acoustical CEILINGS

use & practice

CISCA

the power of partnership

NOTICE

This booklet is a guide to the selection and installation of acoustical ceilings. For more information, consult your local CISCA member. By publishing this guide, CISCA and its member companies make no express or implied warranty or other representation as to the quality, characteristics, or suitability of the materials or techniques described herein and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose which may arise by operation of law or otherwise.

TABLE OF CONTENTS

Authorized and published under the direction of the
Ceilings & Interior Systems Construction Association, St. Charles, Illinois.

CISCA
the power of partnership

To order additional copies of this booklet contact:
CISCA, 1500 Lincoln Highway Suite 202, St. Charles, IL 60174.
Or call 630-584-1919; fax 630-584-2003. Order on the web at www.cisca.org.
Quantity discounts available, inquire to CISCA office.

Purpose of the publication

This manual is published by the Ceilings & Interior Systems Construction Association (CISCA), 1500 Lincoln Highway Suite 202, St. Charles, IL 60174, an international association of major acoustical and specialty contractors who sell and install ceiling systems. Manufacturers and suppliers of these materials and systems are associate members of CISCA.

CISCA serves as a central source for information on commercial acoustical ceiling materials for specifiers, users, and other interested organizations.

The use of acoustical materials to form the interior finished surfaces of rooms has become a standard concept in present day architecture. Although its primary function is to control sound either by absorbing sound, or by acting as a sound barrier, a modern acoustical material is designed to meet other practical requirements of room surfaces. Among these properties, which may vary in relative importance in different types of rooms, are appearance, light reflectance, resistance to flame spread and fire penetration, durability, and maintainability. Consequently, acoustical materials and structures are now available in many different forms suited to the particular architectural requirements of the various types of rooms in which they are used.

It is the purpose of this publication to discuss the basic properties common to all acoustical ceiling materials, to describe the tests used, to explain the terminology, and to suggest how these properties can best be utilized.

It is further intended that this publication can be used to define proper material handling and storage at the jobsite, to make installation recommendations, and set job installation standards.

3.0 Basic Properties of Sound

The sound which one hears in any room, whether it is an auditorium, a classroom, an office, or a hospital corridor, consists of two parts: (1) direct sound, the sound which travels directly to the ear from the point where it originates, and (2) indirect sound, the sound which reaches the ear after being reflected one or more times from the room surfaces or transmitted from one room to another. When sound strikes the surface of any material, a part of its energy is absorbed, part is transmitted, and the remainder is reflected back into the room, Figure 1. Ordinary hard interior finish surfaces, such as drywall, plaster, concrete, and glass, absorb very little sound. Acoustical materials, however, are designed to absorb a proportion of the incident sound energy. The function of an acoustical material within a room, therefore, is to reduce the reflected part of the sound which we hear.

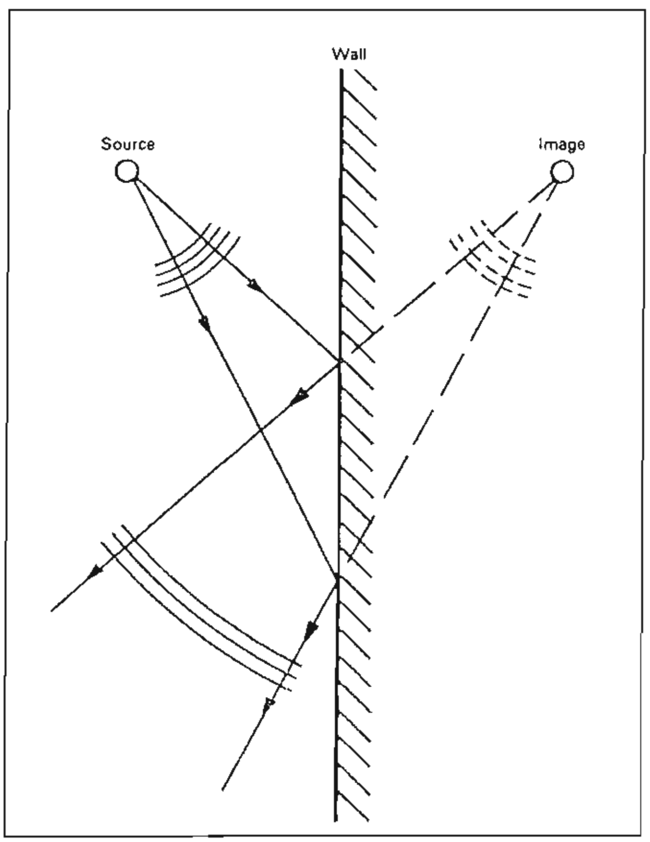


Figure 1. Reflection of Sound from a Plane Surface

The degree of acoustical control required in a given room depends essentially on the use of the room. For example, it is desirable to be able to understand speech clearly throughout a classroom or to listen to music under the most pleasing acoustical conditions in an auditorium. In such rooms, acoustical materials are incorporated with the room design in such a way that useful sound reflections are retained and undesirable ones minimized. On the other hand, the sound one hears in an office, a restaurant, a school corridor, a bowling alley, or a factory, can be classified almost entirely (except for conversation at close range) as undesirable noise. This noise can be distracting and annoying, and may often seriously interfere with communication, comfort, and work effectiveness. In such rooms, acoustical materials are used to remove as much reflected sound as is practical, thereby creating a more comfortable acoustical environment.

In this section, Sound Control Design Considerations will be outlined, together with the criteria which govern the degree of control required for satisfactory acoustical results in various types of rooms.

3.1 Sound Generation

The action of sound waves in a room may be described by analyzing what happens in a typical auditorium seating, for example, 1,000 persons. A vocalist is on the stage producing, at the moment, a single sustained tone. The vibration of his vocal chords generates sound waves, which travel through the air in the form of very small changes in pressure that alternate above and below static atmospheric pressure as shown in Figure 2. The average deviation in atmospheric pressure above or below the static atmospheric value, due to a sound wave, is called the sound pressure.*

	Decibels	Threshold of Feeling
	120	
Deafening	110	Thunder, Artillery Nearby Riveter Elevated Train Boiler Factory
	100	
Very Loud	90	Loud Street Noise Noisy Factory Truck Unmuffled Police Whistle
	80	
Loud	70	Noisy Office Average Street Noise Average Radio Average Factory
	60	
Moderate	50	Noisy Home Average Office Average Conversation Quiet Radio
	40	
Faint	30	Quiet Home or Private Office Average Auditorium Quiet Conversation
	20	
Very Faint	10	Rustle of Leaves Whisper Sound Proof Room Threshold of Audibility
	0	

Figure 2. Sound Pressure Levels of Common Sounds and Noises.

In architectural acoustics, we need to identify both the quantity and quality of the sound that will be heard. Placing a numerical value on the quantity of sound is difficult because of the tremendous sensitivity of the ear, which can detect pressure alterations over a range of a million to one.

In order to measure and calculate this vast range of audible sound, a compact scale is used. In acoustics, the sound pressure level is measured in dB, which is decibels, or a logarithmic unit of measurement. Zero on the decibel scale corresponds to a standard reference pressure ($2x10^{-5}$Pa) which represents the minimum sound that we can hear, Figure 3.

Sound pressure, by vibrating the ear drum, produces the sensation of hearing and essentially determines the loudness of the sound as judged by the listener.

*More precise technical definitions and explanations of some of the terms used in the discussion are given in the Glossary of Acoustical Terms.

The sound waves travel outward from the vocalist's mouth in all directions in much the same manner that water waves spread outward on the surface of a pool from the point at which a stone is dropped. As the sound wave progresses, the sound pressure diminishes in proportion to the distance from the source, in the same manner that the wave dies out as it spreads. Since sound pressure determines loudness, this effect explains the familiar experience of a sound outdoors, and to a lesser degree indoors, becoming fainter as one moves away from the source.

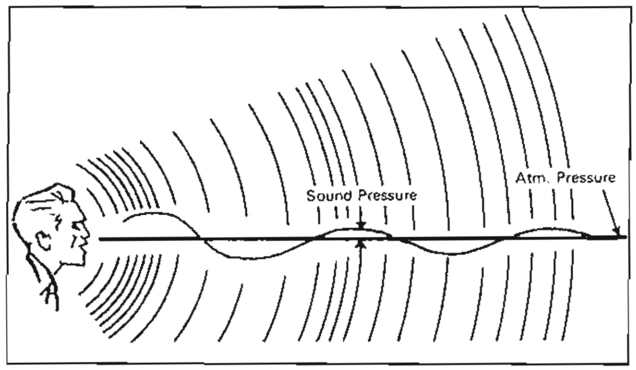


Figure 3. Generation of Sound Waves.

In addition to pressure, sound waves have the important quality of pitch or frequency. Frequency is defined as the number of times per second that the sound pressure alternates above and below the static atmospheric pressure. Each complete alternation is called a cycle, and frequency is expressed in Hertz (Hz), denoting the number of cycles per second.

The frequency of the vocalist's note is determined by the rate of vibration of his vocal cords, and the changes in frequency from one tone to another are perceived by the ear as corresponding changes in pitch of the musical notes. The higher the frequency, the higher is the pitch.

The extreme range of frequencies which the ear can perceive is approximately 20 to 20,000 Hz although the upper limit decreases considerably with advancing age. The performances of acoustical materials varies with frequency, as do the loudness response of the ear and the performance of microphones and loudspeakers.

Sound waves travel through the air at a constant speed of approximately 1,120 feet per second (at room temperature), or a little over a mile in 5 seconds. The speed of sound travel is commonly observed as the time lag between lightning and thunder, or as the delay in hearing an echo from a distant cliff or wall. If our auditorium is 100 feet long, it will take about 1/10 second for the direct sound to reach the back row from the stage.

3.2 Direct Sound

Since sound travels more or less in all direction from the sources, the sound waves originating at the vocalist's mouth will strike the ears of every member in the audience. Each listener will therefore, hear the segment of the sound wave which travels in a direct line from the source to his ear.

This is termed direct sound, and the loudness as heard by the listener will be determined largely by how loudly the vocalist happens to be singing and by the distance from the source to that listener. For a given sound output, the sound pressure level of the direct sound (no reflection) decreases by about 6 dB each time the distance between the measured points is doubled as illustrated in Figure 4. This shows that close to the source the direct sound level rises rapidly as you move closer to the source, but farther away from the source a small change in distance has relatively little effect.

