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UNDERSTANDING

THE SCIENCE OF

AUDIO

ACOUSTICS

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AUDIO

Sound is a most important element of the human experience. Speech and music are among the highest forms of human expression. Through the audio medium, thoughts, ideas and feelings can be exchanged with an effectiveness and efficiency not attainable through other methods.

Facilities are often constructed with the express purpose of allowing audio communication involving a substantial number of people. Churches, auditoriums and meeting rooms are but a few examples of such facilities. In these facilities it is imperative that the audio medium, namely the room acoustics and sound system, should be designed to facilitate the desired communications.

The following information has been prepared by the staff of Architectural Audio Services to aid facility owners, operators, users, architects, and interior designers in their understanding of the science of sound and acoustics.

AUDIO DESIGN OBJECTIVES

There are five main objectives which can be identified for consideration in acoustical and sound systems designs. They are:

1. Achievement of AUDIO COMFORT
2. Achievement of SPEECH INTELLIGIBILITY
3. Achievement of OPTIMUM MUSIC & PROGRAM RENDITION
4. Achievement of EASE OF FACILITY OPERATION
5. Achievement of a BUDGETED COST OBJECTIVE

All subsequent specifications should be directed toward achievement of results relating to these five prime design objectives.

1.AUDIO COMFORT

As with any aspect of the facility design, comfort for the user, listener or guest must be considered.

Numerous studies have proven that people expect certain acoustical conditions in order to feel comfortable. After all, the audio program may be the main reason for their presence in the facility. Poor audio conditions such as excessive background noise and reverberation, tone frequency exaggerations, inadequate or excessive speech or sound levels can cause listener discomfort and aggravation. When listeners become uncomfortable and distracted, they no longer devote their attention to the program, and the effectiveness of the presentation is compromised.

2. SPEECH INTELLIGIBILITY

The intelligibility of speech, depends on several factors, among them:

A. The nature of the talker People who speak professionally do not necessarily speak more loudly than other people, but they do tend to enunciate more clearly and pace themselves according to the local acoustics. Persons not trained in public speaking do not project their voice well and speak too quickly. Foreign accents or area brogue, of course, place an added burden on the listener.

B. The nature of the listener In general, older people do not hear as well as younger people. There are also listeners who are just plain hard of hearing. Speech intelligibility also assumes that the listener will devote his substantial attention to the speech program; if the listener becomes distracted for any reason, his ability to understand the speech will be reduced.

C. Speech level relative to noise level Intelligibility is a rather complicated function of the absolute speech level and the noise level. In a relatively noisy room a considerable signal-to-noise ratio may be required for a given percentage of articulation, while in a quieter room, a lesser signal-to-noise ratio would be required for the same percentage of articulation.

D. Direct-to-reverberant sound ratio The room reverberation time itself and the direct-to-reverberant sound ratio influence intelligibility. When the reverberation time is short, the over-hang of a given syllable of speech does not materially interfere with the next syllable.

An average syllable rate in normal speech is about 3 per second, and reverberation times of 1.5 seconds or less do not usually degrade speech intelligibility. Beyond 1.5 seconds the over-hang of reverberant energy of one syllable tends to cloud the next syllable and intelligibility decreases progressively. As the reverberation time increases, more listeners are effected, as an increasing number are located within the reverberant sound field rather than the direct sound field.

A goal of any speech facility should be to allow for listeners to hear and receive sound with high intelligibility. Translating this subjective description into objective terms, this means that an averagae listener should be able to discern correctly at least 85% of the consonants in a random series of words. As a rule, a 15% Alcons (or 85% consonant intelligibility), assumes that only 3 discreet words out of 100 will be misunderstood. Many facility programs demand and expect consonant intelligibility of 90% to 95%.

3. OPTIMUM MUSIC & PROGRAM RENDITION

The rendition of music and other audio program material also requires a favorable acoustical environment. Room acoustics effect the tonal quality and overall blending of music, as the room itself in effect becomes a part of the instrument through acoustical coupling. It should be realized that quality musical and sound productions can only be achieved in an optimum acoustical environment.

Music and sound reception is influenced by the same factors which effect speech intelligibility. Of course, the quality of the program source must be adequate. As with speech, older people do not hear as well as younger people, particularly with respect to higher sound frequencies. The program sound must be sufficiently louder than the room ambient noise. Room reverberation can effect musical renditions because proper reverberation is necessary to achieve what is commonly termed a "full sound". Rooms that are designed with optimum reverberation times enhance and enlarge the perceived sound image. Rooms with shorter times are considered "dead", while rooms with longer times make it impossible to follow the main musical theme.

4. USER EASE OF OPERATION

As acoustical conditions can cause listener aggravations and distraction, it is also possible for these same factors to cause aggravation and distraction to talkers or musicians in the same manner. For example, an excessive background noise level may force a talker to speak much louder than normal or move closer to a sound system microphone than is practical, in order to achieve satisfactory performance. Speech and program presentations deserve the full attention of the presentors, and it is counter-productive to allow acoustical conditions to interfere with the presentor's primary work.

