or multiple reflections from various furniture panels.
4. Single or multiple reflections from surrounding walls or windows.
5. Sound bending over the top of the panel that separates the talker from the listener.
6. Sound bending around the side of non-enclosing workstation panels.
7. Line-of-sight (distance loss).

In the path through a solid object there are two loss mechanisms: loss due to distance and the loss as sound passes through the material.

Experience suggests that three of these paths are the most important and they are shown in Figure 3-3. However, the sum of the other paths can be important at times.

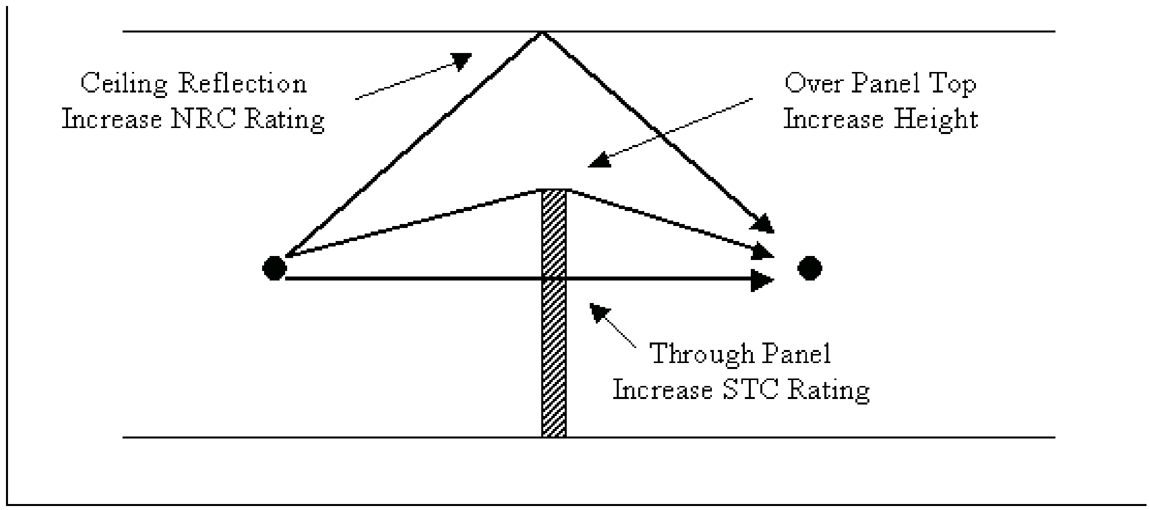

Figure 3-3

Transmission Loss Path (Through Panel)
Because people are generally close to each other in open offices, the panel system has to successfully block speech transmitted through it. Unfortunately, most panel systems are sold on the basis of their sound absorption rating (Noise Reduction Coefficient-NRC) rather than their ability to block sound transmission (Sound Transmission Class-STC). **STC is the important factor, not NRC.** A high STC panel with a high NRC, of course, is good.

Reflection Path (Ceiling Reflection)
If one visualizes the surfaces in an open office as mirrors, it is easy to imagine the large number of fellow workers to be seen in the ceiling reflection. Since speech will reflect from that surface in a similar fashion, sound absorption by the ceiling is most important. **NRC is the important factor, not STC**.

Diffraction Path (Over Panel Top)
Unlike light, sound waves will bend (diffract) significantly around objects. Since most well designed offices have reasonably enclosed workstations, the most important diffraction path is the speech bending over the top of the panel that separates the talker from the listener. **Panel height is the important factor.**

The path that has the least loss contributes most to loss of privacy. CCR ASSOCIATES calls it the *critical* path. Like water dripping from a leaky pail, the weakest path dominates and transmits the most speech. Failure to understand this concept has resulted in what may be called *acoustical overkill*. For example, an office designer, thinking that sound absorption is the only important factor, will specify a high-performing and expensive ceiling material; yet specify panel heights so low that workers are in view of each other. In such a case, the ceiling could be open to the sky so no sound is reflected, and still there would be no improvement in privacy. This leads to the most important design rule for speech privacy:

> *The critical sound path in an office design must be identified and its performance must be improved first.*

This rule might be called *balancing performance*. Since the acoustics of an office can be complex, CCR ASSOCIATES relies on a computer modeling program to determine this balance. That program is described in detail in a later section. When this modeling is done prior to financial commitment, costs are minimized without compromise of privacy.

Details of the Sound Attenuation Factors

Distance

The greater the separation of persons, the more privacy they have from each other but the greater the expense (floor area) to provide that privacy. As space costs have risen, people density has increased also. The common rule for assessing the influence of distance is called the *inverse square law*, where the sound level decreases by 6 dB for every doubling of distance. By this rule, moving two people from 6 to 12 feet apart would increase the Speech Weighted Loss by 6 dB, a significant improvement. Unfortunately, the next 6 dB improvement requires moving from 12 feet to 24 feet! This rule, however, applies only for a space in which there are no reflecting surfaces. Tests have shown that in a room with no, or low, panels, just a carpet and a mineral tile ceiling, the sound level reduction from 6 feet to 12 feet is closer to 5 dB. As a result, there is little privacy advantage in the added expense of increasing distance.

Ceilings

The important characteristics of any ceiling are its height and its ability to absorb speech sound. Higher heights increase the distance the speech has to travel so assist in sound attenuation. Figure 3-4 shows the influence of suspended ceiling height on speech reflected from it for various values of NRC. The lower value of NRC is for a common, and lowest cost, mineral tile; the higher NRC is for a high-performing mineral tile; the highest NRC value is for a fiberglass tile. The fiberglass tiles perform much better than mineral tiles. But is the added cost necessary? These two factors are taken into account with the modeling program along with the other factors to determine the answer.

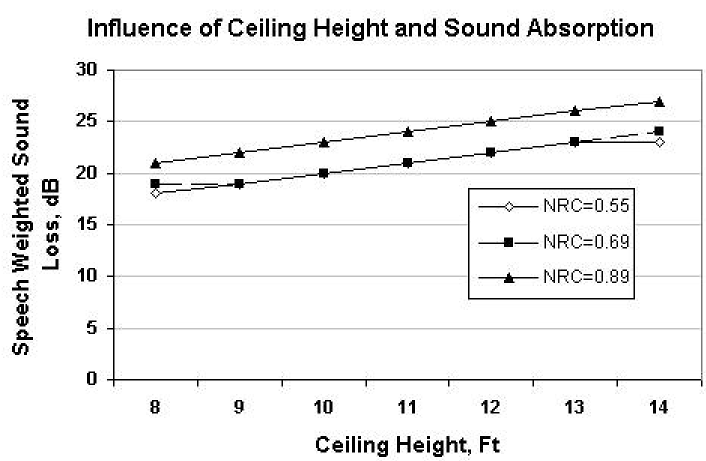

Figure 3-4

Light Fixtures

Ceiling and panel mounted light fixtures can be disastrous in certain circumstances, as can ceiling mounted air diffusers. If ceiling lights are placed in line halfway between two persons, the reflection can be so strong that *all other* privacy improvements are wasted expense. Table 3-1 shows what can happen to the sound reflected from the ceiling for three types of light fixtures that are halfway between two persons seating in 60 inch high workstations.

Ceiling NRC	0.55		0.91	
Condition	None	Fixture	None	Fixture
Flat-Lenses	17	15	26	15
Parabolic-Lenses	17	16	26	16
Pendant	17	17	26	26

Table 3-1

Flat and parabolic fixtures have very high sound reflectance. Since the attenuation of standard mineral tiles is not large, the degradation of a light fixture is not as dramatic, but still is very important. The attenuation of fiberglass tiles is excellent, so light fixtures can destroy the value of an expensive ceiling, if improperly placed. The pendent light fixture scatters the sound reflection so there is little degradation and we recommend them. When they are used, the suspended ceiling is generally higher than nine feet, another benefit. It is important to note that negative comments about loss of privacy due to light fixtures apply only to a small percentage of workstations. Data on the characteristics of light fixtures is included in the analysis program.

Panel Sound Attenuation

The sound attenuation of a panel is described by the Sound Transmission Class (STC). It rates the ability of a panel to block sound (not necessarily speech) passing directly *through* it. The higher the STC rating the more privacy is afforded by that path, but how much is necessary considering other paths? Analysis was made on the worst-case situation; two people facing each other, each three feet from the separating panel; all other paths were ignored to highlight the panel performance. Table 3-2 shows the Speech Weighted Loss using a mineral tile ceiling (NRC=0.55) for several STC ratings and panel heights.

STC	**48”**	**54”**	**60”**	**66”**	**72”**	**80”**
11	8	10	11	12	12	12
18	9	12	15	17	17	18
25	10	12	15	17	18	19
34	10	12	15	18	18	20

Table 3-2

The precision of these data is not high since most manufacturers do not provide detailed sound transmission loss data. In spite of this, it is clear that high values of STC are not important for panels 54 inches high or less. For panels 60 inches high or higher, STC ratings should be 20 or greater.

Panel Height

Speech can bend (diffract) over the top of a separating panel to reach a listener. Figure 3-5 shows the influence of panel height on Speech Weighted Loss for the worst-case. It is clear that there is a critical height below which panel height offers no benefit. Note that this graph relates only to the diffraction speech loss over a panel top and excludes other factors. Many call centers and other offices have panel heights in the range of 48 inches. The speech loss under these conditions is so small that the other factors provide little privacy benefit. In this case, another way to view privacy is the use of Partial Privacy. The height of workstation panels is a key element that is used in the modeling program.

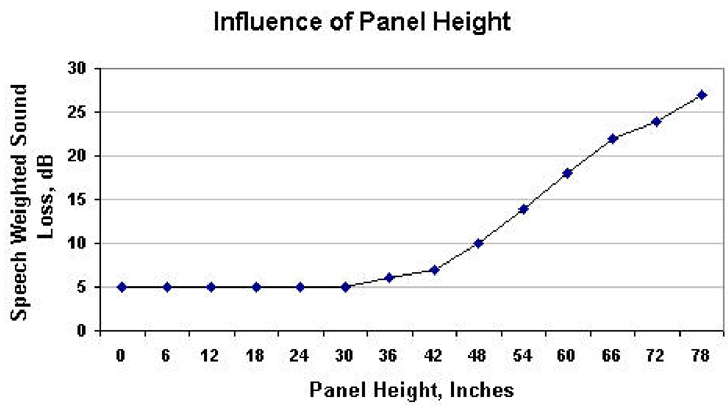

Figure 3-5

Panel Sound Absorption

As noted earlier, panel systems with high NRC ratings have been sold under the mistaken impression that sound absorbing materials alone provide better privacy. Table 3-3 shows the Speech Weighed Loss for several panel heights for the worst-case. The panels had STC values of 25; one was a steel-sided panel (NRC 0.10) with negligible sound absorption and the other was made of fiberglass with a porous cloth cover (NRC 0.80). One additional decimal place is shown in the table to indicate that panel absorption was detectable, but negligible. It is clear that panel NRC is not critical. This is fortunate since most workstations have personal decorations reducing the effectiveness of the sound absorbing materials anyway. Despite this, NRC ratings are included in the analysis program.

NRC	**48”**	**54”**	**60”**	**66”**	**72”**	**80”**
0.10	9.6	12.1	15.0	17.4	18.1	19.2
0.80	9.6	12.2	15.1	17.5	18.2	19.4

Table 3-3

Carpeting

Carpets have negligible influence on improving privacy when there are furniture panel systems in place, even those whose panel bottoms are slightly raised from the floor. However, carpets are necessary to reduce the sounds of footfalls; sound masking is marginally effective in covering these sounds if there is no carpet. Carpets are desirable in areas with no panels or other sound absorbing materials; they reduce reverberation and create a sense of quiet.