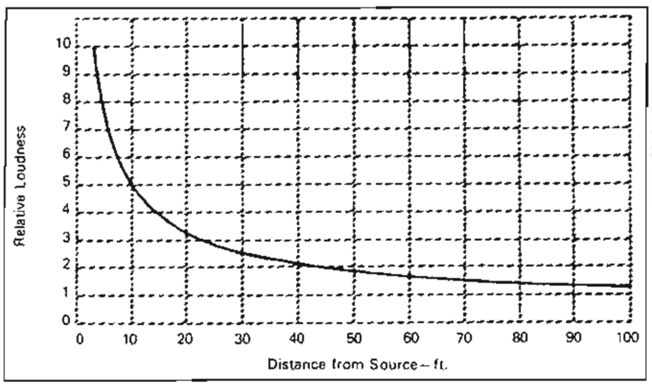


Figure 4. Relationship of Sound Level to Distance from Source for Direct Sound, with No Reflection

3.3 Reflected Sound

The sound originating on the stage travels not only to the ears of the audience but also to the interior surfaces of the auditorium. When a sound wave strikes a surface, its direction of travel is changed by reflection in the same manner as that of a ball bounced from a hard surface.

In addition to the direct sound, a listener will receive segments of the original sound wave which have been reflected at least once before reaching his ears. Several of the many possible reflected paths are illustrated in Figure 5.

The loudness of the sound arriving at the listener's ear by any reflected path will usually be less than that of the direct sound for two reasons: (1) the reflected path is always longer than the direct path, resulting in a greater reduction on loudness due to distance; (2) all reflected sound loses some of its energy at each reflection.

If reflective concave surfaces are present, it is possible to have a situation where the reflected sound could be louder than direct sound at localized positions in the space.

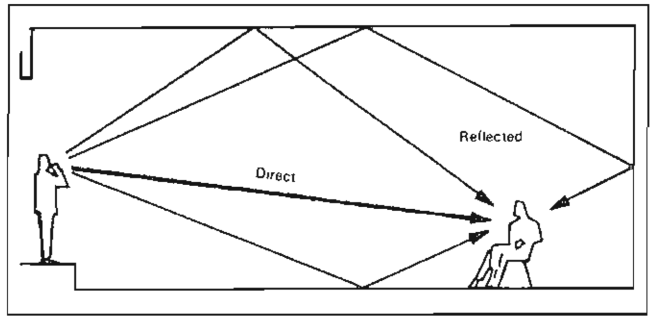


Figure 5. Direct and Reflected Sound in a Room.

As long as the vocalist sustains his note, however, the listener hears not only the direct sound, but the sound which reaches his ear by all possible reflection paths. The combination of all of the reflected components with direct sound at the listener's ear results in a total sound which is always louder that the direct sound alone at the distance under consideration. How much louder depends on the size of the room, the distance of the listener from the stage, and on the absorbing properties of the room surfaces.

3.4 Absorption of Sound

A sound wave reflected by a surface always loses part of its energy. This loss of energy is termed sound absorption and appears as a decrease in the sound pressure of the reflected wave with respect to that of the incident wave.

The speed of travel, being constant for all sound waves, is not affected. The fraction of the energy of the incident sound which is not reflected is called the sound absorption coefficient of the reflecting surface. Hard, massive, non-porous interior finish surfaces, such as drywall, plaster, masonry, glass, wood concrete, etc., absorb generally less than 5 percent of the energy of incident sound waves and reflect 95 percent or more. Such materials, therefore, have absorption coefficients of less than 0.05. Porous materials which permit penetration of sound waves, or soft materials which yield under incident sound pressure, are capable of absorbing much larger amounts of sound energy and may have coefficients approaching 1.00. Acoustical materials include carpets, draperies, upholstered seats and furniture, the clothing of an audience, and acoustical products such as ceiling and wall panels. The absorption coefficients of materials vary with the frequency of the incident sound and for most common materials are less at lower frequencies.

3.5 Room Absorption

As the various components of reflected sound reach the listener's ear, as shown in Figure 5, they will have lost energy in varying amounts depending on the total distance they have traveled between reflections, on the number of times they have been reflected, and on the absorption coefficients of the different surfaces encountered.

The combined effects of absorption by the various room surfaces and the distance of sound travel between reflections on the loudness of the total reflected sound can be stated very simply in terms of a single quantity termed room absorption.

This quantity is obtained by multiplying the area in square feet of each room surface by its absorption coefficient, taking the sum of these products, and adding the absorption supplied by individual objects such as seats, furnishings, and persons. The room absorption is usually determined at all frequencies of interest.

The absorption of a given surface, or of an entire room, is given in units called sabins. One sabin is the equivalent of one square foot of surface area having an absorption coefficient of 1.00. For example, an area of 100 sq. ft. of a surface having an absorption coefficient of 0.80 would furnish an absorption of 80 sabins.

The absorption of objects is usually stated as a certain number of sabins per object. An upholstered theater seat can have an absorption of 3.0 sabins. In large rooms and at high frequencies, an appreciable amount of sound energy is absorbed by the air itself. The contribution of the air absorption should therefore be included in the total room absorption. Air absorption is usually stated in sabins per 1,000 ft.^{3} of room volume.

3.6 Reverberation

When the vocalist cuts off his note, the sound at the source will end immediately. The time delay in the ending of the direct sound from this note at the listener's position will be a function of the distance between the vocalist and the listener.

However, the sound waves which are already in the room will continue to travel back and forth between room surfaces, and a listener will hear them as a continuation, or echo, of the sound after it has stopped at the source. The sound waves lose energy by absorption at each successive reflection, and since this energy is no longer supplied by the source, the sound will die out gradually.

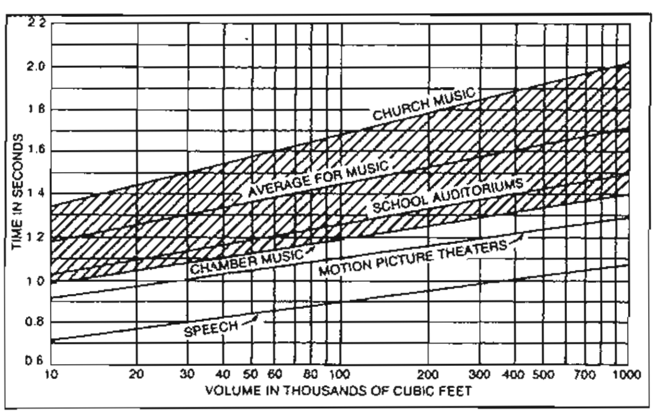


Figure 6. Recommended Optimum reverberation Times for Various Room Uses. (Reproduced with permission from *Acoustical Designing in Architecture*, V.O. Knudsen and C.M. Harris, American Institute of Physics, Paperback Edition, 1980. Copyright 1950, 1978, Acoustical Society of America.)

This prolongation of the sound after the source has stopped, due to continued multiple reflection, is termed reverberation. If sound dies out very slowly, a room is described as "live" or "excessively reverberant" and if it dies out very rapidly, a room is called "dead".

Reverberation is an important factor governing hearing conditions and it has an important bearing on the "noisiness" of working areas.

Of special importance is its effect on the understanding of speech. If sound ides out very slowly in an auditorium used for speaking, the prolongation of each speech sound causes an overlapping and confusion of intelligibility extremely difficult or impossible. In rooms where quiet surroundings are desired, reverberation is annoying because it prolongs distracting noises.

3.7 Reverberation Time

The amount of reverberation in a room is measured by its reverberation time. This is defined as the number of seconds required for the energy of the reverberant sound in the room to decay 60 dB.

The reverberation time is a basic acoustical property of a room which depends only on its dimensions and the absorbing properties of its surfaces and contents. In a typical room with normal acoustical treatment, the reverberation time is essentially the same throughout the room, regardless of the position of either the source or the listener; however, for unusual room designs this may not be true.

The reverberation time as just defined corresponds roughly to the number of seconds which a sound of "average" initial loudness can be heard by a person with normal hearing activity before it dies out to inaudibility under completely quiet conditions. This may vary typically from a fraction of a second in a very dead room to the order of 5 to 10 seconds in a very live room. Unfortunately in real life situations, most sounds are not of "average" initial loudness, and the background is never completely quiet. Therefore, it is difficult to roughly estimate reverberation time of a space by a subjective observation.

The reverberation time of a room, like the reflected sound energy, varies inversely with the room absorption. However, reverberation time also varies directly with the volume and geometry of the room, being in general longer in large rooms and rooms with oblique angled surfaces. This follows from the fact that in a large room, sound on the average travels farther between room surfaces, and therefore reflections and the accompanying absorption occur less frequently. Other complications occur in real life. Room shape can also enter into the picture. Long hallways or large rooms with low ceilings have grossly different reflection patterns than spaces that are more nearly cubic in shape.

3.8 Sound Transmission

Many familiar problems of room acoustics are encountered when sound or noise is transmitted from sources in adjoining rooms or corridors through walls, floors, and ceilings. The most common complaint is due to excessive sound transmission and the resulting lack of speech privacy or transmission of unwanted sound.

It is often desirable to know what sound level will occur in the receiving room due to the presence of a sound or noise in the source room. The difference in average sound pressure level between the two rooms is termed the noise reduction.

If the noise reduction between two rooms is 50 dB, the transmitted sound will always be 50 dB lower than that in the source room. The amount of noise reduction required for a particular design will depend both on the expected source room levels and the ambient sound pressure level in the receiving room. A reduction in level below the receiving room ambient level is unnecessary.

The noise reduction between rooms depends on several factors: namely, (1) room absorption, (2) transmission loss of each path, and (3) frequency.

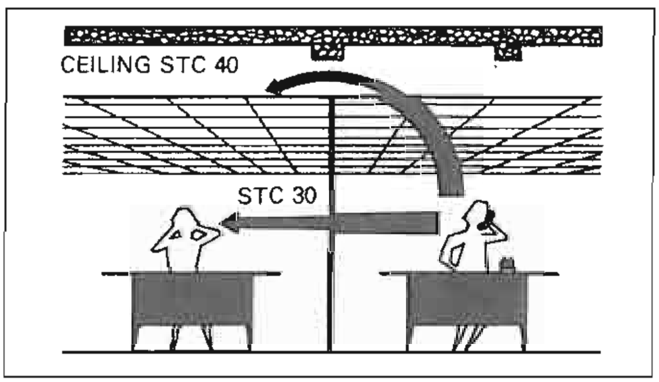


Figure 7. The Rating Methods Now in General Use is the Sound Transmission Class (STC) For Walls and Ceiling Attenuation Class (CAC) for Ceilings.