5. BUDGETED COST OBJECTIVE

It is important for everyone involved with facility design, management and usage to recognize the proper context of the budget considerations. Yes, it is true that almost everyone must work within a budget. It is also true that certain facilities are constructed for the specific purpose of permitting quality audio program presentation. It defeats the primary purpose of a church or meeting room etc.,if the facility is constructed and is incapable of allowing for effective speech and program presentations. The proper budget amount is that amount which will allow for achievement of the facility design objectives. To impose an arbitrary budgetary restriction at the onset of the audio and acoustic design work is not advised. Frequently, after the preliminary acoustic and sound system design and specification work has been completed, a budget can be established which will allow for achievement of the desired results, and a contract can be negotiated for actual implementation of the required work.

ESTABLISHING DESIGN PRIORITIES

In dealing with the design objectives outlined above, a relative value and priority must be given to each objective by the client. In this way, the best possible audio design can be developed based on all factors and their relative priorities. If accuracy and intelligibility of speech and program rendition are selected as having the highest priority, other considerations must become subordinate to that objective, if necessary to achieve the desired results. If user ease of operation, for example, is the next highest priority, it must be subordinate to the accuracy and intelligibility objectives but listener comfort and cost will be subordinate to it. If a budgeted cost objective is selected as having the highest priority, the purchaser should be aware that the design might necessarily compromise the other performance objectives in order to achieve the budgetary objective.

It is highly recommended that the arrangement of priorities be carefully considered so that the final result will satisfy the client's needs and concerns for design priorities.

TRANSLATING DESIGN OBJECTIVES INTO SPECIFICATIONS

Optimum acoustical results can only be achieved through careful specification and coordination. There are several key acoustical parameters which must be controlled to achieve the performance objectives. They are as follows:

1. Background noise control
2. Reverberation control
3. Transmission isolation control
4. Echo elimination

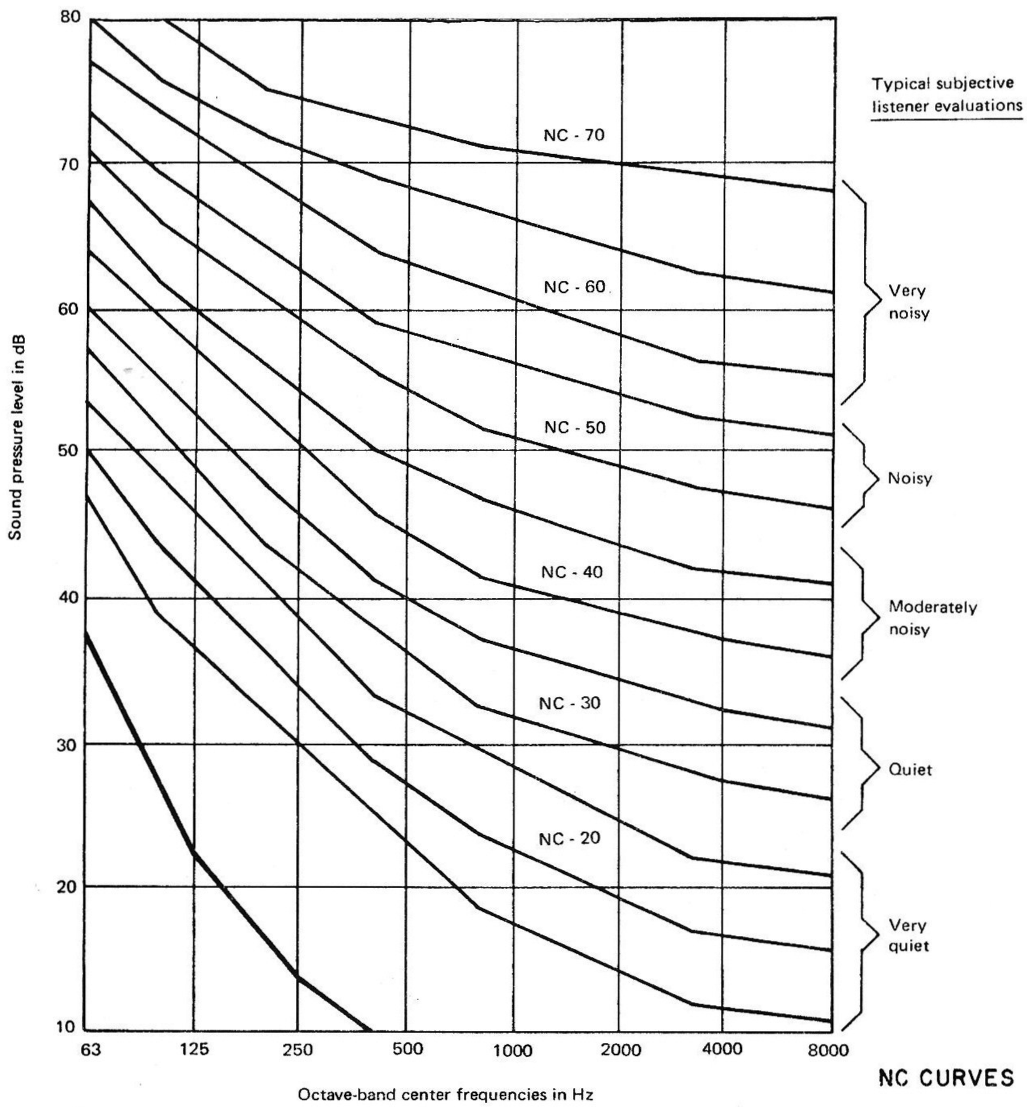
In the following paragraphs the design criteria for each will be discussed and methods for implementing the needed control will be presented.