Combining the Sound Attenuation Factors

All the sound attenuation factors are added together for two typical workstation situations. These are examples of how CCR ASSOCIATES creates computer models the acoustics of open offices.

Workstations away from Walls

Figures 3-6 and 3-7 show The Speech Weighted Loss for seated persons in two 7 by 7 foot workstations, each 3 feet from the separating panel. The panel STC is 24. In Figure 3-6, the talker is facing the listener (worst-case) and in Figure 3-7, the talker is at right angles to the listener. Two types of ceilings are shown, the standard mineral tile (NRC 0.55) found in most offices and the better performing fiberglass tile (NRC 0.91). It is clear that when the talker is facing the listener and the panel heights are less than 60 inches, no benefit is derived from adding the more expensive ceiling tile, but there is about a 3 dB improvement when higher panels are used. This improvement translates to 3 dB less masking or 9 PI points of improvement.

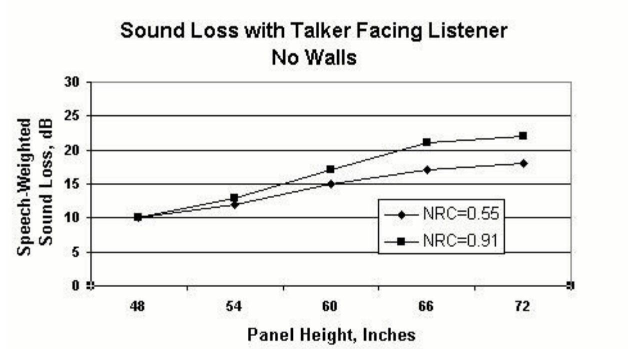

Figure 3-6

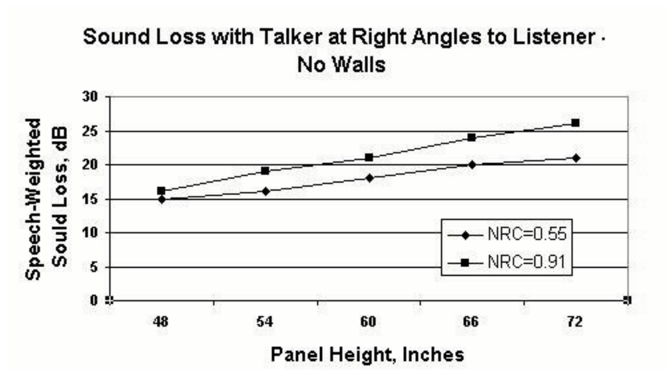

Figure 3-7

When the talker is at right angles to the listener, the loss is higher for all panel heights. The better performing ceiling provides about a 3 dB improvement even for panels 54 inches or higher. Is the additional ceiling expense applicable to all configurations?

Workstations against Walls/Windows

When workstations are near walls or windows there is an additional amount of sound reflection from those surfaces, reducing the potential for good privacy. Figures 3-8 and 3-9 show the Speech Weighted Loss associated with a talker in a corner workstation (typical of managers), while the listener's workstation is along one wall. The talker and listener are seated, each 3 feet from the separating panel. Again both workstations are 7 by 7 feet and the panel STC is 24. In Figure 3-8, the talker is facing the listener while in Figure 3-9 the talker is facing the sidewall. Although the loss of privacy is not great, wall reflections have some negative influence.

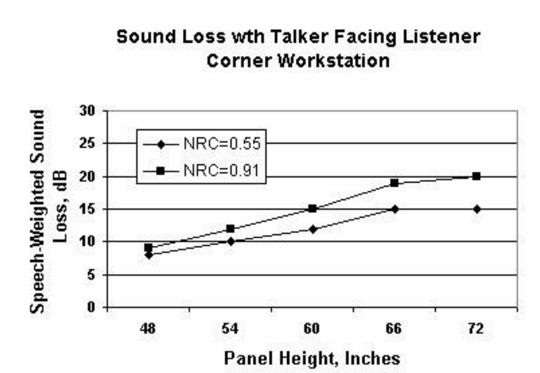

Figure 3-8

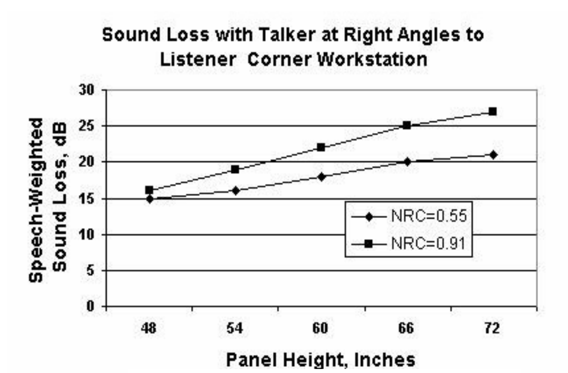

Figure 3-9

Creating Privacy with Sound Masking

The Final Factor

A person near a talker hears him or her clearly. A person listening at another workstation hears the talker's voice attenuated by the above noted sound attenuation factors. However, the understanding of speech is determined by how much that reduced speech level is above the background; the *signal-to-noise ratio*.

In most offices, the background level is the steady sound of the air handling system. This sound is insufficient to provide speech privacy, so sound masking is normally required to provide adequate privacy. The optimum amount of sound masking only can be obtained by computer modeling. Normal Privacy is the goal for most open office workstations.

The Masking Spectrum for Open Offices

Not only is the level of the sound masking important, but the spectrum *contour* is important also. This is particularly true in open offices. Most standards relating to the acceptability of a sound suggest that sounds with more high frequency content are considered "hissy" and less desirable. However, speech privacy is improved with masking sounds that contain higher frequency content. Which is more important, masking that is slightly more effective at a lower level but hissy (so-called pink noise), or masking that is not hissy but requires a slightly higher level to be effective? Most consultants and masking specialists have opted for the latter case because pink noise is generally less acceptable to employees. Figure 3-10 shows examples of several masking spectra used by consultants for open offices, including CCR ASSOCIATES. It is clear that there is a difference of opinion about what exactly is needed at high frequencies. This is because the specific products used in offices differ significantly at high frequencies. The overall level of each has been adjusted to 47 dB(A) for comparison purposes, but it is not necessarily the overall level needed in every case. The heavy line with data points is the average spectrum and the dashed line is a spectrum that decreases at 5 dB/octave, the so-called *neutral contour*.

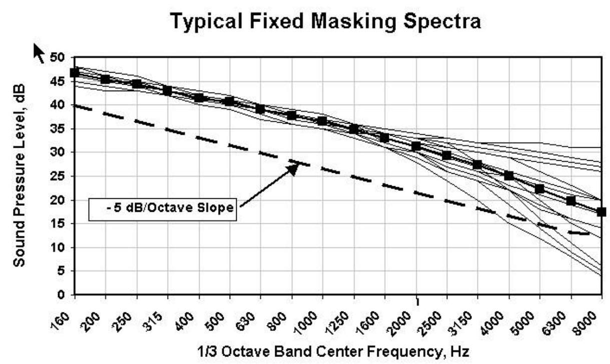

Figure 3-10

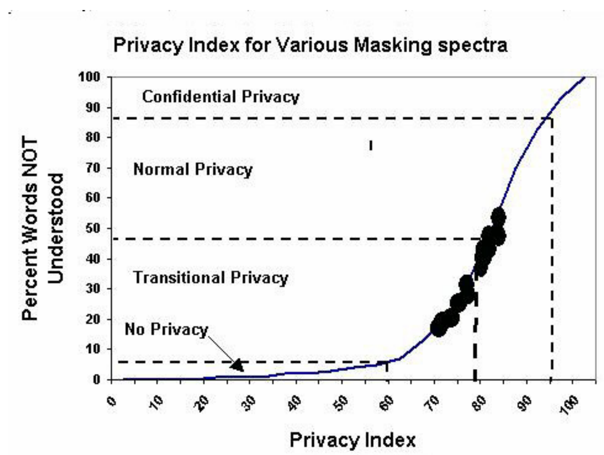

Figure 3-11

Figure 3-11 shows the privacy results plotted on the Privacy Index graph for each of the spectra shown in Figure 3-10 for an open office workstation with 66 inch high panels and the worst-case situation. One spectrum provided a Privacy

Index of 73 while another provided a Privacy Index of 85; a wide and very significant difference in performance. It is clear that some of these spectra must have higher levels to provide adequate privacy. A general rule for sound masking near this range of Privacy Index is that an increase of 3 PI points is achieved with 1 dB increase of sound masking. The poorest spectrum required a 4 dB(A) higher level to provide the same speech privacy as the best performing spectrum. The following rule must be taken into account when choosing the masking spectrum contour for an open office:

The masking spectrum contour is very important in open offices.

The CCR ASSOCIATES modeling program has an extensive database of masking spectra that can be used to determine which spectrum is best for a particular case. Also, the software can be used to design the optimum masking spectrum.

Unfortunately, there is more to masking than improving privacy; it must be acceptable to employees. Pink noise, promoted by one manufacturer, is one example of a spectrum contour that is generally not acceptable. All of the spectra in Figure 3-10 are the result of years of field experience so are considered to be acceptable. The heavy line is the average of those spectra and has a similar slope to the dashed line called the *neutral spectrum*. One standard states that for contours near the neutral contour: "there were no complaints of rumble or hiss." The other aspect is level. Levels between 40 and 49 dB(A) are generally acceptable. The results suggest that a number of masking spectra can provide speech privacy, so it becomes a trade-off between performance (overall level and spectrum contour) and acceptability. We suggest modeling an office to determine the best masking spectrum.

Universal Privacy with Sound Masking

Look at two common occurrences for the worst-case situation: an open workstation away from reflecting walls and a corner workstation. The panel STC is 25 and the panel NRC is 0.65, typical values for enclosing workstations. A-weighted levels of sound masking are used, since they are common overall descriptors. The standard mineral tile is again compared with the high performance fiberglass tile, for several panel heights. The masking spectrum contour is the average shown in Figure 3-11. The question here is: How high must the masking be to achieve Universal Privacy. Figure 3-12 shows the level of sound masking required to achieve Universal Normal Privacy (PI=80) in a workstation with no surrounding wall or windows. The dashed line suggests a level (48 dB(A)) above which the masking might be unacceptable to most occupants. For panel heights lower than 60 inches, the use of highly absorptive fiberglass ceilings creates extra cost, but virtually no improvement. It is clear that Universal Normal Privacy cannot be achieved for these panel heights, and one must resort to the concept of Partial Privacy. For panel heights of 60 inches or higher, mineral tile ceilings can be used with reasonable levels of sound masking.