3.8.1 Room Absorption

The various surfaces or openings which transmit sound into the receiving room may be considered as secondary sources having a total sound power output, which is determined by the sound pressure level in the source room and by the transmitting properties of each surface or opening.

For a given total power output from the transmitting surfaces, the sound pressure level in the receiving room will depend to a measurable degree on the receiving room absorption. The greater the receiving room absorption, the lower will be the sound pressure level in the receiving room, and therefore the higher will be the noise reduction between the rooms.

The effect of an increase in receiving room absorption on the noise reduction is computed in the same manner as for the case where a sound source is wholly contained in the room.

As a general rule, to reduce the sound pressure level in the receiving room to as low a value as possible for a given source in the source room, it is desirable to provide as much absorption as feasible in both the source and receiving rooms in addition to providing walls, floors, and ceilings which are effective noise barriers.

3.8.2 Transmission Loss

Sound may be transmitted by several paths between rooms, but the simplest practical case is that in which the only path is a dividing partition having no opening or sound leaks. The transmission loss of a partition having no openings or sound leaks at joints or boundaries is essentially a basic property determined only by the materials and construction of the partition. The transmission loss does, however, vary with frequency in a manner depending also on the construction of the partition. In general, the transmission loss tends to increase with frequency. Sound transmitting surfaces become sound sources within the receiving room. Usual sound transmitters can be walls, floors, or ceilings. In addition, actual openings in the interior room boundaries such as the crack around a door, a hole in the wall around pipes or utilities, or a connecting ventilating duct, can also act as pathways for sound.

Solid, air-impervious room surfaces transmit sound by being set into flexural vibration. When this vibration is caused by the pressure of sound waves striking the other side of the wall in the source room, the sound transmission is referred to as airborne. This is the type of transmission due to voices or loudspeakers, and the air provides the only coupling between the sound source and the structure.

Vibration of the receiving room surfaces may also be caused by direct mechanical coupling of a source of vibration to some point in the building structure. This is termed structure-borne transmission. The most common examples are the impact of footsteps on a hard floor and the transmission of vibration from a machine such as a motor or compressor, which is in direct contact with the building structure. In this case, there is a direct physical connection between the noise generator and the structural element of the building.

Of course, openings between a source and receiving room transmit sound waves directly, without the intermediate mechanism of flexural vibration.

Even a material which is porous rather than air-impervious, such as an unpainted lightweight concrete block partition, will transmit sound directly through the pore structure.

At the same time, as noted above, the incident sound pressure will tend to vibrate the partition as a whole, resulting in some sound transmission by this means. The overall transmission will be governed largely by the path which transmits the most sound energy.

These considerations also apply directly to acoustical materials when they are used as the suspended ceilings of two rooms having a connecting plenum. In this case, sound which reaches the receiving room from the source room by way of the common plenum is transmitted twice through the acoustical ceilings; thus the plenum may be thought of as an intermediate or secondary source room.

3.8.3 Frequency

As with sound absorption, the noise reduction provided by a building system is a function of the frequency of the sound involved. Therefore, computations of noise reductions are usually carried out over the range of frequencies of interest. Bandwidths of one-third octave with the following center frequencies are commonly used for sound transmission measurement and computations: 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000 Hz.

In order to predict accurately the ability of a structure or system to meet the demands of a particular noise control problem related to sound transmission noise, it is necessary to compare its curve of transmission loss vs. frequency with the curve showing the frequency distribution of the particular noise existing on the source side. For example, if the original noise is of predominantly high frequency, then the construction should have its highest transmission loss in the same frequency region. It is desirable, however, to have a means for describing by a single number rating the performance of a construction when exposed to an "average"noise since, in many applications, the exact nature of the noise source is not specified.

The rating methods in general use for walls is the sound transmission class (STC). This rating is obtained from a knowledge of the sound transmission loss in each of the 16 frequency bands and the fitting of a standard STC contour (see ASTM procedure E 413) to these sound transmission loss data. The shape of this contour has been drawn to represent the performance of the average acceptable partition, and generally covers the requirements for speech privacy.

4.0 Basic Properties of Acoustical Ceiling Materials

In this section the basic properties of sound absorption, sound attenuation, light reflectance, flame spread, fire resistance, appearance, and maintenance for acoustical materials will be reviewed. A review of open plan acoustics is also offered.

This discussion includes a definition of each physical property, a description of the test method used to measure each property, and the performance considerations or limitations that apply in the practical use of these materials.

4.1 Sound Absorption

The primary function of an acoustical ceiling is to absorb sound and to resist transmission of sound. A material with a noise reduction coefficient of .50 or greater is normally considered to offer significant sound absorbing properties. The degree to which a material contributes to a room's acoustics depends to some degree on the room's absorption before the material was installed. The installation of an acoustical ceiling system would have more effect on a "hard" room than on a "soft" room.

The manufacturers' catalogues list coefficients for six frequencies: 125, 250, 500, 1000, 2000, and 4000 hertz (Hz). The "Noise Reduction Coefficient" (NRC) of an acoustical material is defined as the average, to the nearest multiple of 0.05, of its absorption coefficients at the four one-third octave bands with center frequencies of 250, 500, 1000, and 2000 Hz.

Sound Absorption Test Method

The sound absorption coefficients of materials are determined by ASTM test method C43, "Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method." Coefficients for individual one-third octave bands at octave intervals from 125 to 4000 hertz (Hz) are given in many manufacturers' literature. For average noise reduction treatments, the NRC values of materials adequately indicate their general effectiveness.

Performance Considerations

It has long been recognized that minor differences in the noise reduction coefficient value are generally not significant since the average listener will be unable to detect the difference in an acoustical environment which differs by just a few points in the ceiling coefficient.

The exceptions to this general rule of thumb occur in specific considerations: 1) where the noise generated within the area consists principally of a narrow range of sound frequencies (in such instances, the selection of acoustical material should be based on

E 795

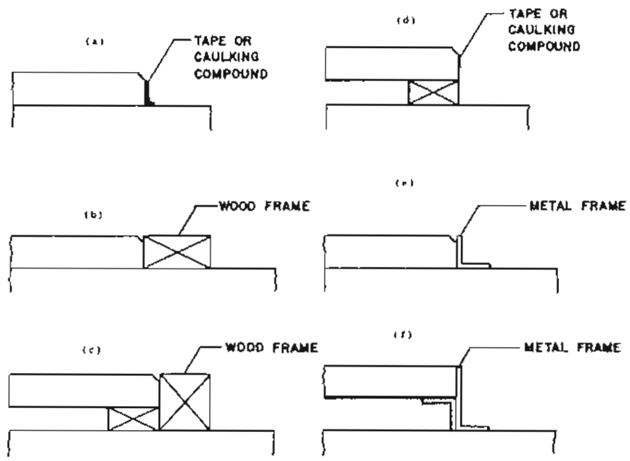
TABLE 1 Relationship Between ABPMA Mounting Numbers and Mounting Types Specified in These Practices

ABPMA Designation Mounting No.[A]	Present Designation Mounting Type
1	B
2	D-20
4	A
5	C-20
6	F-25
7	E-405
8	C-40
X-00[B]	E-###[C]

[A] Designations assigned by the Acoustical and Board Products Manufacturers Association

[B] The "00" in the X-00 designation should be replaced by the distance from the face of the test specimen to the test surface in inches

[C] The "###" in the E-### designation should be replaced by the distance from the face of the test specimen to the test surface rounded to the nearest integral multiple of 5 mm



(a) Tape or caulking compound used to seal a Type A or Type B mounting
(b) Wood frame used to seal a Type A or Type B mounting
(c) Wood frame used to seal a Type D mounting
(d) Tape or caulking compound used to seal a Type D mounting
(e) Metal angle frame used to seal a Type A or Type B mounting
(f) Metal angle frame used to seal a Type F-25 mounting

Typical Edge Seals

E 795

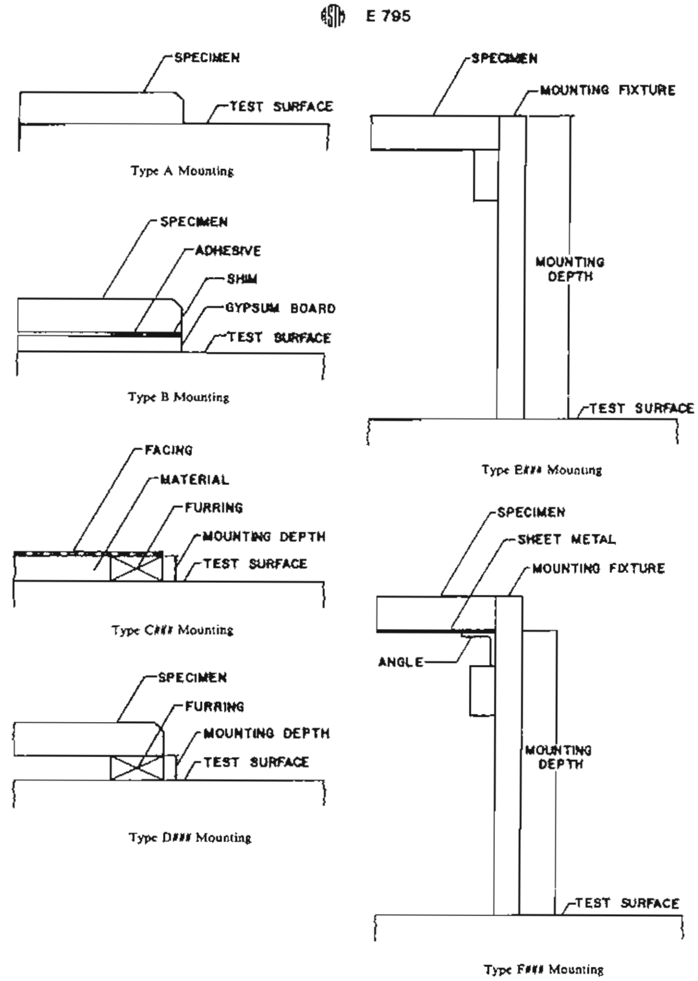


Figure 8. Standard Mountings for Sound Absorption Tests

the specific absorptive quality listed under the frequencies at which these sound occur), and 2) in central listening areas such as concert auditoriums, where the full spectrum of absorption must be known to choose the right mix of finishes to obtain the desired acoustical balance in the space.