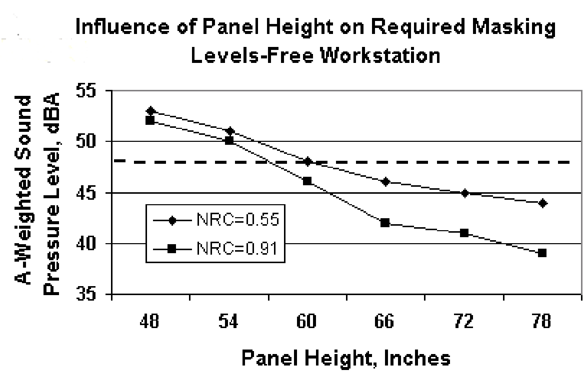

Figure 3-12

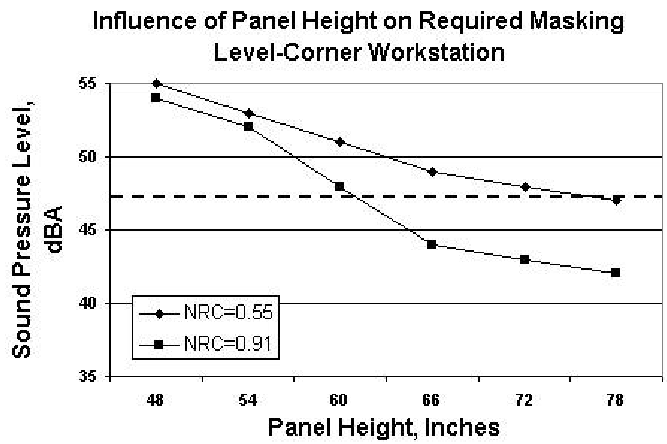

Figure 3-13

Figure 3-13 shows the level of sound masking required to achieve Universal Normal Privacy (PI=80) in a corner workstation where the wall reflections decrease the sound loss; more masking is required to achieve Universal Normal Privacy.

A comparison of the figures shows that the required levels are about 2-3 dB higher due to these additional reflections. To achieve Universal Normal Privacy for a panel height of 60 inches a fiberglass ceiling tile is required. For higher panel heights, a high performance mineral tile (NRC=0.75 or greater) is acceptable. For panel heights less than 60 inches, high NRC ceilings provide no benefit. It is clear that Universal Normal Privacy cannot be achieved for these panel heights and one must resort to the concept of Partial Privacy.

It should be noted that a PI of 80 is the lower limit for Normal Privacy. An early government document suggested that a PI of 89 would satisfy most occupants. Unfortunately, this would require a 3 dB increase in masking level, with the potential for loss of acceptability. As a result, the above comments should be interpreted as the *minimum* requirements for panel height and ceiling type.

The Total Masking Spectrum

Masking spectra are designed primarily for speech privacy so only the speech range of frequencies is important, but what a person hears and evaluates is the entire sound spectrum, which is the masking and, most often, the air handling sound. This has an impact on employees. A well-designed air handling system generally creates significant low frequency sound, but is deficient at the higher frequencies. Sound masking covers the higher (speech) frequencies, but is deficient at low frequencies The two spectra added together generate a spectrum that is more like that desired by occupants. If the air handling system is not designed well, the low frequency noise level is much higher, resulting in a negative response to rumble, which often is attributed erroneously to masking system malfunction. The background spectrum is included in the acoustical analysis program.

Partial Privacy with Sound Masking

Noting that Universal Normal Privacy is not achievable at reasonable levels of sound masking for low panel heights, one might infer that masking is not useful under those conditions. That is not the case. The *call center* is a common example of offices with low panels; typically they are 48 inches high. Is there any benefit in using masking for that situation? Figure 3-14 shows what is called the ***Radius of Distraction*** in an office with an array of open workstations. This radius is the distance beyond which persons have Normal Privacy from the person talking. In this example, the workstations are 7 by 7 feet, the panels are 48 inches high, the unmasked level was 38 dB(A) and the masked level was 48 dB(A). The large radius (46 ft) is the distance associated with the unmasked condition, while the smaller radius (15 ft) is for the masked condition. Since a person's speech is directional, the actual shape is not a circle, but since we have no control over that direction, a circle handles the worst case. More than 80 people might have been distracted by the talker without masking, but only 8 people would have been distracted with masking; a huge improvement. Obviously, not all offices are this large, so the ratio is generally smaller. Less obvious is the fact that each person is within the Radius of Distraction of numerous talkers, so there are multiple benefits in reducing that distance. Sound masking in call centers has an additional benefit. The customer on the receiving end of the call is not aware of the conversations of the other employees, thus preserving confidentiality critical for medical-related conversations. Also, it eliminates the "boiler shop" atmosphere sensed by a prospective customer in sales messages.

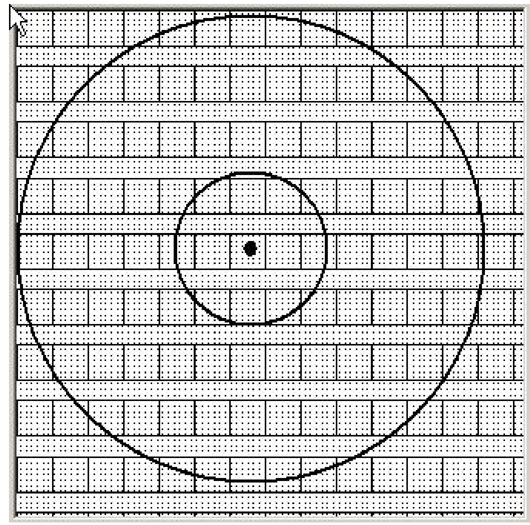

Figure 3-14

Some Guidelines

To achieve Universal Normal Privacy in open offices with reasonable sound masking levels, panel heights 60 inches or higher are recommended. Table 3-4 lists some critical characteristics necessary to achieve acceptable degrees of privacy with reasonable masking levels. Note that panel NRC is not listed. The masking spectrum contour used was the one recommended in a previous section and 47 dB(A) is considered a widely accepted overall level.

Panel Height, Inches	Minimum Panel STC	Ceiling NRC	Masking Level, dB(A)	Privacy Index
54 or lower	None	0.55 to 0.65	48	Partial Only
60	20	0.55 to 0.65	47	75
60	20	0.88 to 095	47	81
66	24	0.55 to 0.65	47	81
66	24	0.88 to 0.95	45 to 47	82 to 90
72	24	0.55 to 0.65	43 to 46	80 to 85
72	24	0.88 to 0.95	43 to 46	80 to 93
80	24	0.55 to 0.65	42 to 45	80 to 88
80	24	0.88 to 0.95	41 to 45	80 to 93

Table 3-4

For panels less than 60 inches high, Partial Privacy is the best that can be achieved with a Radius of Distraction on the order of 15 to 20 feet.

For panels 60 inches high, highly absorbing ceiling tiles are recommended if Universal Normal Privacy is to be achieved at reasonable masking levels. To achieve this degree of privacy with standard mineral tiles, a level of 48 dB(A) is needed. For panels 66 inches high, Universal Normal Privacy can just be achieved with a standard mineral tile. High performing mineral, or fiberglass, tiles would yield better privacy or permit lower masking levels. For panels 72 inches high or higher, satisfactory Universal Normal Privacy can be achieved with standard mineral tiles and reasonable masking levels. The addition of high performing mineral, or fiberglass, tiles would put the listener well into the Normal Privacy degree and would permit lower masking levels.

Handling the Spatial Aspects of Privacy

The discussion above is specific to two persons near each other. The ceiling and carpet normally extend throughout an office so they are relevant to all open office workstation privacy situations. Although installed workstation panels are generally from one manufacturer, the specific workstation layout can vary resulting in variations of speech privacy. Further the degree of privacy can vary depending on the work function of a group. The remaining factor to handle these variations is sound masking. The general approach to handle variations of office layout and employee needs is first to define privacy groups in general terms. Those areas that need only masking must be separated from those that wish added signals such as paging or music and also from those areas where privacy is not needed. Next, it is best to separate groups by administrative functions; sales areas require a degree of privacy that is different from clerical or technical areas. Further division may be required based on how these groups physically relate to each other. CCR ASSOCIATES handles this by creating masking *zones,* each of which is designed to handle specific privacy needs. If the needs of adjacent zones are considerably different, the masking level is tapered to avoid adverse response to changes.

Handling the Temporal Aspects of Privacy

An employee's desire for a specific degree of privacy varies throughout the workday and workweek. A constant degree of privacy is desired throughout the most productive part of the workday. Employees in partially occupied offices, either during the normal workday or after hours, have a greater need for community than privacy, so masking levels should be reduced. Security personal do not want privacy when making rounds at night or on weekends, so masking should be low at those times. When addressing the worse-case situation, it was implicitly assumed that the talker was speaking all the time. Although no studies have determined how many distractions, or how often they must occur, or how loud they need to be, to create annoyance and complaints, it is abundantly clear that the time-of-day plays a key role in the development of annoyance and subsequent loss of productivity. How is it to be handled?

As noted earlier, the building structure is static and cannot be changed during the workday. Employees on occasion will speak less loudly in partially occupied offices, but it is not one easily under control of the owner. The only remaining factor is the sound masking. When the time factor is important, CCR ASSOCIATES will include a masking generator that will automatically adjust levels by hour-of-day and day-of-week.

Chapter 4: Achieving Acoustical Privacy in Closed Offices

To determine the proper design of a closed office the same three major factors must be taken into account and they must be properly balanced both with respect to cost and performance.

This chapter concerns closed offices where the same three major factors apply (voice level, sound attenuation, background level), except that the sound attenuation components are different. Another important difference is that Confidential Privacy is the desired level of privacy; a more demanding requirement. One type of closed office is one in which there is only one occupant who wishes confidentiality from persons outside the room. Another is the larger conference room with multiple occupants but, with privacy requirements. Inside the room, good communication is important.

The Problem with Closed Offices

Because closed offices most often provide a high degree of visual privacy, it is often assumed that they have high degrees of speech privacy. Unfortunately, there are a number of factors that make this assumption invalid. Prevailing social customs keep office doors open for easy accessibility; closing the door results in the belief that outsiders are being excluded from interesting conversations. Modern construction techniques use thinner walls to control costs making the walls more sound transparent. Having an open plenum above the suspended ceiling as a low cost return air duct further increases the sound transparency of the office. Early on, fiberglass ceilings were used in closed offices under the erroneous assumption that if they were good in open offices, they must be good in closed ones. That assumption made matters even worse, but that error has been corrected.

Constructing a closed office makes use of only one factor in the speech privacy equation: the sound attenuation. This solution is a *static* one, i.e., once the building is built, it has fixed acoustical properties. The other two factors, voice levels and background levels, are *dynamic*, i.e., they change from minute to minute. A heated discussion occurring in a closed office designed for normal speech levels will lose its privacy just when privacy is needed most. Often speakerphones are used in closed offices and, as with most audio equipment, they are set too loud. In rented offices, where wall construction is the lightest, confidentiality is lost when the air handling system is turned off in evening hours. These comments show the fundamental weakness of the construction-only solution. This is not to say that the building structure is unimportant, but rather that its properties should be integrated with the other factors in the privacy equation. The most important sound paths for a closed office are shown in Figure 4-1on the next page.

In the vertical plane, the wall (or door) and ceiling plenum are the important factors as well as any gaps in those surfaces. In the horizontal plane, the side wall or windows may provide a flanking path.