In theory, the maximum sound absorption that can be provided by a continuous surface of acoustical material is an absorption coefficient of 1.00. This occurs when none of the sound waves which strike a surface are reflected. Sound absorption coefficients exceeding 1.00 will at times be seen in the literature. This can result from the diffraction effects at the edges of test samples which are usually limited to areas of 72 square feet or less.

All surfaces and finishes of a room which absorb sound must be taken into consideration in determining the sound absorption characteristics of the room. The hard, non-porous interior finish surfaces—such as drywall, plaster, masonry, glass, wood or concrete—are poor because they absorb less than 20% of the energy of the incident sound waves. On the other hand, porous materials which permit penetration of sound waves or materials which yield under incident sound pressure can absorb larger amounts of sound energy. Drapes, upholstered seats, carpets and furniture, the clothing of an audience, and people themselves provide some sound absorption.

The types of mounting used in the sound absorption tests as illustrated in Figure 8 are typical of actual installation methods used in the field. These mountings are described in ASTM Practices E795.

Sound absorption values of most materials vary with the method of mounting. With suspended ceilings, typified by the Type E 400, sound absorption values vary with the depth of air space behind the acoustical material.

Tests at a 16" mounting depth (E 400) have been found to provide sound absorption coefficients which are representative of the performance attained for plenum depths of 16" as found in common building construction. This mounting depth is the generally used spacing when conducting tests on suspended ceilings for Type # 400 listings.

Unit Acoustical Absorbers

Unit acoustical absorbers are elements of acoustical material which differ from surface-type acoustical materials only in shape, configuration, and/or distribution during use. Specifically, the unit absorbers are not installed to be contiguous with similar elements, nor to be used as a continuous surface. Unit acoustical absorbers are often installed in proximity to wall or ceiling surfaces, such as hanging baffles. Unit acoustical absorbers are used to improve acoustical conditions within a room and in areas where the application of usual sound absorbing materials is not practical. The sound absorption characteristics of unit acoustical absorbers are determined by ASTM Test Method C423 and are usually reported both in sabins per unit and sabins per square foot of effective specimen area. In contrast to continuous surface coverage, the sound absorption coefficients of unit absorbers, because of sound diffraction effects, may be greater than 1.0. The absorption coefficients will be dependent upon the unit spacing, and the spacing used in the test must be specified in the test report.

Continuous Acoustical Wall Panel Systems

Acoustical wall panel systems provide a continuous, acoustically absorbing surface for control of reflected noise. Panels installed directly on studs or applied to existing surfaces create a full floor-to-ceiling sound absorber. Since the systems are continuous, they may also offer some reduction in sound transmitted through the system. The sound absorption characteristics are determined by ASTM test method C423 and are reported in sabins and sabins per square foot.

4.2 Ceiling Sound Attenuation

The "Ceiling Attenuation" can be defined as the noise reduction measured in decibels at each test frequency for the ceiling-plenum path between two rooms.

It was previously stated that the primary function of an acoustical ceiling is to absorb sound within a room. Under current construction practices, a significant number of installed acoustical ceilings are also required to provide a measurable sound attenuation between rooms as well as sound absorption within a room.

Sound Attenuation Test Methods

Manufacturers of acoustical materials list ceiling attenuation in decibels at 16 one-third octave frequency bands. The listing of 16 bands, instead of the usual six bands for sound absorption, is because the individual components of sound are much more significant for ceiling sound attenuation. The ceiling attenuation factors are determined by the ASTM E 1414 "Standard Test Method For Airborne Sound Attenuation Between Rooms Sharing a Common Ceiling Plenum." The single number Ceiling Attenuation Class (CAC) rating is determined from the 16 ceiling attenuation factor values by following the procedure in ASTM E413, "Determination of Sound Transmission Class." Results are reported as a single value as per ASTM E-1264. Typically the minimum CAC value for a product (e.g. min. CAC 35) will be reported by manufacturers. Care should be taken not to use the simple average of the 16 frequency ceiling attenuation factors as a guide for specifications because two materials with the same average may have widely different individual sound attenuation factors at frequencies which are important for specific situations. For those special cases, the attenuation factors at the troublesome frequencies should be carefully considered.

Performance Considerations

The common practice in building construction of using acoustical materials as a suspended ceiling leaves a plenum space above for the accommodation of ducts, piping, and utilities. The acoustical ceiling on either side of the partition, together with the common plenum, serves as another sound transmission path which parallels the transmission directly through the dividing partition.

Room dividing partitions are carried to the under surface of the suspended acoustical ceiling (continuous ceiling configuration), or they may be extended just above the suspended ceiling, interrupting the ceiling plane (interrupted ceiling configuration).

If the acoustical ceiling is extremely light or porous, or if it is suspended in such a way as to allow numerous leakage paths around the ceiling units, the plenum may have a greater influence on the sound transmission from room to room than the partition. The results could be an overall attenuation which may be much less than would be expected from the partition alone leading to an unsatisfactory noise or privacy situation.

Sound attenuation requirements of a ceiling generally depend on two factors:

a) Speech privacy. The intrusion of intelligible conversation from an adjoining room or work space can be distracting to the occupant. A ceiling system should be designed to provide required speech privacy and to minimize distractions. The frequency range for speech intelligibility lies between 500 and 2000 Hz; therefore, the transmission loss of the ceiling system is particularly important at these frequencies. A quiet room requires ceilings and partitions with higher transmission loss than rooms with higher ambient noise levels.

b) Need for control of excessive noise levels from adjacent area. A ceiling system should be selected that will, in combination with other components, reduce the sound from adjacent areas to acceptable levels in the room. These levels are approximately 35 to 45 dBA in areas occupied by office workers and higher in areas where production work is performed. Special attention must be paid to sound attenuation at the frequencies where the noise occurs, and the ceiling and other barrier elements such as partitions must be selected with these factors in mind.

As noted earlier, improved attenuation via the plenum can be obtained by extending the partition or other suitable barrier through the ceiling and blocking all or virtually all of the plenum. Another effective approach is to place a sound attenuating blanket over the top of the acoustical ceiling

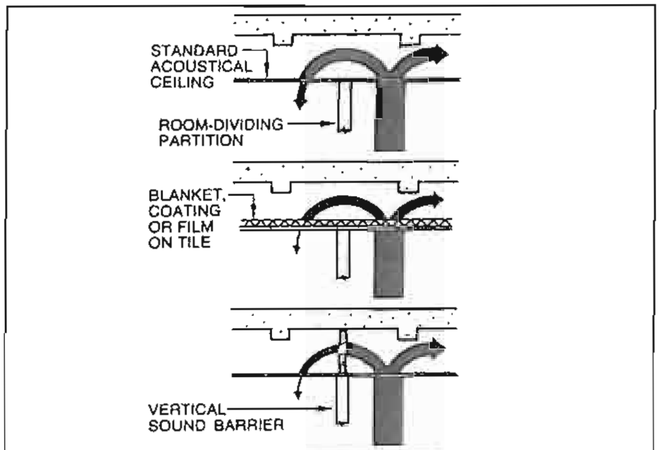


Figure 9.

extended out at least four feet on both sides of the partition line; however, a sound attenuation blanket should not be used in the case of Fire Resistance Rated assemblies unless the specific test includes such a blanket. The weakest link in the chain of sound transmission will determine the actual privacy which can be obtained within an area. For example, specification of an acoustical ceiling with 40 decibel sound attenuation at 2000 Hz is defeated when the partition at that frequency provides substantially less than the specified ceiling attenuation. The objective of a meaningful specification should be that each component reaches, or is slightly above, the minimum sound attenuation required.

Close attention must be paid to all other sound paths—such as air ducts, electrical outlets, and closure panels at exterior walls, which may interfere with the performance of the wall or the ceiling construction which has been selected.

These important practical considerations, based on laboratory and field testing of suspended acoustical ceilings, should then be borne in mind:

1. One of the weak points in the ceiling plenum transmission path is the joint or seal between the dividing partition and the ceiling, especially if the ceiling is continuous over the top of the partition. Special closure panels, caulking, and special suspension systems can provide a better sound seal at this point.
2. The performance of a suspended ceiling depends quite critically on how well the acoustical tiles or lay-in panels are fitted into the suspension system. Loose joints or cracks are especially harmful with materials which, in themselves, have relatively high sound attenuation.
3. The overall sound attenuation of a suspended ceiling and a dividing partition is governed essentially by the weaker of the two. See Figures 9 and 10.
4. Recessed light fixtures, because of the wide variety manufactured, are not included in standard ceiling sound attenuation tests. The number, type, and location of fixtures in a ceiling may significantly affect the total ceiling performance. Fixture attenuation boxes should be considered when designing ceiling systems to reduce the adverse effects of fixtures on ceiling attenuation performance.
5. Air grilles into return air plenums generally provide direct sound paths negating ceiling attenuation performance. Return air plenums should be avoided in situations where sound attenuation is of major concern.
6. It is sometimes found that more sound travels through cracks or openings in and around an adequately sound rated partition than is transmitted through the plenum path.

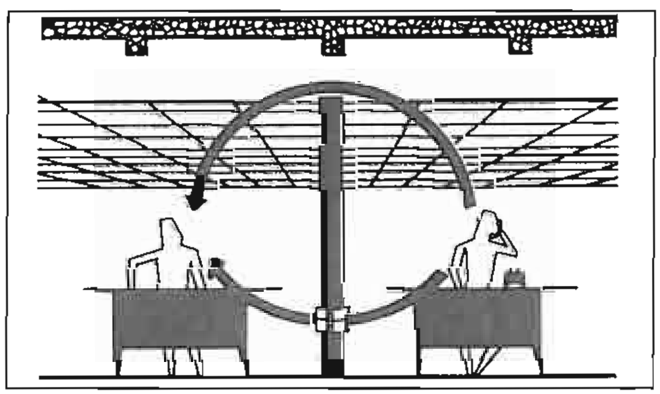


Figure 10. Speech Transmission Through the Plenum and Wall.