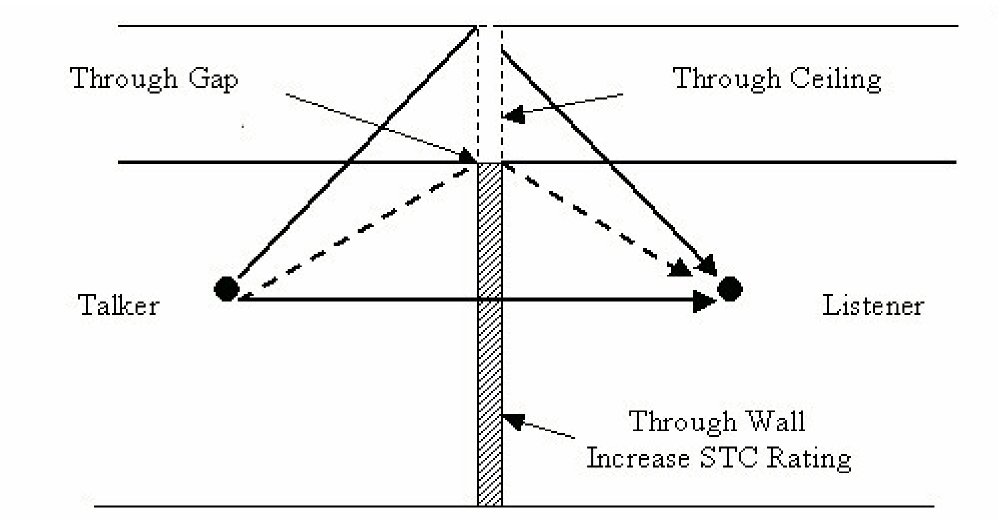

Figure 4-1

Details of the Sound Attenuation Factors

Walls

The standard approach to increasing the sound attenuation of a wall is to specify a wall with a high STC rating. Although the higher the better, the higher is also costlier, and how much is enough to guarantee privacy? STC is a laboratory rating where the best possible performance of the wall is obtained. Applying the Speech Weighted Loss rating to the published STC data shows that most common partitions have about 3 dB more attenuation of speech than the STC rating suggests. However, field installation always degrades tested performance, so that small benefit is not realized. There are a number of reasons for decreased performance. The first concerns sound passing through the wall itself. If the construction is poor, the partition may have extra transmission paths not tested for in the laboratory. The other paths can be grouped into what is called *flanking paths*. For example, floors or suspended ceilings that are not flat and level result in gaps. Doors in a wall will reduce the wall's attenuation, particularly if it is poorly installed and has gaps such as the gap at the floor. A continuous ceiling plenum can contribute significantly to weakening the walls performance; the sound passes over the top of the wall. The safe approach for a designer is STC overkill. The wall may be extended partially, or fully, above the suspended ceiling. In both cases there is also cost overkill. As in open offices, it is necessary to deal with parallel paths, the weakest of which dominates the sound attenuation. Acoustical consultants estimate the weaknesses of various flanking paths and recommend improvements that will permit the wall performance to come close to that specified by the STC rating. A common rule-of-thumb is that the performance of an installed wall will have a field STC (which includes all other paths) that is 5 to 7 points less than the published value.

Doors

An open door permits conversation to be heard immediately outside, but if it opens on a corridor, speech reflected from the corridor wall may be understood in the next office if that door is also open. The standard solution for privacy is the best one: close the door. In some cases, expensive doors have been purchased that have gaskets to prevent sound leaks around the edges. Experience has shown that a normal *solid core* door without gasketing will create sufficient sound attenuation when coupled with sound masking.

Windows

Persons in closed offices typically demand, and get, windows. When a building has curtain walls with windows that are common to two offices, there is a problem. The usual fix when the occupants notice the loss of privacy, is to have foam fill the gap between wall and window. Foam is not particularly effective in stopping the speech transmitted through the gap. Worse though is the fact that conversations excite window vibrations that completely *bypass* the wall, resulting in more sound transparency. These two flanking paths do not occur often but are disastrous when they do.

Ceiling Plenum

If the surrounding walls extend to the structural ceiling and the return air is ducted, the plenum path is generally of no concern. The exception occurs with large ducts that have no insulation and large diffusers in contiguous rooms. In most offices, the ceiling plenum is open and continuous to permit return airflow without the cost of adding return air ducting. This path is of concern. There are several structural solutions, not all of which are successful. Walls can be raised to the structural ceiling but with an opening for the return air. Walls raised to the structural ceiling add cost, but also make the installation of a suspended ceiling more complex and costly. Walls can be raised 6 to 12 inches above the suspended ceiling line. This allows the ceiling to be a return air plenum, but the continuity of the suspended ceiling is interrupted, causing additional construction costs. In most buildings, particularly "spec" buildings, the wall terminates at the suspended ceiling, so there is a path from room-to-room through the plenum as well as through any gaps because of mismatch between ceiling and wall. Often this sound path is not recognized until after the rooms are occupied. The usual fix is to add fiberglass batts to the ceiling plenum; they are totally ineffective. Other practitioners have hung lead sheets in the plenum as a retrofit improvement. They work, but are quite expensive, difficult to install, and interfere with return air flow. Again, all of these fixes are static, so they may, or may not, be sufficient to insure speech privacy.

Return Air Grilles

If the return air system uses an open plenum, the return air grilles are potential transmission paths for speech to contiguous offices. Most often this situation is ignored until occupants complain and then a short muffler is added above the grille. A muffler increases system pressure drop and changes the airflow balance in the building as well as adding installation and operating costs.

Combining the Sound Attenuation Factors

Sound Transmission Class (STC) and Noise Isolation Class (NIC) are used as sound attenuation ratings for walls or other partitions. STC is a rating for a wall partition under laboratory conditions, while NIC is a similar rating but with a reduced frequency range. Neither is speech weighted. CCR ASSOCIATES does two things that improve the accuracy of these ratings. We convert the sound transmission loss levels used in the ratings to Speech Weighted Loss so they are applicable to speech privacy. Through a number of field measurements, we have decreased the published rating to one that is more applicable to actual use.

Because the sound transmission process going through a ceiling is more complex, the STC rating cannot be used. Ceiling Attenuation Class (CAC) was developed for this case. It is speech weighted.

Figure 4-2 shows the expected Speech Weighted Loss for walls of typical closed offices with an open plenum above. The STC rating was degraded to account for flanking paths. The lower value of STC applies mostly to what is referred to as "spec" offices where low cost rental space is obtained. It is clear that the CAC rating of the ceiling plays a major role. Values of CAC near 20 apply to fiberglass ceilings that work well in open offices, because of their high sound absorption, but are **disasters** in closed offices. The CAC rating of the ceiling is an important factor for design of closed offices.

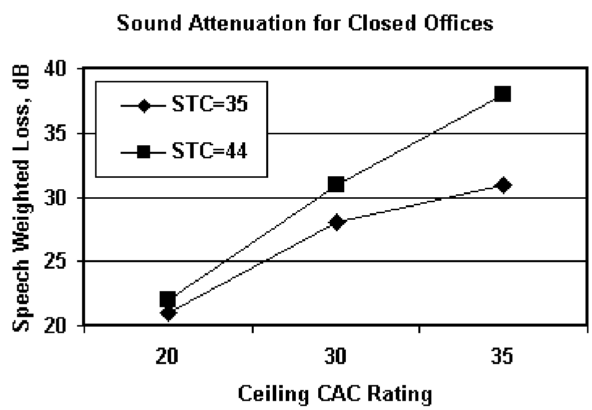

Figure 4-2

Creating Privacy with Sound Masking

Again, as in open offices, there are multiple paths of sound from one office to another. Structural solutions require that the critical path be identified and fixed. Sound transmission in closed offices is more complex than that in open offices, so it is much more difficult to estimate the improvement made by any structural changes. Again, the weakness of any structural change is that it is *static*, unchanging. If a raised voice conversation occurs, confidentiality is severely compromised. Since sound masking works, regardless of the path of the speech, and can be adjusted to handle different voice levels, it is a very practical and cost effective tool in closed offices as well. Figure 4-3 shows the required level of sound masking to achieve Confidential Privacy in a typical closed office with the door closed. The dashed line is the recommended maximum masking level for closed offices. It is clear that sound masking will *not* be acceptable for low CAC ceilings such as fiberglass. The CAC ratings of ceilings should be 30 or greater with 35 being preferred; and ceilings with this rating are commonly

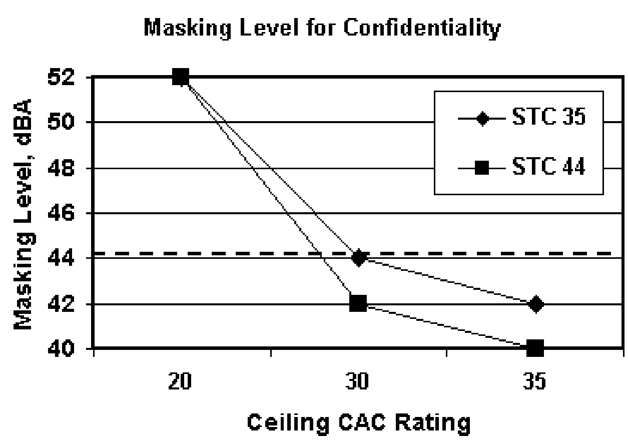

Figure 4-3

available. Another interesting result is that sound masking can be used effectively in offices with the least expensive walls.

Since persons in closed offices want confidentiality from outsiders, the listeners are those outside the talker's office and it is there that the masking must be applied. If the outside area includes other closed offices, then we apply the levels noted above in those offices also. If the outside area is an open office, or corridor, we apply the levels needed for the open offices there. Those levels will provide increased privacy since they will be higher.

It is necessary to have minimum characteristics of the building structure in order to avoid having excessive masking levels in a closed office. Recommended ratings for closed offices are shown in Table 4-1.

Item	**Recommendation**
Wall STC	45
Wall NRC	Not important
Ceiling CAC	30 or higher
Door STC	Solid Core Door
Return Air Grilles	Center in Room

Table 4-1

Chapter 5: Medical Facilities

For more than forty years, people involved in medicine (researchers, doctors, nurses, and even patients) have written innumerable articles on the negative effect of hospital noise on both nurses and patients. Yet very little has been done to solve the problem beyond administrative controls (i.e. please talk quietly, do not page so often), which are of limited effectiveness. The passage of federal legislation, which includes requirements for speech privacy associated with medical information, has provided an unprecedented opportunity to solve both the disturbance and privacy problems. In this chapter, we show how tools used to solve speech privacy problems in other applications can be used to solve the medical facility noise problem as well.

Federal Regulations

The Congress of the United States passed the Health Insurance Portability and Accountability Act (HIPAA). It mandates that individually identifiable patient health information be protected. Although written and computer files are obviously to be protected, verbal information must also be protected. "Covered entities" (those who must comply with the law) must make *reasonable* efforts to safeguard patient information from being overheard. The law itself gives no specific guidance on how this is to be accomplished, but a document released by the Department of Health and Human Services provides some clarification. It includes, as part of the protection, the phrase "health information whether it is on paper, in computers, or communicated orally." The Office of Civil Rights also has published a document on this issue, stating that the law does *not* require retrofitting spaces, such as soundproofing of rooms, in order to comply. Again, the bias toward the structural solution is showing. This effectively rules out one of the three privacy factors and limits solutions to the other two factors: low level speech (administrative controls) or higher background levels (masking). Eventually these requirements will be decided in court. As a result, many medical facilities have already realized that compliance is wise, and have begun retrofitting their facilities using all three of the important factors that create speech privacy.

The Noise Problem

For a number of years, noise in hospitals has been a problem, in part because of the need to have all surfaces hard and cleanable. A large number of measurements and reports in prestigious journals, dating as far back as 1963 in the United States and other countries, testify to the seriousness of the problem [30-47,65,68]. The primary problem from the patient's viewpoint has been the distraction and annoyance caused by the noise of people, which results in less rest, poorer sleep, and possibly longer recuperation time. The increased socialization now permitted in hospitals, as well as the increased use of medical machinery, has exacerbated the problem. Figure 5-1 exemplifies the standard administrative attempt at a solution.

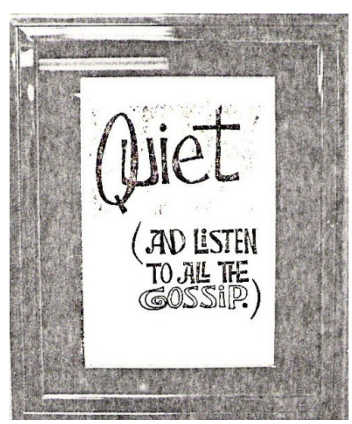

Figure 5-1

An extensive survey by the Public Health Service in 1963 showed that patients interviewed were frequently disturbed by speech and distress sounds, some of which were caused by the staff during night hours. Other studies concerned the noise interfering with sleep and recuperation; the most disturbing noise was patients in distress.

Another study indicated that over 70% of patients suffered from excessive noise. Several studies have shown that exterior noise can be a problem also. Heavy traffic on local streets as well as ambulance and helicopter arrivals can penetrate patient's rooms. The World Health Organization recommends that nighttime levels not exceed 35 dB(A). Other organizations recommend similar levels. One author recommended that "average" sound levels be kept below 45 dB, but pointed out that higher maximum levels could be tolerated if the ambient level is *not* very low. Meeting such stringent level requirements is impossible; it would require cessation of all activity. Even libraries are noisier than that. These results only suggest that medical professionals are focused on medicine and not privacy.

An interesting study found that the amount and rate of increase in the sound level from the constant background was the main contributor to full awakening, or changes in the stage of sleep. ***He determined that the magnitude of the change in level, regardless of its median value, was more significant than the level of a steady sound of the same median value.*** Another researcher expanded this finding by stating "it is clear that intermittent and impulsive noise is more disturbing than continuous noise of equivalent energy, and that ***meaningful sounds are more likely to produce sleep disruption than sounds with neutral content***." The difference between the ambient and the single event levels should not exceed 8-10 dB. In their opinion, the difference between the maximum level and the steady background level is the important factor. Many articles have missed these crucial observations, but rather have addressed just maximum levels. In keeping with this major point, one must look at the fluctuations of sound in a hospital environment. An example of the percentage of time the noise exceeded a given level in hospital corridor is shown in Figure 5-2.

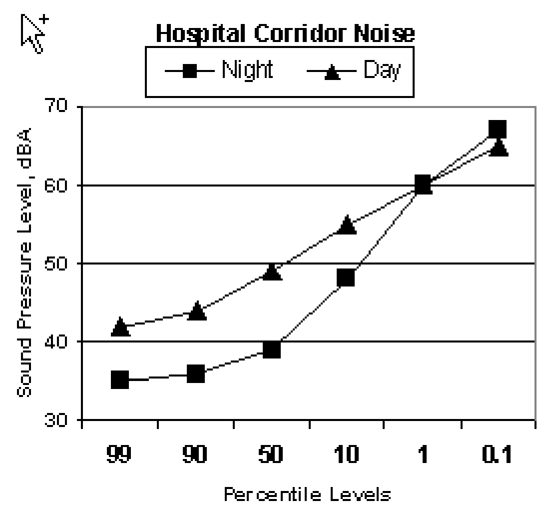

Figure 5-2

It is clear that medical professionals have been focused on medicine, not privacy, and few of the concepts commonly applied in the open office environment have found their way in hospital acoustics.

Hospitals

The primary function of sound masking is to bury unwanted sounds in a steady sound, reducing the fluctuations that disturb patient rest and sleep. Application of sound masking to hospitals can solve two problems; the regulatory one associated with HIPAA and the one dealing with patient rest and recuperation. Since masking reduces the range of sound levels experienced by patients, there would also be a large reduction in patient disturbances from all types of sounds, not just speech.

Patient Rooms

Rooms must be protected from both hallway sounds and those external to the building. It appears to be a common practice in hospitals to keep the doors to patient rooms open, exacerbating the problem. Some data have been collected on nighttime levels in a single patient room. Figure 5-3 shows the percent of time a given level was exceeded in the hourly periods from 8 PM to 8 AM. The noise floor was near 40 dB(A) and was created by the air handling system. If, as suggested above, the maximum level difference over hourly intervals should be less than 10 dB, the results of Figure 5-3 can be re-plotted as shown in Figure 5-4. The periods of activity during the night hours were related mostly to noise emanating from the corridor and less so from nurse visits to the patient. The early morning activity was caused mainly by activity within the room (doctor and nurse visits). It is clear that the level variations during some hourly periods were sufficient to awaken the patient. Sound masking was added to the patient room at several levels to reduce the disturbance. Figure 5-5 shows the approximate influence of sound masking on these data when averaged over the twelve-hour nighttime period. Even modest levels of masking (45 dB(A)) create significant reductions in the potential distraction.

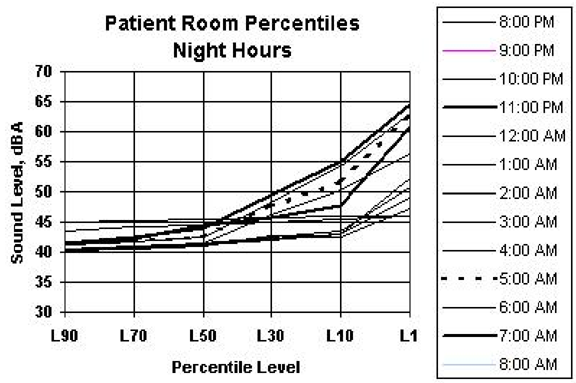

Figure 5-3

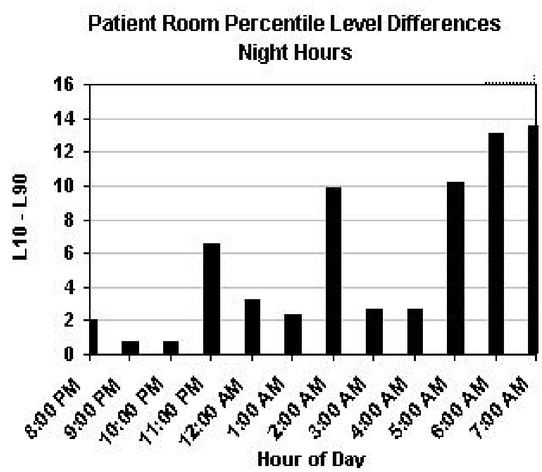

Figure 5-4

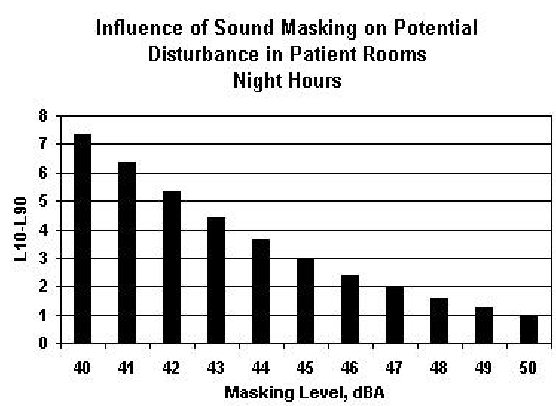

Figure 5-5

Because of the close proximity of patients in multiple occupancy rooms, masking cannot protect doctor/patient conversations. Masking cannot prevent the sound from one patient's television set from being heard by the other patient. Some hospitals have a small speaker next to the patient's head so levels can be set low to avoid disturbing the other patient. Speakers inside pillows have been proposed. The data presented in the previous figures did not include any exterior noise, such as helicopter and traffic noise, but masking should alleviate the impact from those sources also.

Fortunately, patient rooms in modern hospitals have suspended ceilings above which a masking speaker can be placed. A masking system was installed on one floor of a hospital. One masker was placed above the suspended ceiling in each room and one was placed in the corridor outside the room. The geometry is shown in Figure 5-6; the rooms were 13 by 37 feet with two beds. The masking level in the patient rooms was set at 42 dB(A) with a sound spectrum typical of that used in closed offices, while the masking outside the rooms was set at 47 dB(A) with a sound spectrum typical of that used in open offices. Both objective and subjective tests of speech privacy were made with doors open. Patients could not understand conversations outside the room, nor could persons outside the room understand conversations within the room. As an acceptance test, the masking level in the patient rooms was slowly raised. Comments about the sound by the patients began to occur between 46 and 47 dB(A), suggesting that might be an upper limit for acceptability.

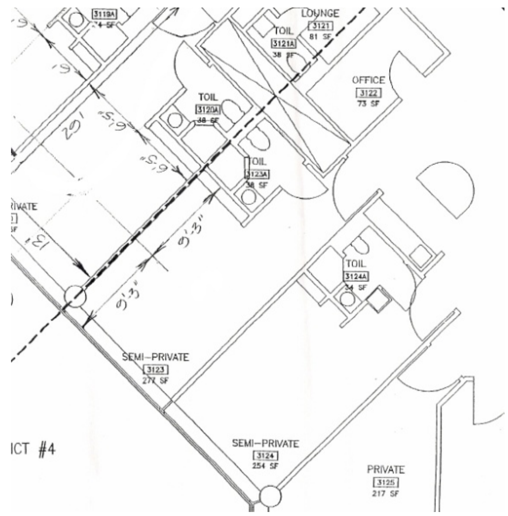

Figure 5-6

Corridors and Nursing Areas
Masking has been used in corridors to block speech and other sounds from one patient room to another as a low cost alternative to providing each room with masking. The primary value however is to provide confidentiality of conversations within patient rooms from those persons outside. Levels similar to those used in commercial open offices can be used for this purpose. The data from Figure 5-2 were adjusted to add sound masking in order to demonstrate the reduction in distraction that would occur in corridors. As a result, the most intrusive sounds (those occurring one percent of the time) were reduced by 8 dB. This improvement is significant and the improvement is even better in patient rooms. This result does point out the fact that sound masking is not a cure-all, but must be used in conjunction with other sound attenuating factors.

Nursing Homes

It has been noted that older people are more likely to have their sleep disturbed than younger people and they are more likely to be awakened in the early hours of the morning. Modest increases of sound level (6 dB or more) in nursing homes were a significant factor in awakening residents. The use of sound masking in these facilities appears to be beneficial.

Doctor’s Medical Suites

Included in this category are physician’s offices, medical laboratories, clinics, and on-site employee medical suites. Most suites are rented in standard buildings where the ceiling plenum is continuous, acting as a duct for air returning to the air supply system. Further, the walls are of light construction permitting speech to pass through them. Experience has shown that confidentiality is not achieved in examination rooms under these circumstances. Patients seated in a waiting area generally can understand patients at the sign-in window. One erroneous structural solution is to create a glass window with a small circular hole for conversations with the staff. People naturally speak louder under these conditions and the sound reflection from the window itself further exacerbates the problem. Many doctors have installed masking systems, even before the passage of HIPAA. The addition has been shown to be of considerably less cost than structural solutions and effective in creating the needed confidentiality at low masking levels.

Pharmacies

Pharmacies have a situation similar to the window in a doctor's office in that a number of people may have oral access to the conversation at the window. Again, a plate glass window is not the solution. In keeping with the bias toward structural solutions, many pharmacies have placed a yellow line at a distance from the counters, as is done at immigration windows, to maintain a distance from the person being helped. Aside from spatial constraints, it has been found that in *all* pharmacies using this method, the conversations were clearly intelligible at the specified distance. At what distance should the line be placed? A low level of masking immediately above the counter, either in a suspended ceiling or on the wall above the counter can be used to create Confidential Privacy.

Psychiatrist's Offices

Psychiatrists have suggested that the use of masking *within* the counseling room has a calming effect on patients. One noted that the presence of the masking gave the patient a sense of privacy from any relatives in the waiting room and that made it easier to speak about problems. The patient was unaware that the masking in the waiting room was providing the needed confidentiality. The other use of masking in these offices is to provide Confidential Privacy.

Medical Providers

Included in this category are public health authorities, life insurers, billing agencies, and service organizations. Most of these have facilities much like standard office settings, with both closed and open areas. As a result, they can be handled in the same way as for normal open and closed offices. In many open areas, customer support personnel use telephones continuously. This case is similar to call centers where the primary object is to prevent one customer listening to a support person from understanding the conversation of a nearby support person talking to another customer.