4.3 Light Reflectance

All light reflectance values are from tests using the method described in ASTM C1477, "Standard Method of Test for Light Reflectance of Acoustical Materials by the Integrating Sphere Reflectometer." Average samples are selected by laboratory personnel from factory-painted material submitted for sound absorption tests. The light reflectance value given is for a finish designated as "white."

Light reflectance coefficients (LR) indicate light reflectance values of newly manufactured material in ranges as follows:

LR 1 - .75 or more

LR 2 - .70 to .74 inclusive

LR 3 - .65 to .69 inclusive

LR 4 - .60 to .64 inclusive

Illumination engineers indicate no need for more definite values than given in the above ranges since the aging of paint surfaces of the accumulation of dust or dirt will reduce light reflection.

4.4 Flame Spread

Performance Consideration

Recognizing the greater significance of ranges of performance than that of individual values, the manufacturers list the flame spread index in classes. This system parallels that used in many building codes. The data are interpreted according to the scheme used in E1264 since wide use is also made of this particular specification:

Flame-Spread Index Range	ASTM E1264
0-25	Class A
26-75	Class B
76-200	Class C

The flame-spread rating of products is listed in the manufacturers' literature.

4.5 Fire Resistance

Fire protection for buildings is designed to prevent fire spread to adjacent floor spaces, or to nearby buildings, and to keep the structure intact as long as possible. The use of acoustical ceiling systems designed for hourly fire-resistive ratings has gained wide acceptance as they provide dry, fast construction, earlier occupancy, and generally lower costs than other methods. They also offer accessibility, acoustical treatment, and an opportunity to aesthetically enhance the ceiling plane.

Test Method

Fire Resistance Ratings are based on fire tests conducted in accordance with ASTM E-119, "Fire Tests of Buildings Construction and Materials". Fire Resistance Ratings are expressed in time (hours or fractions of hours) for the total assembly. The acoustical ceiling is but one of the components.

Performance Considerations

A majority of the fire resistance tests listed are conducted at Underwriters Laboratories, Inc. UL publishes a Fire Resistance Directory every year. Fire rated assemblies are shown in this directory with a sketch and detailed description of the assembly tested. Tests are also conducted at other nationally recognized laboratories.

Most details and dimensions are generally omitted from assembly sketches since they are intended merely to schematically illustrate the various constructions relating to the data.

Although the various elements of the assemblies as tested are critical to the performance of the assembly, experience suggests that certain deviations from the assembly as tested are inevitable in actual construction practices. This is not to suggest that the assemblies are impractical, but rather that variations in surface area, depth of plenum, depth of structural members, and thickness of floors and roofs are governed by architectural and structural design considerations not always identical to laboratory requirements or limitations. Departures from the listed construction assembly requires approval by the governmental code authorities in the jurisdiction in which the installation will be made.

4.6 Appearance of Acoustical Materials

After occupancy, the largest interior area visible to the occupants beyond the interior furnishings is the ceiling surface. It is, therefore, essential that the acoustical ceiling be in harmony with the space to be occupied, the design of the building, and the individual taste of the occupant. The manufacturers list many possible varieties of surface designs on acoustical ceiling products as well as various suspension members available.

Certain ceiling products are specified to coordinate the texture and/or color of the ceiling panel with the grid in which it is suspended. In cases such as this, a compatible or low gloss type grid should be used, following the recommendations of the ceiling manufacturer. This type of grid is usually made to the specifications of the ceiling panel manufacturer, therefore assuring a compatible match of grid and ceiling panel.

Individual manufacturers maintain samples and literature which show styles more completely:

- Perforated Cellulose Fiber Tile
- Textured, Finely Perforated, Fissured or Simulated Fissured Cellulose Tile
- Cellulose Fiber Lay-in Panels

- Perforated Mineral Fiber Tile
- Fissured Mineral Fiber Tile
- Textured, Finely Perforated, or Smooth Mineral Fiber Tile
- Mineral Fiber Lay-in Panels
- Perforated Metal Pans with Mineral Fiber Pads
- Special Acoustical Panels and Materials

4.7 Permanence and Maintenance

Under normal circumstances, acoustical tile and lay-in panels will stay fresh and new looking for a long time with no maintenance at all. If the environment is especially dusty, or if the tile or panels are marred by improper handling, here are some simple tips:

- Repainting of acoustical ceiling products may be accomplished by using a roller or spray. Care should be taken to select a non-bridging paint so that the acoustical efficiency is not greatly impaired. Repainting may affect flame-spread rating.
- Loose dirt may be removed with a soft brush or vacuum cleaner with a soft brush attachment. Small spots and streaks often can be removed with an art gum eraser. Larger smudges may be removed carefully with fresh wallpaper cleaner. Washing should be with a mild white facial soap or white soap flakes. Some detergents are satisfactory but should be used with care or tested first on an inconspicuous spot. Do not soak or excessively moisten tile! If tile has been installed with an adhesive,it is desirable to postpone cleaning or painting for at least 90 days. This is usually considered an adequate setting period for adhesive. (Consult the manufacturer if additional information is required).

4.8 Open Plan Acoustics

"Open-plan" offices—sometimes called "landscaped" offices are a staple of office design.

The open-plan office may be defined as a space in which individuals and work zones are not separated by ceiling-high barriers. Instead, free-standing barriers or screens that do not extend to the ceiling are used to provide a measure of privacy. The prime advantage of an open-plan office is its flexibility. Organizational changes can be implemented with minor effort and at a cost lower than in conventional offices. Properly planned, the work flow determines layout and function becomes a primary consideration. A primary problem faced in open-plan office design is the achievement of practical speech privacy for individual work stations while maintaining the featured flexibility, economy, and openness.

Performance Considerations

The components used in open-plan office configuration are: screens and/or work module panels which serve both as sound attenuator and as a sound absorber, walls covered with sound absorbing materials, and the ceiling which should be highly sound absorptive. The floors should be carpeted primarily to eliminate impact or scraping noise. The final component of an open-plan office is the masking sound system which controls the level and spectrum shape of background sound. In this way, unwanted sound and speech which has not been absorbed can be covered over, (i.e. masked) and not be obtrusive. All these elements—screens, work module panels, absorbent ceiling systems, walls, and masking sound are required to achieve speech privacy.

Open Plan Acoustic System Testing

The sound reflective characteristics of a ceiling system when used in conjunction with partial-height space dividers in an Open Office layout is represented by the Articulation Class rating as measured using ASTM E-1111 "Standard Test Method for Measuring the Interzone Attenuation of Ceiling Systems, and ASTM E-1110 Standard Classification for Determination of Articulation Class." The Articulation Class (AC) is the primary measure of acoustic performance of a ceiling for speech privacy in open office design. The AC rating is indicative of the ceilings ability to absorb sound that strikes it at the angles (approximately 30-60 degrees) at which most sound waves pass over furniture dividers, and at the frequencies critical so speech intelligibility.

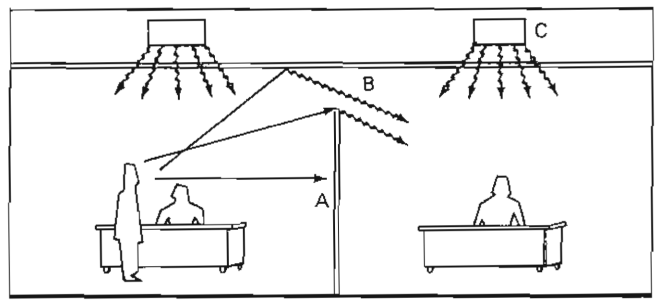


Figure 11. Factors affecting speech privacy: (a) the screen eliminated transmission through it and provides a partial barrier, (b) ceiling reflection is minimized by highly absorptive ceiling, and (c) residual diffracted and reflected speech sounds are masked by background systems for rimming intelligibility.

The AC is measured as a function of the distance from the sound source. Often only the minimum AC value is reported, and the higher this minimum value, the better the performance. A standard ceiling will have an AC of 150 or less, and a good open office ceiling will be in the range of AC 170-210.

The AC is measure according to ASTM E-1111 for the interzone attenuation using a test layout as described in Figure 12 with a fixed ceiling height of 9 ft. The sound source is placed at a 4 ft. height representing a seated person positioned at 6 ft. from a standard 5 ft. height partition. The sound attenuation between the source side and receive side (interzone attenuation) is measured at a 4 ft. height again representing a seated listener positioned at 7 ft. to 14 ft. from the talker. The interzone attenuation is averaged over 3 measurement points and recorded at the distances of 8 ft. to 13 ft. in 1 ft. increments.

The AC rating is calculated according to ASTM E-1110 by applying weighting factors to the one-third octave band interzone attenuation determined in the previous step. The weighted sound attenuations are totaled and rounded to the nearest multiple of 10 for each receiver distance, and that number is the AC rating for that distance. The minimum AC for all of the distances is then reported when only a single AC rating is without reference to distance.

A high AC rating means more effective speech privacy, and an AC of 210 (but not less than 170) is recommended for open office applications.

Both AC and NRC rate sound absorption but in very different ways. The AC is a measure of the ceiling sound attenuation (in dB) at specular angles of reflection . . . and is only applicable for adjacent open office privacy evaluations. The NRC is a measure of ceiling sound absorption (from 0.0 to 1.00) for all angles of incidence . . . and is applicable in all spaces for sound level and reverberation time effects.

While open-plan office design is simple enough in concept, the mechanics of achieving the objectives is highly complex. The services of a qualified space planner and acoustical consultant can provide the most effective open-plan office design with the best

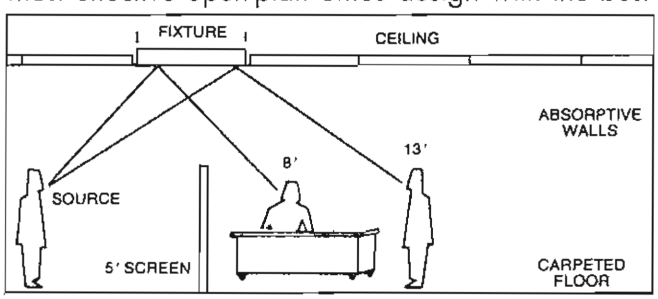


Figure 12. A Typical Set-up to Evaluate Open-Plan Ceiling System Performance by the Method of Test.

cost combination of movable screens, and/or work module panels, masking sound system, and sound-absorbing surfaces, including the acoustical ceiling and walls.