Chapter 6: Secure Facilities

Most of the acoustical design for normal offices deals with *accidental* listeners that have no interest in the conversations overheard. Unfortunately, there are many cases where the listener is a *deliberate* eavesdropper who may make use of sophisticated listening devices to improve speech intelligibility. Examples occur in government, military, and commercial situations. For deliberate listening, the normal methods of acoustical design are not adequate and new techniques and equipment must be utilized.

The reason for concern is that most major strategic and tactical decisions are first made orally at meetings and, if an eavesdropper can obtain access, it gives him a distinct time advantage over written or computer documents. Therefore speech is again the primary focus.

To protect conversations, it is normal practice to use the structural "solution'; rooms that have high sound attenuation. For example, the government uses the technique of a room-within-a-room that is very expensive. Unfortunately, many facilities do not have the budget for such measures, particularly when one considers all the ways audio access might be achieved. Worse yet, rooms with high sound attenuation do *not* guarantee protection. As with normal office design, there are three factors that play a role in protecting conversations: how loud the conversations are, how much those conversations are attenuated en route to a potential eavesdropping location, and how loud the background sound is at the eavesdropper. The technical weaknesses of rooms with only high sound attenuation are apparent. If a sound system is used to amplify speech (PA system, speaker phones), the room cannot be changed to accommodate the raised levels. When a room is constructed, there is no knowledge of the background sound level at locations where listening devices might be placed. A less obvious weakness is that modern listening devices can be placed in locations that building structure cannot protect against (inside wall cavities, remote sensors of window vibration).

Sound masking fills that gap; we call it *security masking* to differentiate it from normal sound masking methods. Not only does it permit the user to adjust and verify the degree of protection from most eavesdropping methods, but it also affords very large cost reductions in both room construction and security maintenance. As shown below, this method of protection is accepted and used by the federal government. In addition, masking systems can be installed permanently or used in temporary locations such as hotel meeting rooms. The goal for secure facilities is Secret Privacy.

Since most facilities are protected, CCR ASSOCIATES is involved with only security masking aspects and not facility design.

Applications

CCR ASSOCIATES has found there are a growing number of applications for secure masking. Any organization that has a need for protecting sensitive conversations from actual or potential eavesdroppers should consider using sound masking as an effective deterrent. Organizations that benefit from such protection are:

- Department of State facilities, such as embassies
- Department of Defense facilities
- All military departments
- Department of Homeland Security agencies
- Narcotics agencies
- Intelligence and counter-espionage agencies
- Corporate research facilities
- Corporate planning facilities
- Corporate human resource departments
- Corporate mergers and acquisitions departments
- Corporate boardrooms
- Legal offices
- Accounting firms

Standards

There exist a number of regulations for protecting sensitive conversations, most are promulgated by the federal government. Examples of them are Defense Intelligence Agency Manual 50-3, Director of Central Intelligence Directive 6/9, Air Force Pamphlet 8-26, and the Gramm, Leach, Blily Act that protects financial information. These regulations point to the important of protecting classified, sensitive and financial information.

Concepts of Security Masking

Categories of Surveillance
Two must be addressed. *Uncontrolled areas* are those where the persons attempting to protect themselves have little or no control over the environment. Generally, this includes all areas outside the building in which the secure room resides, such as parking lots or other public spaces where it is possible to gain access without detection. *Controlled areas* are those within a building where there is a measure of control. The method of protection depends on this difference.

Types of Masking Signals
Taking into account the capability of sophisticated listeners to recover speech buried in noise, it is necessary to provide *layered* protection. Instead of just one type of masking signal such as was discussed in earlier chapters, the generator creates and mixes several signals. For uncontrolled areas, *non-stationary* random noise must be the first layer. It covers the entire speech spectrum as in commercial sound masking, but its non-stationary characteristic inhibits signal recovery. For controlled areas, the less expensive stationary random noise generator is adequate. Music may be used as the second layer; it is buried below the random noise so it is not actually audible to room occupants. Voice babble or speech samples may be used as a third layer; it may be set at the same or lower level as the music signal. If equalized properly, the fourth layer, the actual voices to protect, will be sufficiently buried below the other layers.

Types of Masking Systems
There are two types of masking systems, the fixed and the portable. Most of this discussion will concern the fixed system permanently installed in the room to be secured. However, there are situations where sensitive conversations must be conducted while traveling, such as in hotel/motel rooms. The portable system can be used for this situation. It provides coverage of windows, doors, walls and air vents. Installation is quick; the maskers are attached temporarily and are removed when done. Evidence of attachment can be removed easily. This system does not have the refined capability of fixed system equipment, so levels are set higher than for fixed facilities in order to guarantee protection. As a practical control, all equipment and wiring should be contained within the secure room whenever possible.

Handling Amplified Speech
In some secure facilities, such as conference rooms, audio amplification of speech is used; it may be with a microphone or as part of a playback system. There are several aspects of such use that make eavesdropping simpler. These systems are almost always set too loud, and the level can be too easily adjusted with the turn of a knob. Protection of speech requires precise measurement, which can be completely undone with the turn of a knob. Worse yet, the adjustment of treble controls can enhance speech intelligibility just as is done with hearing aids and paging systems. To ensure that protection schemes are effective in protecting speech, audio systems should *not* be used. Unfortunately, some rooms, e.g., boardrooms, will have them. When this is the situation, physical controls need to be put on the equipment to limit the maximum level and the frequency spectrum. This requires modification of the equipment.

Locations for Protection
Consider the perimeter envelope of a room as a location for listening devices. Windows, walls, doors, ducting, piping, ceiling plenums, raised floor cavities, and loudspeakers are all penetration points. Each location is discussed in more detail below. First, the threat is addressed, then the standard solution, and finally the sound masking solution.

Protecting Windows

The Threat
Windows face uncontrolled areas so special measures need to be taken. A prerogative of high office has always been windows, both in offices and conference rooms. The word "eavesdropping" originated with listening at window eaves. It should go without saying that an open window is an open invitation to listening, so that aspect is not discussed. However, speech near a closed window causes a minute vibration of the pane that appropriate sensors can detect. Since windows respond well at speech frequencies, the window easily carries intelligible speech in the form of vibration. Figure 6-1 shows how strongly a voice can excite the vibration of a window, especially at frequencies where intelligibility is high (2000 to 4000 Hz). This was for a male talking at normal voice level at three feet and facing the window. Although the actual vibration levels are not large, any vibration detection device can recover them. It is clear from this figure that windows are ideal locations from which to detect conversations within a room.

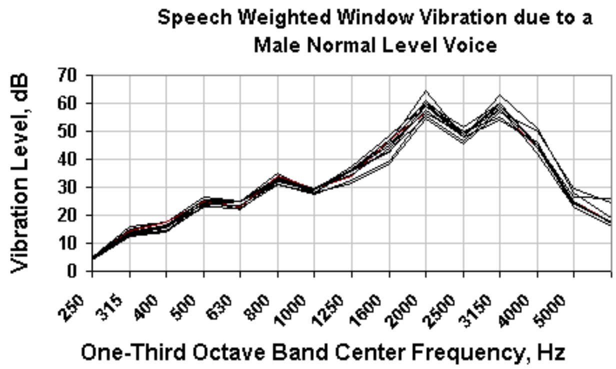

Figure 6-1

There are three ways to eavesdrop. First is the direct attachment of a *vibration detector* on the window pane or the frame. Accelerometers or strain gauges are difficult to see, but can be discovered by inspection so are unlikely to be successful when attached. These devices are commonly available. Second is the *laser microphone*. The transmitter of this device sends an infrared beam that reflects from the window to a receiver. The minute vibrations of the window modulate the carrier frequency that is later demodulated into speech. Theoretically, such a device can operate from any distance and, since the beam is invisible, is a potent detection device. Since the beam undergoes nearly specular reflection, very careful positioning is essential, which is time consuming and reduces the number of microphone locations and the number of windows that can be covered. Although manufactured in Europe and the United States, ordinary citizens are not permitted such devices. The present widespread protection of windows in secure government facilities suggests that these devices are in common use. Further, many websites suggest designs for such devices. Random window vibration caused by high winds or high levels of traffic noise will act as masking and so will inhibit detection, but these factors are not under the control of the person attempting to protect the room. Third is the *highly directional microphone* that detects the velocity fluctuations of the window (the radiated sound). The advantage of this device is that it can be at relatively arbitrary angles to the window; the disadvantage is that the distance must be shorter than for the laser microphone. Not all such microphones have a large parabolic reflector that would make it easier to detect. These devices are commonly available, such as for sports events. Again window vibration caused by exterior noise sources will inhibit detection.

The Standard Solution

The most secure solution, and the one recommended by CCR ASSOCIATES, is to eliminate the windows entirely. Although it is the best solution, it is not always acceptable to occupants. Some have considered double pane windows with a higher STC rating as adequate protection; that is not so.

Since more than acoustic emissions occur through windows, films have been applied to block any electromagnetic emissions. There have been claims that such films will protect speech also. Unfortunately, a film will *not* sufficiently reduce the mechanical vibration of a window that carries the speech.

The Masking Solution

Early masking methods placed a loudspeaker facing down from the suspended ceiling. They were called *window washers* since the sound “washed” over the window causing random window vibrations. Unfortunately, the level required at the window was loud enough to interfere with the speech to be protected, as well as to annoy the occupants. To converse, voices had to be raised, a self-defeating proposition.

The modern method is to attach a vibration masker to the window; it creates a broad band random vibration covering all speech frequencies. Because windows have many vibration modes, positioning of the masker is important.

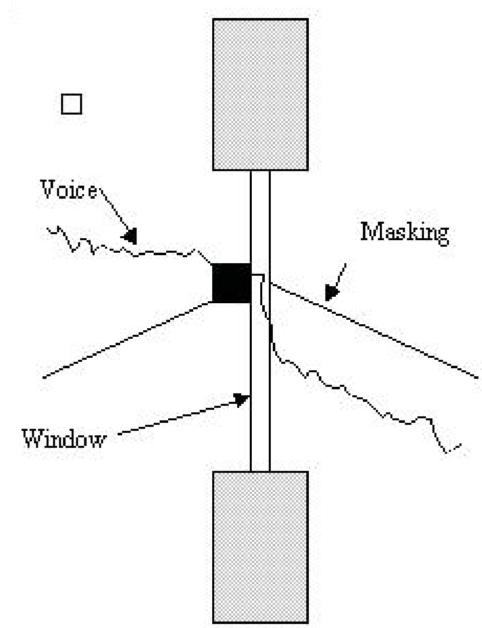

Figure 6-2

Figure 6-2 shows a schematic of the masking effect. The window vibration blocks the laser microphone and any attached devices, and the radiated sound on the exterior of the building blocks the exterior directional microphone. Since the speech sound in the room decreases as it approaches the window and the vibration masking decreases as is moves away from the window, persons in the room do not have to speak louder than normal.

For masking purposes, CCR ASSOCIATES has defined groups of windows; each has to be treated differently. They are:

- Windows with the largest dimension less than five feet.
- Windows with the largest dimension greater than five feet.
- Windows with a number of smaller panes.
- Windows with double Panes.

Protecting Walls

The Threat

Again, there are two categories of walls, exterior walls facing uncontrolled areas and interior walls facing controlled areas.