One of the most important elements in minimizing reflected sound is a highly absorbent acoustical ceiling. It must be highly absorbent to reflected sound in the 30-60 angles of incident sound in the frequency range of 500-4000 Hz. In order to achieve maximum flexibility in layout of furniture, the entire ceiling system must have similar charac-

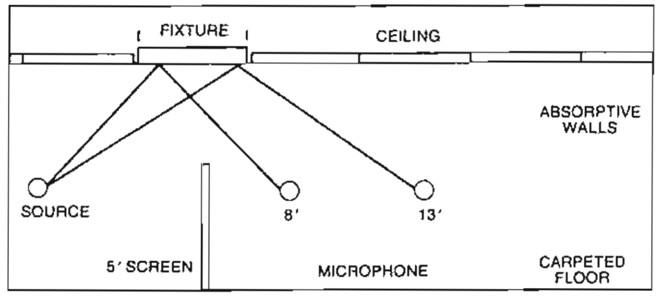


Figure 13. A Typical Set-up to Evaluate Open-Plan Ceiling System Performance by the PBS-C.2 Method of Test.

teristics. For example, 2'x4' flat lensed light fixtures will reflect considerable sound and, if located in the ceiling directly between occupants, can reduce privacy. Special fixtures are available and may be required to maintain maximum flexibility.

In actual practice, specifiers and owners are modifying the original "open-plan" concept by including private offices on the perimeter of the space. When this situation occurs, it is imperative to consider the sound attenuation of the ceiling as well as its absorptive properties unless plenum barriers are provided above the partitions. Highly absorbent acoustical ceilings, suitable for speech privacy in open plan spaces, are offered with special treatment to improve CAC ratings and should be requested where needed.

5.0 Installation Recommendations

A ceiling system must incorporate properly designed and engineered suspension systems and acoustical materials and be installed by contractors who understand the total relationship of all the components of the system. Acoustical ceiling materials are manufactured under rigid quality control standards, assuring the highest possible degree of dimensional accuracy. However, the manufacturing standards of both the ceiling material and suspension system, the specific product selected, and the quality control employed during its installation, all have a significant effect on the final installed appearance. ASTM C635, "Standard Specification for Metal Suspension Systems for Acoustical Tile and Lay-in Panel Ceiling" and ASTM C636, "Standard Recommended Practice for Installation of Metal Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels", provide descriptions of terms, tests and types of systems available to the specifier.

It is imperative that the specifier research the performance and aesthetic capabilities of the product desired before selecting it for the project. Vital to the success of the final installation of the acoustical ceiling and the suspension system is the quality of work provided by the acoustical ceiling contractor. It is important that reputable acoustical contractors, with mechanics experienced and trained in the installation of the systems being installed, be used, and that specifications be properly interpreted before work commences. If recommended job site conditions are not available, artificial and natural light sources are not properly controlled, or inexperienced mechanics are used, the final appearance of the ceiling could be adversely affected. Each part of the ceiling systems team, the acoustical material manufacturer, the suspension system manufacturer and the contractor have an interworking relationship.

5.1 Job Conditions

Critical to the success of a ceiling systems installation are the job site condition, the preparation preceding the acoustical work, and the workmanship and performance of the acoustical contractor.

The following recommendations are adapted from the CISCA Code of Practices. First adopted in 1966, this was prepared with the anticipation that its widespread acceptance would upgrade the acoustical ceiling installation industry through better understanding of what constitutes quality workmanship.

In writing specifications to include the following recommendations, the architect should clearly state the responsibilities of the various contractors involved. There is a distinct relationship between the finished ceiling system, its manufactured components, and construction trades whose work may impinge upon that of the ceiling systems contractor. The following are sections from the CISCA Code of Practices:

1. Mechanical trades and electrical trades shall have completed their work above the ceiling line prior to the installation of acoustical ceilings. Where duct work makes it impossible to install hangers in an area, the mechanical trades shall provide proper framing of adequate strength to support ceiling from the framing. It shall be the responsibility of the mechanical trades and/or other trades which incorporate into the ceiling any recessed, surface, or suspended units, to do so without distortion or damage to the acoustical ceilings. Mechanical trades and electrical trades shall make available adequate descriptive literature or information to the acoustical ceiling contractor prior to the start of installation of any item that is to be incorporated into the ceiling installation that would affect same (dimensional data and fixture weight). Mechanical and electrical trades shall provide adequate trim where less than full module sizes occur.
2. All windows and exterior doors shall be in place and glazed, and the roof shall be watertight prior to the start of acoustical installation. All wet work such as plaster and terrazzo should be completed prior to start. Installation of acoustical material shall be made only when the temperature and humidity conditions closely approximate the interior conditions which will exist when the building is occupied. This condition should be maintained prior to, during, and after installation. Temperature and humidity conditions are a vital factor in the long-lasting appearance of acoustical installations and this job condition is of paramount consideration for a proper installation. The acoustical contractor shall not be responsible for installation of this work when proper humidity and temperature conditions are not maintained. It should be noted that not all acoustical materials are equally sensitive to humidity and temperature. Humidity resistant ceiling panels and hot-dipped galvanized suspension systems are now available for use in high humidity conditions. Refer to material manufacturer for specific product involved.
3. Unless the appropriate humidity-resistant ceiling and suspension system have been selected, the permanent heating and cooling system shall be installed and operating to maintain proper installation conditions. Standard humidity performance acoustical materials are interior finish products and as such are designed for installation within the normal occupancy condition range of 60F to 85F at a maximum of 70% R.H. Humidity resistant systems can be installed in environments with higher humidity and temperatures. Exposure to temperatures or humidities outside the products' design range may result in unsatisfactory appearance. The air conditioning shall be continuous to maintain proper conditions and to be a type not to discolor or damage the tile, suspension system, and other elements, or damage the base to which the tile must be applied. Where a pressurized plenum is being used, the ventilation system should be operating 48 hours prior to the installation of ceiling tile to cleanse the duct system.
4. While considering job conditions which affect the appearance of the completed ceiling installation, it is advisable to consider that the lighting selected be of the type that will complement the ceiling rather than promote an adverse or unsatisfactory appearance. Many lighting factors influence the appearance of the ceiling, such as intensity of light, height of ceiling, direction of light, and mounting of fixtures.

The most critical factor is the direction of the light source. A critical horizontal light that strikes the ceiling surface at an acute angle accentuates normal ceiling irregularities, affecting the final appearance of the installation.

Fixtures located close to the underside of the ceiling, such as surface mounted or semi-recessed and cove lighting are generally unsatisfactory. In such cases, light grazes across the ceiling and emphasizes variations as small as .005". This causes shadow problems that accentuate slight unevenness of joints, affecting final appearance of the ceiling.

Exterior lighting from high windows and window walls can result in similar problems to the ceiling.

The selection of recessed lights and skillful use of shielding of semi-recessed or surface mounted lights, as well as the use of valances, or draperies, can help minimize the problem of troublesome, low angle, side grazing light.

Ceiling height windows or other critical low angle conditions will adversely affect the appearance of even a properly installed ceiling with the best quality materials, especially if square edge ceiling tiles are used.

When low incident light from surface mounted fixtures or from ceiling height windows illuminates a joint between two square edge tile, the resulting shadow is far longer than the difference in level between the two tile. This exaggerates even small variations in level between tile. Frequently, a ceiling may appear unsatisfactory during installation due to low angle daytime illumination. However, when the job has been completed with draperies or blinds installed and lighting fixtures in operation, the ceiling will provide a commercially acceptable appearance. This is due to a reduction of the contribution of low angle light to the total light illuminating the ceiling, thereby reducing the intensity of shadow exaggerated joints. It is then recommended that inspection and acceptance of a ceiling installation be made under normal occupancy lighting conditions. If it is impossible to eliminate grazing light, and there is concern over the final installation appearance, the specifier should consider the use of bevel edged tile.

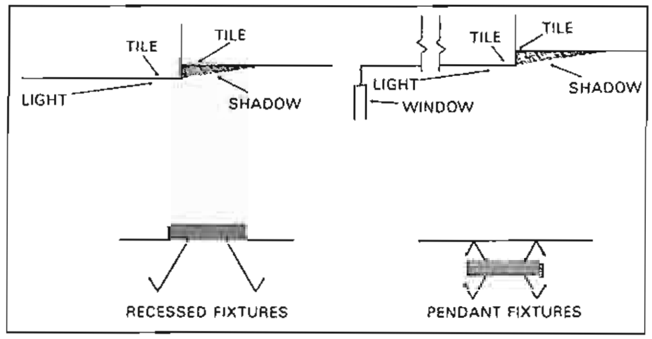


Figure 14. Effects of Lighting.

Even under favorable lighting conditions, some tile surfaces and joint lines may appear unsatisfactory when installed without bevels. Finely fissured pattern tile which lack deeply textured surfaces should be beveled for best total installation appearance.

In recent years, federal, state, and local government agencies and private building owners have reduced energy usage by eliminating heating or air conditioning on weekends and other periods of extended shutdown, attempting to conserve energy and reduce energy costs.

Such action may cause rapid changes in temperature and humidity in the room and plenum. This may result in the ceiling material absorbing and/or releasing moisture. Permanent change of the physical dimensions and appearance of the ceiling materials may take place, unless appropriate humidity-resistant materials are installed.

5.2 Installation Methods

Acoustical materials are, in general, installed in mechanical suspension systems. However, in some instances they are applied by adhesives to solid backings such as plaster, concrete, or suspended gypsum board. Guide specifications describing recommended installation systems and techniques are available from each of the acoustical material and suspension systems manufacturers. For best results, their recommendations and specifications should be followed. While special systems and combinations of tile or lay-in panels can be made available by the individual manufacturers, the following list includes the more common methods of installing acoustical ceilings.