Exterior walls can be constructed of many materials, not all of which require protection. Because interior walls are most often constructed with studs and gypsum board to reduce weight, listening opportunities are better if access to the wall cavity can be achieved. For example, standard construction may consist of one or two sheets of gypsum board on either side of a wooden or metal stud with an air cavity that may, or may not, be filled with fiberglass. There are several ways speech can be detected through walls.

Remote from the wall. On all types of walls, listening can be done remotely from the far side, with microphone or ear. On exterior walls this method is greatly inhibited by the heavy wall structure and the fact that the outdoor background sound level is generally high enough to further inhibit eavesdropping. However, on interior walls, with much lighter construction, such is not the case as persons in many closed offices can attest. This method of listening must be taken into account for both interior and exterior walls.

On the far side of the wall. Detection of wall vibration on the far surface can be accomplished with a remote laser microphone or by attachment of a vibration detector. On most, but not all, exterior walls, detection of this type is very difficult. On interior walls, with their lighter construction, vibration probes can be used quite effectively. This method of listening must be taken into account for both interior and exterior walls.

Within the wall cavity and on interior surfaces. Wall cavities can be hollow or filled with fiberglass for thermal insulation or for additional sound attenuation. Penetration of either exterior or interior walls having cavities can be used to place acoustical devices in the cavity as well as to attach vibration devices on either of the inner surfaces of the cavity. There are two acoustical devices that can be used within the cavity. The first is the normal microphone that converts sound to an electrical voltage. Many are quite small. They may require a wire to carry the signal out, or have a transmitter to send it remotely. The second is the less known *fiber optic microphone*. It is an analog to the laser microphone used on windows, except that the beam is confined to a fiber optic cable. It has no metallic parts except for a thin aluminum diaphragm. It is very difficult to detect, is quite small and may be mistaken for a normal fiber optic cable if merged with others. This method of listening must be taken into account for both interior and exterior walls.

How good is the acoustical environment in a wall cavity? A sound source was placed in a room. The speech weighted sound attenuation across the wall to an adjacent room was 41, a loss that would be considered acceptable. The speech weighted sound attenuation *into the wall cavity* was only 21, a considerable advantage for an eavesdropper. What about the background spectrum inside the wall? The level was about 15 dB lower than that in either room; an excellent listening environment.

The Standard Solution

The standard solution has been to require high Sound Transmission Class walls. Established methods die hard; federal standards require walls with STC ratings of at least 45. As with all structural solutions, one may ask the question: Is the sound attenuation adequate to create speech privacy? It is only adequate if the background level in the listening room is sufficiently high (See Chapter 4 on closed offices). It does not, and cannot address, the listening environment *inside the wall*. As a result, a high STC rated wall, although recommended, is not sufficient to solve the privacy problem. Fiberglass is often added to the wall cavity to enhance the STC rating. Unfortunately, it is only partially effective against listening devices beyond the wall, and is not effective for devices within or on the wall. Further, fiberglass inhibit the distribution of sound masking within the wall. Whenever possible, **fill the wall with sound, not fiberglass**.

The Masking Solution

An early masking solution was to place a loudspeaker masker inside the wall cavity; it was mounted on the secure side wall with an inspection plate. The cavity volume was filled with sound. The interior sound field vibrated both layers of gypsum board, the outer layer of which radiated masking to adjacent rooms. Thus it covered *all* possible listening devices and locations. The sound level created by the masking did not create speech interference or annoyance within the secure room.

The current solution is to attach a masking vibrator to the wall on the secure side, as shown in Figure 6-3. This newer method has certain advantages. It is simpler to install and inspect, does not require penetration of the gypsum board, wiring can be seen and inspected, and is just as effective. If the vibrator meets building codes, it can be placed above the suspended ceiling. The sound masking is created by motion of the secure side wall, radiating sound into the cavity. The unsecure side wall vibrates in response to the cavity sound and reradiates masking beyond the wall. Thus, contact devices on either wall board are masked, the interior cavity is masked, and the unsecure side room is masked. As with windows, the voices in the secure room decrease as they approach the wall, but the sound masking decreases as it radiates away from the wall. The sound masking does not interfere with secure side conversations.

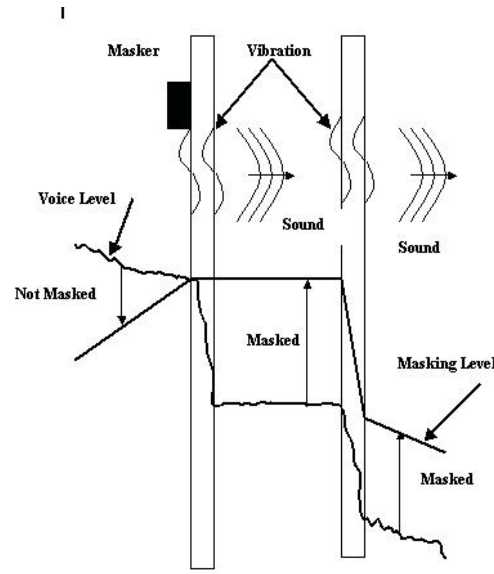

Figure 6-3

Protecting Doors

The Threat

Doors are weak links in walls. Typical doors may be hollow core, solid core, metal, or special. They can open to exterior uncontrolled areas, or to internal controlled areas. Every door has a gap around its periphery. These gaps may, or may not, have gaskets. Because carpeting is often used, the gap at the bottom is generally larger. Doors with built-in return air grilles are *never* acceptable. Because listening at a hollow core door results in clearly intelligible speech, such doors are *not* acceptable. Listening at a door gap, without a gasket, can result in intelligible speech at reasonable distances from the door. For interior doors, eavesdropping with the ear is the most likely surveillance method, although it is unlikely that a person will stand close for an extended period of time. It is also unlikely that detection devices will be attached to interior doors. This is not the case for doors opening to uncontrolled areas (e.g. emergency exits, or seldom used adjoining doors). Remote sensing of exterior door vibration or sound radiation are potential threats similar to that for windows. Listening with a vibration device, or directly, at an exterior door is possible but can be detected by inspection.

The Standard Solution

The standard solution is an architectural (structural) one where a hollow core door is replaced with a solid core door internally or with a metal door externally. To provide more protection, gaskets are added at the gaps and a *floor wiper* is placed at the bottom. Although these solutions improve matters and are recommended, they have the same limitations as all sound attenuating mechanisms; they might not be enough. Avoidance of exterior doors is the best solution when permitted.

A more effective structural solution is to install doors with very high STC ratings. These doors are specially built to greatly improve sound attenuation. Unfortunately, they still are sound attenuating devices. They have several drawbacks. They are very heavy, much more difficult to install and are very expensive compared to normal doors. Further, the wall framing has to be altered to accept the thicker frame and that means adding more gypsum board to match.

The Masking Solution
A vibration masker is added to the secure side of a normal solid core interior door that has gaskets and a floor wiper. The door masker is the same as that used for walls. The door vibration radiates into the door gap as well as from the outer door surface. Vibration protection is provided on the door surface as well as beyond the door. As with wall masking, the sound radiated back into the secure room decreases with distance. As a result, conversations within the room are not impeded. The same concept applies to exterior doors which are most often metal. With sound masking, very high STC doors are not needed.

Protecting Air Ducts

The Threat
Listening through air ducts is a time honored source of eavesdropping since almost all rooms have supply ducts, either round or rectangular, metallic or fiberglass, that connect to a multiplicity of rooms. Local ducts are typically metallic with no sound absorbing materials and therefore are decent speaking tubes. Speech within a room is attenuated as it passes through the grille and duct bend, but after that the decay rate is quite small. Fiberglass ducts transmit much less speech so if there is more than 10 feet between openings they usually are not a concern. For listening purposes, a microphone is inserted into the duct. It is also possible to use a vibration detector placed on the duct wall near a room diffuser for listening purposes. Since the devices are on or within the duct, detection must be by visual inspection or by a search for wires. There are cases where the duct connects to uncontrolled areas where access is easier.

The Standard Solution
Duct mufflers have been the traditional method of solution. They were added at each point where the ducts penetrate the room perimeter. For many secure rooms, this implies a number of mufflers. They are expensive, bulky, and require an adequate plenum height to fit and because of their weight are difficult to install. The worst part is that they have the weaknesses of sound attenuating devices. How much attenuation is needed? Further, they add significant pressure drop to the air handling system which creates additional operating costs.

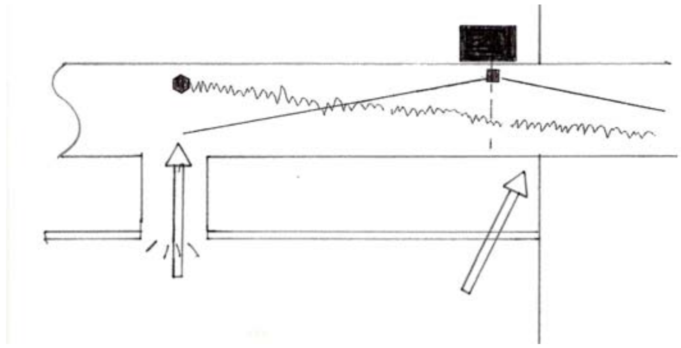

Figure 6-4

The Masking Solution
Speech that enters an air duct decays as it passes down the duct. Figure 6-4 shows a schematic of the two sound levels in the duct; one created by speech in the room and the other created by a vibration masker placed on the duct at the room perimeter. The sound attenuation of the masking into the secure room is so large that occupants are not aware of it. Similarly, the speech transmitted past the masker is completely buried in the masking, so privacy is assured.

Protecting Piping

The Threat
Normal liquid filled pipes do not carry significant speech energy nor does conduit piping filled with wires. Empty conduit pipes in secure room power panels are like speaking tubes on a ship. On some occasions, empty pipes passing through a room can carry some speech energy and should be protected.

The Standard Solution
One solution has been to place vibration breaks at the room perimeter for pipes passing through a room. Empty power panel conduits have rubber plugs inserted on the secure side; they provide adequate protection.

The Masking Solution
Masking is only required if an empty conduit is not plugged or specifications require protection on a liquid filled pipe. A vibration masker is attached to the pipe or conduit at the room perimeter.

Protecting Raised Floors

The Threat
In some facilities a raised access floor is used. Cabling or ventilation air may be supplied to the room under it. Both imply penetrations of the perimeter that must be protected. It is possible for *probe microphones* or *fiber-optic microphones* to be placed in the floor cavity, but because of the high sound attenuation of the floor they would have difficulty detecting speech unless an open grille is located on the floor nearby. *Vibration detectors* may be attached to the underside of a floor plate.

Since these plates are stiff enough to carry the floor load, they act more like a window in that they prefer to respond at speech frequencies, making such detectors effective.

The Standard Solution
If the threat is recognized, a wire mesh grid is placed over each perimeter opening. The only weakness of this solution is that alterations in the cabling often compromise the integrity of the mesh.

The Masking Solution
Loudspeaker maskers are placed under the floor; they serve two functions. Placing them near penetrations provides protection against listening devices there. Placing them uniformly under the floor, as is done in commercial facilities, provides speech privacy within the room itself as well as protection from any listening devices in the floor.

Protecting Plenum Ceilings

The Threat
Secure rooms often have a suspended ceiling with a plenum above to accommodate air ducts and cable runs. The walls defining the room may extend to the structural ceiling to create a closed plenum, or they may not to create a continuous open plenum. The plenum space is normally used for non-ducted return air. If the room has walls to the structural ceiling, there must be an opening in the wall above the ceiling to permit the air to return to the fan and it is normally not in view for inspection. Cable trays often penetrate the walls creating the same weakness. If the walls extend only to the suspended ceiling, the plenum is accessible to all other rooms. In each of the above situations, listening devices, such as microphones, can be placed in the plenum.