A. Mechanical Suspension Systems

1. Concealed Z-runners of H & T members are clip fastened to suspended primary channels. Suspension members engage appropriately fabricated kerfs in the tiles. Anti-breathing splines are positioned in tile not occupied by supporting suspension members. These systems are available with or without access detailing and accessories.
2. Concealed direct hung grid system eliminating need for primary channels, consists of main tee runners with either interlocked cross tee members or non-locking cross tees. Stabilizer bars to properly position and space the main tee runners are required when non-locking cross tees are used. Accessory concealed supporting suspension members are available to provide either upward or downward access. (Reference: ASTM C635, C636, and E580)
3. Concealed full access systems are available in various rolled metal configurations for attachment to suspended primary channels or for direct suspension. Tee or other shaped supporting members engage tile kerfs.
4. Semi-concealed systems consist of pre-painted, or finished, exposed main runners of Tee, Zee, or other configuration exposed in one direction only. Tiles kerfed on two or more edges are positioned on the exposed flanges of the main runners by concealed cross tees. Systems of this type generally require specially sized tiles

to conform to the main running spacing. Accessory concealed supporting suspension members are available to provide upward access.

5. Exposed grid systems consist of direct hung main tees generally spaced 48" o.c. and interlocking tees spaced 24" o.c. Tile and suspension system manufacturers should be consulted for other practical spacing of grid members. Acoustical or non-acoustical lay-in panels, nominally sized, are simply laid in the grid openings and are supported by the exposed flanges of the grid members.
6. Fire resistant mechanical ceiling suspension assemblies are specially designed and have been tested in certain specified floor/ceiling or roof/ceiling assemblies and are certified by an independent testing laboratory to meet specific time rated assembly requirements. These systems provide a fire protection membrane for structural steel members and the floor or roof assemblies above. It is important that each component of a time rated system be selected and installed in strict accordance with the material manufacturer's recommendations and the requirements of the design.

B. Integrated Ceiling Systems

Total environmental ceiling systems integrated to provide lighting, air distribution, fire resistance design classifications, acoustical control, and a means of support for partition systems are available to meet almost all environmental requirements. These systems consist of uniquely shaped direct hung main and cross runners assembled to meet varying module spacings and lighting intensity requirements. Lighting fixtures in various sizes, specially designed to fit the individual manufacturer's system, are available as a part of the specific system.

C. Adhesive Applications

Acoustical tile may be applied to level surfaces of concrete, plaster, or gypsum board. The acoustical contractor should be responsible for examination and acceptance of all surfaces and conditions affecting the installation of his materials. In new construction, moisture tests should be made to ensure that concrete and plaster surfaces serving as a backing for the adhesive applied tiles are properly dried out. Generally, new concrete should cure approximately six months, and new plaster should be allowed to dry out four or five weeks. The acoustical contractor should install the materials with an approved acoustical adhesive in accordance with the adhesive manufacturer's recommendations.

Here are specific safeguards to ensure good adhesive applications:

1. No oils, form residue, or other foreign agent shall be on concrete surfaces that are to receive acoustical tile.
2. All concrete or pre-cast concrete, pre-cast block, concrete plank, or plaster shall be level to 1/4" in 12' with minimum irregularities.
3. Surfaces shall be sufficiently aged and dried to receive tile. Moisture tests shall be made by the acoustical contractor to determine this condition.
4. Acoustical tile should not be cemented directly to interior face of concrete slabs unless proper insulation is provided on the top side of the slab so that temperature difference does not occur.
5. All new concrete surfaces to receive acoustical tile installation shall be properly primed with primer recommended by manufacturer of mastic used or unless otherwise specified.
6. All dusty surfaces where adhesive is to be applied shall have dust removed by the acoustical contractor.

D. Nailing, Screwing, or Stapling to Wood Strips

Furring strips should be kiln dried soft wood, not less than nominal 1" x 3" and installed on 12" centers maximum unless otherwise specified by the acoustical material manufacturer. Where joists or other framing members are on greater than 24" centers, they should be cross furred with nominal 2" x 3" or 2" x 4" members, or the furring strips themselves should be of 2" stock to guard against possible "whipping" and lack of rigidity when the acoustical material is secured.

5.3 Insulated Ceilings

All acoustical materials have some thermal insulation properties. Under some conditions, depending on the thermal nature of the entire assembly, the ceiling panels can supplement the thermal resistance of the assembly. In relatively cold climates where the problem is one of preventing condensation on the underside of cold roof surfaces, it is considered the best practice to locate surfaces, vapor-sealed insulation on top of the roof slab with the acoustical ceiling material installed in the conventional manner in the room below.

If this cannot be done, thermal insulation (batts and blankets) can be installed in the plenum above the suspended ceiling. However, excessive weight applied to the back of the ceiling panels could cause deflection. Consult manufacturer for specific recommendations.

It should be noted that placing thermal insulation directly on the suspension system or on the back of the acoustical ceiling panels could interfere with the plenum accessibility, depending on the method of installation. If thermal insulation has to be installed above a suspended ceiling, adequate ventilation should be provided in the plenum to prevent high humidity conditions. Failure to provide ventilation could lead to condensation and subsequent damage to the ceiling panels and suspension members.

Under no circumstances should thermal insulation be installed on the back of a fire-rated ceiling unless so designated in a specific fire-resistance design assigned to the structure.

For highest efficiency, the insulation behind the ceiling should be continuous and uninterrupted. However, it is also important to remember that insulation laid directly on top of light fixtures can cause heat generation that may shorten the life of the ballast in that fixture.

5.4 CISCA Code of Practices

Excellent workmanship and proper job site conditions do not happen by accident. They are the result of careful planning by the contractor, architect, and owner. Following are the twelve criteria established by CISCA which will produce those conditions under which the most satisfactory installation of acoustical materials can be made.

- All workmanship should be of the highest standard in accordance with the Ceilings & Interior Systems Construction Association policy of upgrading quality.
- Ceiling units shall be so arranged that units less than one-half width do not occur unless otherwise directed by reflecting ceiling plans of job conditions.
- All title joints and exposed suspension systems shall be straight and in alignment.
- All acoustical ceilings shall be level to 1/4" in 12' at the time of installation.
- Tiles shall be neatly scribed against abutting surfaces and to all penetrations or protrusions when mouldings are not required.
- Tile surrounding recessed troffer lights and similar openings shall be installed with a positive method to prevent movement or displacement of these tile.
- Tiles shall be installed in a uniform manner with joints neat and fitted to hairline joints between adjoining tiles.
- Wall mouldings shall be firmly secured, corners neatly mitered, or corner caps used, if preferred. Edge mould shall not be used at each tile; springs not required on access systems.
- The acoustical contractor shall leave ceiling in a clean and undamaged condition.
- The acoustical contractor shall assist in coordination of placement of layout control for acoustical ceiling areas but not be responsible for mechanical and lighting layout control. Center lines and elevation bench marks shall be established by the general contractor, and all trades, including mechanical, shall work to these lines.
- The acoustical contractor shall be responsible for the inspection of the plenum space prior to installation of ceiling system and shall notify the general contractor and/or owner of any noticeable leakage or cleanliness in ventilated ceiling systems.
- The acoustical contractor shall cooperate with the general contractor and/or owner and with all the trades to insure a proper and lasting ceiling installation.

Quality workmanship is a nebulous item and difficult to define and can be achieved only by the integrity of every Ceilings & Interior Systems Construction Association member, who energetically strives to make each acoustical installation of the highest quality.

With skilled workmanship, proper job conditions, and quality materials, every installation shall be of the standard desired by Ceilings & Interior Systems Construction Association members.

6.0 Glossary

Absorption Coefficient—See Sound Absorption.

Acoustical Correction—In auditoriums, churches, theatres, concert halls, or wherever an audience assembles to hear speakers or music, the treatment of the room should be to make hearing conditions as ideal as possible.

Acoustically Satisfactory Auditorium—Optimum acoustic conditions in an auditorium are obtained when an average sound rises to a suitable intensity in every part of the auditorium with no discernable echoes or distortion of the original sound and then decays quickly enough not to interfere with the succeeding sounds. This ideal is seldom reached, but the human ear allows a rather wide variation from ideal without damaging the overall effect.

Airborne Transmission—Transmission of sounds which originate in the source rooms in the air.

Amplification—The increased intensity of sound by mechanical and/or electrical means.

Attenuation Factor—The difference in noise level measured in decibels between a source room and an adjacent receiving room when it is assumed that all the sound entering the receiving room travels by way of the common ceiling of the two rooms.

Binaural Hearing—The reception of sounds through both ears.

Ceiling STC—A single—number rating of room—to—room sound attenuation by the ceiling path, (or ceiling sound transmission class).

Cycle—Each complete round trip of any vibrating body starting from its neutral position, moving to one side then to the other side, and back to neutral.

Dead Spots—In certain acoustically incorrect auditoriums, places where sound emitted on the stage is scarcely audible.

Decibel—Ten times the common logarithm of the ratio of two like quantities proportioned to power or energy.

dBA—A single number measurement in decibels that is weighted to approximate the response of the human ear with respect to frequencies.

Decibel Reduction—A reduction in the sound intensity level expressed in decibels.

Diffuse Sound—Sound in an enclosure is diffuse when sound waves travel equally in all directions throughout the enclosure, and the sound level varies minimally throughout the enclosure.

Diffraction—The tendency of sound waves to flow readily around obstacles which are small in comparison to the wave length of the sound.

Echo—A single reflection of sound which can be heard as distinct repetition on the original sound.

Flow Resistance—A measure of the ability of a material to impede the flow of air through it.

Flanking Sound Path—A sound transmission path such as a structural path which bypasses a transmission barrier.

Flutter—A multiple echo set-up between parallel reflecting surfaces.

Frequency— The number of complete pressure fluctuations or cycles occurring in one second. Expressed in Hertz (Hz).

Frequency Scale—The audible frequency scale extends from approximately 20 Hz to 20,000 Hz. In acoustical work the range from 100 to 7,000 Hz is most important. The absorption of acoustical materials is typically reported at octave intervals between 125 and 4,000 Hz.

Hertz—The unit of frequency. One cycle per second is one Hertz (Hz).

Impact Transmission—Transference of sound into another area through a wall or floor which has been set into vibration by direct mechanical impact.

Intensity—The amount of sound energy per second that is carried across a unit area.

Intensity Level—Expressed in decibels is ten times the common logarithm of the ratio of the intensity of a sound to a reference intensity. (I.L. = 10 $\log^{10}$. The reference intensity I0 is usually taken as 10^{-12} watts per square meter.)

Interference—The destructive or reinforcing action of two or more waves arriving at the same position simultaneously.

Loudness Levels in Sones—A linear expression of loudness that compares sound to a 1,000 Hz tone of 40 dB.

Loud Spots—Places in a room where intensity level is higher than average level.

Noise—Unwanted sound.

Noise Isolation Class (NIC)—A single—number rating of noise reduction.

Noise Quieting—The reduction of sound intensity, through the use of sound control materials and procedures, to a level permitting comfortable working conditions.

Noise Reduction—The difference in noise level measured in decibels between a source room and a receiving room.

Noise Reduction Coefficient (NRC)—The average sound absorption coefficient to the nearest .05 measured at the four one—third octave band center frequencies of 250, 500, 1,000 and 2,000 Hz.

Normalized Attenuation Factor—An attenuation factor corrected to a receiving room total absorption of 126 sabins (Cf. Attenuation Factor.)

Open Plan Office—An office in which acoustical screens are used in place of ceiling—high partitions and in which office layout is partially dictated by work flow considerations.

Optimum Time of Reverberation—The reverberation time which will give the best acoustical conditions for the intended use of the room.

Phon—A unit of loudness level of a sound equal to the sound pressure level of a 1,000 Hz tone judged to be as loud.

Pitch—The auditory sensation in response to the frequency or sound on a scale from low to high. The higher the frequency the higher the pitch.

Porosity—The ratio of the volume of an acoustical tile's pores to its total volume. Acoustical tile owe their sound absorptive values to the fact that they are highly porous.

Reflection Coefficient—The fraction of sound energy returned into a room after a sound wave strikes a surface in the room. The fraction not returned to the room is the absorption coefficient.

Reverberation—The persistence of sound in a room after the sound has stopped.

Reverberation Method—A method of determining the sound absorption of a space by the direct measurement of reverberation times.

Reverberation Time—The time required for any average sound to decay to a value one—millionth of its original intensity or to reduce sixty decibels after the sound source has stopped.

Sabin—One square foot of a surface having perfect absorption, an absorption coefficient of 1.00.

Sabine Formula—Relates room volume and total acoustical absorption to reverberation time:

$$T = \frac{.05V}{A}$$

T = Reverberation time in sec.
V = Room value in cu. ft.
A = Total absorption in sabins

Sound—A wave motion of an audible frequency in the air or other materials that cause the sensation of hearing.

Sound Absorption Coefficient—The fraction of the incident energy absorbed (not reflected) by a material when a sound wave strikes it is called the sound absorption coefficient of that material.

Sound Absorption Unit—See Sabin.

Sound Insulation—See sound transmission control.

Sound Leaks—Cracks under doors, openings in a wall, pipe or wiring holes, etc., which allow sound to escape through a structure from one room to another.

Sound Level Meter—An electronic device which measures the decibel level of sounds.

Sound Power—The total sound energy radiated by a source per second, expresses in watts.

Sound Transmission—See Sound Transmission Control.

Sound Transmission Class (STC)—A single—number rating of a building element's efficacy. (Cf. Ceiling STC.)

Sound Transmission Control—The use of sound insulation barriers or other means to reduce the level of sound transmitted from one location to another (Cf. Air Borne Transmission and Structure Borne Transmission.)

Sound Wave—A pressure disturbance in air proceeding at a finite velocity (approximately 1,120 ft./sec. at room temperature.)

Speed of Sound—1,120 ft. per second or 763 miles per hour is the speed of sound in air under standard conditions of temperature and pressure.

Standard Mounting—Acoustical ceiling board or tile are usually tested in standard mountings which simulate common installation conditions: e.g., B, direct application as with glue; D, on furring; E, on a simulated suspension system. See ASTM Practice E 795.1.

Structure—borne Sound Transmission—Sound transmitted through the building structure is termed structure—borne (Cf. Airborne transmission.)

Threshold of Audibility—Intensity level of the faintest sound the ear can hear.

Threshold of Feeling—Intensity level at which a sound is so loud as to begin to cause pain to the normal ear. This is approximately at 130 decibels.

Transmission Loss—The difference (in decibels) between the level of sound power incident on the barrier from the source room and the level of sound power radiated directly into the receiving room.

Two—Room Attenuation Factor—See Attenuation Factor and Ceiling STC.

Wave Length—The distance a wave travels in one cycle. It is approximately equal to the speed of sound in the medium (1,120 ft. per second in air) divided by the frequency.

7.0 Sound Absorption Coefficients of General Building Materials and Furnishings

Complete tables of coefficients of the various materials that normally constitute the interior finish of rooms may be found in the various books on architectural acoustics. The following short list of materials gives approximate values which will be useful in making simple calculations of the reverberation in rooms.

	Coefficients					
Materials	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Brick, unglazed	.03	.03	.03	.04	.05	.07
Brick, unglazed, painted	.01	.01	.02	.02	.02	.03
Carpet						
1/8" Pile Height	.05	.05	.10	.20	.30	.40
1/4" Pile Height	.05	.10	.15	.30	.50	.55
3/16" combined Pile & Foam	.05	.10	.10	.30	.40	.50
5/16" combined Pile & Foam	.05	.15	.13	.40	.50	.60
Concrete Block, painted	.10	.05	.06	.07	.09	.08
Fabrics						
Light velour, 10 oz. per sq. yd., hung straight, in contact with wall	.03	.04	.11	.17	.24	.35
Medium velour, 14 oz. per sq. yd., draped to half area	.07	.31	.49	.75	.70	.60
Heavy velour, 18 oz. per sq. yd., draped to half area	.14	.35	.55	.72	.70	.65
Floors						
Concrete or Terrazzo	.01	.01	.01	.02	.02	.02
Linoleum, asphalt, rubber or cork tile on concrete	.02	.03	.03	.03	.03	.02
Wood	.15	.11	.10	.07	.06	.07
Wood parquet in asphalt on concrete	.04	.04	.07	.06	.06	.07
Glass						
1/4", sealed, large panes	.05	.03	.02	.02	.03	.02
24 oz., operable window (in closed condition)	.10	.05	.04	.03	.03	.03
Gypsum board, 1/2" nailed to 2x4's 16" o.c., painted	.10	.08	.05	.03	.03	.03
Marble or Glazed Tile	.01	.01	.01	.01	.02	.02
Plaster, gypsum or lime, rough finish or lath	.02	.03	.04	.05	.04	.03
Same, with smooth finish	.02	.02	.03	.04	.04	.03
Hardwood plywood paneling 1/4" thick, Wood Frame	.58	.22	.07	.04	.03	.07
Water Surface, as in swimming pool	.01	.01	.01	.01	.02	.03
Wood Roof Decking, tongue—and—grove cedar	.24	.19	.14	.08	.13	.10
Air, Sabins per 1,000 cubic feet @ 50% RH				.9	2.3	7.2

Absorption of Seats And Audience*

Values given are in sabins per person or unit of seating at the indicated frequency

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Audience, seated, depending on spacing and upholstery of seats	2.5—4.0	3.5—5	4.0—5.5	4.5—6.5	5.0—7.0	4.5—7
Seat, heavily upholstered with fabric	1.5—3.5	3.5—4.5	4.0—5.0	4.0—5.5	3.5—5.5	3.5—4.5
Seats heavily upholstered with leather, plastic, etc.		1.5—2.0				
Seats, wood veneer, no upholstery	.15	.20	.25	.30	.50	.50
Wood pews, no cushions, per 18" length			.40			
Wood pews, cushions, per 18" length			1.8—2.3			

*Reference to Acoustical Manufacturers catalogs for acoustical materials data.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Philadelphia, Pennsylvania

ASTM: A 164	Standard Specification for ELECTRODEPOSITED COATINGS OF ZINC ON STEEL
ASTM: A 366	Standard Specifications for STEEL, CARBON, COLD—ROLLED SHEET. COMMERCIAL QUALITY
ASTM: A 526	Standard Specifications for STEEL SHEET, ZINC—COATED (GALVANIZED) BY THE HOT—DIP PROCESS, COMMERCIAL QUALITY
ASTM: C 423	Standard Test Method for SOUND ABSORPTION AND SOUND ABSORPTION COEFFICIENTS BY THE REVERBERATION ROOM METHOD
ASTM: C 1477	Standard Method of Test for LIGHT REFLECTANCE OF ACOUSTICAL MATERIALS BY THE INTEGRATING SPHERE REFLECTOMETER
ASTM: C 635	Standard Specifications for METAL SUSPENSION SYSTEMS FOR ACOUSTICAL TILE AND LAY—IN PANEL CEILINGS
ASTM: C 636	Standard Recommended Practice for INSTALLATION OF METAL CEILING SUSPENSION SYSTEMS FOR ACOUSTICAL TILE AND LAY—IN PANELS
ASTM: D1779	Standard Specifications for ADHESIVE FOR ACOUSTICAL MATERIALS
ASTM: E 84	Standard Test Methods for SURFACE BURNING CHARACTERISTICS OF BURNING MATERIALS
ASTM: E 119	Standard Methods of FIRE TESTS OF BUILDING CONSTRUCTION AND MATERIALS
ASTM: E 413	Standard Classification for DETERMINATION OF SOUND TRANSMISSION CLASS
ASTM: E 492	Laboratory Measurements of IMPACT SOUND TRANSMISSION THROUGH FLOOR—CEILING ASSEMBLIES USING THE TAPPING MACHINE
ASTM: E 795	Standard Practices for MOUNTING TEST SPECIMEN DURING SOUND ABSORPTION TESTS
REFERENCE AMA 1-11	CEILING SOUND TRANSMISSION TEST BY TWO—ROOM METHOD Standard Recommended Practice for APPLICATION OF ASTM E580 CEILING SUSPENSION SYSTEMS FOR ACOUSTICAL TILE AND LAY—IN PANELS IN AREAS REQUIRING SEISMIC RESTRAINT
PBS-C.1	METHOD FOR THE DIRECT MEASUREMENT OF SPEAKER—PRIVACY POTENTIAL (SPP) BASED ON SUBJECTIVE MEASUREMENTS
PBS-C.2	METHOD FOR THE SUFFICIENT VERIFICATION OF SPEECH—PRIVACY POTENTIAL (SPP) ON OBJECTIVE MEASUREMENTS

To order additional copies of this booklet contact:
CISCA, 1500 Lincoln Highway Suite 202, St. Charles, IL 60174.
Or call 630-584-1919; fax 630-584-2003. Order on the web at www.cisca.org.
Quantity discounts available, inquire to CISCA office.