The Standard Solution
For return air penetrations in structure high walls, duct mufflers have been added. Again, they suffer the weaknesses of sound attenuating devices. Another exceedingly ineffective solution has been to lay fiberglass batts on the suspended ceiling. Cable trays have been either ignored or each cable has been individually sealed at the wall penetration, adding expense.

The Masking Solution
For structure high walls with a return air opening, a stub duct is added and a duct masker attached. For walls with cable tray penetrations, a loudspeaker masker is placed in the plenum just inside the opening. For open plenum spaces, loudspeaker maskers are distributed above the suspended ceiling throughout the secure room. One additional benefit, not normally contemplated, is that such masking provides speech privacy between individuals *within* the room. The levels within the room are set as with commercial facilities without compromising the protection afforded in the plenum.

Protecting Internal Loudspeakers

The Threat
Many building codes require the presence of speakers in a secure room for emergency announcements. Although speakers are intended for creating sound, the speaker also responds to external sound as a poor microphone. With proper detection, the voltage generated in the wire can be converted to speech.

The Standard Solution
An optical isolator is attached on the wire to the speaker inside the source room. It is an electrical diode; it permits a signal to go to the speaker, but prevents any signal to pass back from the speaker. This is the recommended solution; and such devices are commercially available.

The Masking Solution
If an optical isolator is not available, a masker can be placed next to the speaker. The required levels are sufficiently low as not to cause distraction within the secure room or interfere with the sound from the speaker.

Protecting Computer Keyboards

The Threat
A method has been developed to analyze the sound spectrum of computer keyboard strokes and thereby determine the characters that have been struck. Most modern keyboards are reasonably quiet, so sensing cannot be distant. Microphones embedded in local equipment, keyboard, or desk, mounted vibration detectors are potential sensing devices.

The Standard Solution
None is known.

Masking Solution
A vibration masker applied to the underside of the keyboard, with the proper spectrum, masks all spectral components of the keystrokes both with regard to keyboard vibration or the sound radiated. The user is not disturbed by the low level of the masking.

Special Generators Required

Stationary Random Noise
Generators that create this type of random noise are commonly available commercially and are used for normal sound masking systems. Special signal processing methods make use of the unchanging statistics of the noise to eliminate it and so recover an speech buried in it. These generators are less expensive and are used in controlled areas where the likelihood of signal processing is remote.

Non-Stationary Random Noise
These generators create a masking signal that changes its statistical characteristics from second-to-second to inhibit recovery of speech buried in the masking. These generators are more expensive and are used in uncontrolled areas where the use of signal processing is likely.

Special Speakers Required

Loudspeaker Maskers
These maskers are used in commercial applications. Their application to secure facilities is for ceiling plenum masking, under floor masking, or as window/wall washers. No modifications to them are required for these applications.

Vibration Maskers
These maskers are attached to surfaces and vibrate the surface to which they are attached. An example of the vibration masker that is attached to windows, doors, walls, or rectangular ducts, is shown in Figure 6-5. It is relatively small and neutrally colored to minimize visibility on windows.

Figure 6-5

Appendix: A Primer on Sound Masking

Sound masking is generally unfamiliar to office designers and facility managers. This appendix describes and discusses the value and limitations of it for both open and closed offices.

What is masking and what does it do?

Masking is merely the covering up, or disguising, of something. That something is not changed, but simply hidden. Physical masks cover the face of the wearer. Deodorants mask odors; they do not eliminate them. One-way windows mask the persons on the other side so they are not visible. Sound can mask other sounds to cover them up. In every case, the objective is to hide something that exists.

Many people have heard of noise cancellation, but incorrectly believe that it is a form of sound masking. In noise cancellation, the sound to be eliminated is sensed by a microphone, reversed, and then added back to the sound so that it is removed. Unfortunately, this technique works only within spatially constrained areas, such as headphones, so it is not applicable to entire rooms.

When unwanted sounds are covered up, the listener is less distracted. This results in more satisfaction with one's environment and permits the person to be more productive. Sound masking can provide speech confidentiality in situations where otherwise it cannot be obtained without inordinate expense.

Distraction is caused by transient sounds that are sufficiently higher than the steady background to attract the inadvertent listener's attention. The higher the level of that transient sound above the background, and the more information contained in that sound, the greater is the disturbance. The standard way to reduce these distractions has been to add sound attenuating materials that reduce the unwanted sounds to the point where they do not protrude above the existing background. A newer way to reduce distractions is to increase the existing background level to complement the existing sound attenuation. This idea took a long time to take root, but it has been found to be not only cost effective, but also much more versatile than the standard way.

The primary function of masking, whether done structurally with sound attenuating materials or active background level control, is to reduce the range of fluctuations in sound level.

For every situation there is an optimum background sound level, just as there is an optimum lighting level. In the home that sound level is low, and at sporting events that level is high. Therefore, we can consider the function of sound masking to be bringing the background level *up* to the optimum. If the background is already above the optimum, sound reduction materials must be applied, not sound masking. A classic example is a noisy restaurant, where the background sound level is already above the optimum level and the listeners have difficulty understanding others at their own table.

What is in a Name?

The equipment and technology of ***active*** masking has been known by several names. By active we refer to background sound that is under the control of the user for privacy purposes, not the background sound that is generated by air handling systems for temperature control and no directly under the control of the user. The term ***sound masking*** is now most widely used to describe this technology. The term ***noise masking*** is sometimes used to help imply that masking blocks your unwanted sound or noise. Some practitioners avoid this term because of its negative connotation. However, these terms and their word order are best at describing what masking does. The terms ***white noise*** and ***speech privacy system*** are also used but are less accurate. White noise is a purely theoretical concept where there is equal energy at every frequency; there is no relationship whatsoever between true white noise and any useful or acceptable sound masking spectrum. The term speech privacy system is descriptive of its use, but gives a potential user the impression that masking can be applied *only* to speech. Speech is the major reason for applying sound masking, but not the only one.

Quiet vs. Privacy

When people are annoyed by the activity sounds around them (noise), they futilely search for "quiet.” By common definition, noise is the presence of unwanted sound, so "quiet" is considered the absence of noise. The word "unwanted" implies a subjective human response. Not everyone will agree that a given sound is, or is not, noise. Most people think of noise as a distracting or interfering sound, which usually causes annoyance and complaints. Most people believe that "quiet" is a desirable condition of low background sound level, but what they are really searching for is the freedom from the acoustical distractions that ultimately cause annoyance. Those distractions are caused by unwanted *transient* sounds, such as speech, that rise above the background level and are noticeable. Thus, a better definition of "quiet" is the absence of those distracting sounds, not an absence of all sound. The only way to achieve the former definition of "quiet" is to maintain a low background sound level with *no* transient sounds; a condition that requires complete isolation from all activity sounds.

There are three ways to reduce the magnitude of transient sounds. First, one may use the age-old technique, once employed by librarians, of simply asking persons not to talk. Administrative controls, such as these, are generally ineffective. The second way is to physically isolate people from sources of sound by putting them behind sound attenuating structures, such as enclosed offices. One favorite method is to add materials that are highly sound absorbing. Unfortunately, these materials cannot decipher "wanted" from "unwanted" sounds so the distraction merely occurs at a lower level. This is not to imply that sound absorbing materials are ineffective, but rather that they may not be sufficient by themselves. Another method is to increase the amount of materials between the listener and the source of the sound, to block transmission of the transient sounds. Both methods can be expensive and may, or may not, be adequate to achieve the desired freedom from distraction. The third way is to alter the background sound level so that the transient sounds do not penetrate significantly above the ambient level at the listener. Persons not familiar with this method ask "How can you make it ‘quiet’ by adding noise?" Hopefully, this document will convince the reader that, if done properly, adding sound masking will make it possible to achieve the new definition of "quiet." By implementing this technique, it is possible to achieve a level of background sound that is socially acceptable. Low levels are required for bedrooms, yet when most people are questioned about aircraft flights, they do not object to the level of "noise" despite the fact that the sound energy is thousands of times greater than that in a typical masked office. Acceptance depends on the context.

The Evolution of Sound Masking

It is very likely that primitive people never camped near a rushing stream. They understood that the stream noise could mask the approach of enemies or predators. The fountains in Roman villas may have served a useful purpose in blocking out the sound of iron-rimmed chariot wheels on the cobble-stoned streets. The sound of water is still used as sound masking; visit shopping malls or buildings that have a large atrium. Water is too expensive and impractical, among other factors, to be used as a universal masking tool so electrical means of sound masking were developed. There is evidence that, after World War II, a dentist in New York used earphones with broadband random noise to cover up the sound of his drills. Shopping catalogs carry advertisements for small masking devices for home use. The serious development of commercial sound masking began with the introduction of the open plan office by a design firm from Germany in the 1960s. The General Services Administration, Public Buildings Service, published documents (PBS-C.1 and PBS-C.2) in the early 1970s on open office acoustics. They developed a rating called Speech Privacy Potential and Interzone Attenuation. Central to these documents was the use of sound masking. Since that time, the use of sound masking has increased. The American Society for Testing and Materials (ASTM) and the Acoustical Society of America (ASA) have developed several standards that address office acoustics and sound masking establishing the correct way to use sound masking. Currently, there are a number of manufacturers of sound masking equipment and it is used worldwide.

The Major Reason for Developing Sound Masking

As many American office product manufacturers switched to making furniture panel systems (cubicles), the open office grew rapidly, as did the loss of speech privacy that employees had been accustomed to in closed offices. Office workers have clearly expressed this problem in office surveys:

> *"The ability to concentrate without noise and other distractions rates FIRST among office workers as the one functional characteristic of an office that is most important in helping them to get their jobs done well."*

> *"Most office workers give their offices low scores on the ability to concentrate without noise and other distractions and on conversational privacy."*

> *"The implications for office planners and designers here are very straightforward: no matter what kind of office is being planned, a great deal of attention has to be paid to the issue of limiting noise and other distractions in the office."*

> *"Cutting down on the amount of noise and distraction is considered likely to be implemented by 73% of the business executives interviewed in 1978."*
> *(Steelcase/Harris Survey 1978)*

A later survey showed:

> *"The other element of discomfort to which office workers are powerfully attuned is the unmet need for a place to work when they need to concentrate without distractions. As was found in the first study, the need for quiet and privacy is a deeply felt one, and one that many office workers feel is unfilled. Confirmed in this study is the fact that not only is it felt that this affects productivity, but it is a cause for complaints about physical discomfort and inhibits job performance."*
> *"49% of the office workers say they do not have quiet in their office."*
> (Steelcase/Harris Survey 1980)

Many later surveys have shown the same result, namely that about 75% of office employees had complaints about privacy. These complaints drove the audio industry to develop sound masking equipment to improve the privacy between individuals in open offices. Unfortunately, owners have been slow to adopt sound masking as a privacy tool, as they are generally unfamiliar it.

The Reputation of Sound Masking

As with all change, denial is the first response. Sound masking has suffered the same rejection (and with some justification). When the first open offices were developed in the late 1960s, only freestanding panels were used. The employees realized that adding plants, although nice to look at, did not provide any improvement in speech privacy. Designers searched for a quick and inexpensive solution: sound masking. After it was found that too much added sound was needed to overcome the privacy deficiencies, it was concluded that masking was an excuse for a poorly designed job. An unwarranted extrapolation was: *any* job that needed masking was a poorly designed job.

With the evolution of excellent panel systems by major manufacturers, that assumption has changed. Control of projects by experienced interior designers, acoustical consultants and other specialists, development of quality sound masking equipment, scientific research, and standards have caused the change.   Use and acceptance has grown enormously since 1972.