BACKGROUND NOISE CONTROL

Background noise is that noise within a facility resulting from the building's HVAC system, mechanical or electrical equipment, noise entering the room from external sources, noises caused by occupants of the room, etc. Background noises are not a part of the speech or program sounds and are usually not intentionally generated. Background noise must be controlled, however, in order to achieve the proper ambient condition which will allow the spoken word and program material to be easily understood. Various facilities have different optimum background noise levels. The chart below illustrates the optimum background noise levels for some typical unoccupied facilities.

Recommended Noise Criteria Curves

Type of Space	Curve
Broadcast studios	15–20
Concert halls	15–20
Legitimate theaters (500 seats, no amplification)	20–25
Music rooms	25
Schoolrooms (no amplification)	25
Television studios	25
Apartments and hotels	25–30
Assembly halls (amplification)	25–35
Homes (sleeping areas)	25–35
Motion-picture theaters	30
Hospitals	30
Churches (no amplification)	25
Courtrooms (no amplification)	25
Libraries	30
Restaurants	45
Coliseums for sports only (amplification)	50



NC CURVES

Excessive background noise can be a source of listener discomfort and irritation, as it makes concentration and comprehension more difficult. It can also impose an undesirable burden on the talker or other program source to produce a higher sound level.

As background noise levels rise, sound listeners will necessarily require an increasing speech or program level in excess of the background noise level in order to maintain intelligibility . Ideally, the differential between the signal and noise should be 15 to 20 dB. This is referred to as the signal-to-noise ratio, and will be specified appropriately based on the background noise levels and the room reverberation time.

REVERBERATION CONTROL

Reverberation occurs within a room as sounds are reflected from interior surfaces. Since sound is radiated in many directions simultaneously, it will proceed to move throughout the room until it encounters a solid object or surface large enough to reflect or absorb it. Sound reflection follows the same principle as optical reflection, in that the angle of reflection equals the angle of incidence, measured with respect to a normal line perpendicular to the point of impact. A reflection may also be considered as a new sound originating from the reflective surface similar to the effect of producing a new visual image by the action of a mirror. When a sound encounters a reflecting surface, a portion of the energy is absorbed by the surface. The remainder is reflected. The fractional part of the energy that is absorbed is termed the sound absorption co-efficient of the material. It is really a percentage expressed as a decimal which defines the amount of energy which is abosorbed. For example, if a marble surface has an absorption co-efficient of .01 this means that 1% of the sound energy striking it will be absorbed while 99% will be reflected. Similarily, acoustical materials having an absorption co-efficient of .95 will absorb 95% of the sound and reflect only 5%.

Reflected or reverberant sound varies in facilities in relation to the absorbtive capabilities of the material in the room. A high concentration of reflective material will cause a greater number of reflections. For example, if sound is produced in a room constructed entirely of marble, it will be reflected hundreds of times at 1% absorption per reflection. In contrast, if highly absorptive materials are predominant, the sound may be reflected only once or twice before being reduced to a level below audibility.

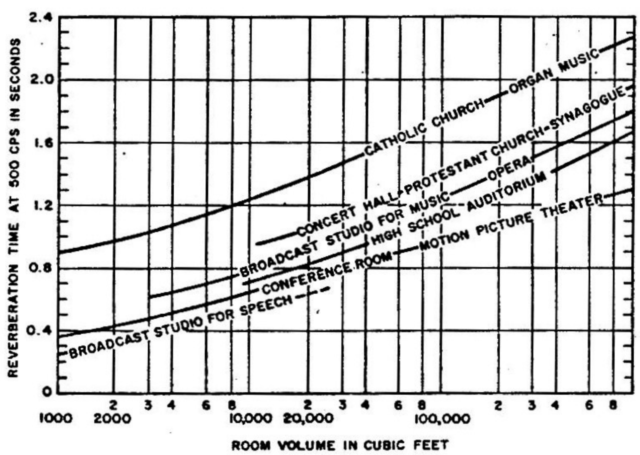
The time required for the sound to decay 60 decibels, (generally considered to be a typical dynamic range of hearing), owing to the sound reflections is termed the reverberation time of the room. (RT60)

Every facility has an optimum reverberation time based on the size of the facility and the intented use. The chart below indicates the optimum reverberation time for various facilities. Reverberation is one of the important factors governing the intelligibility of speech. It also effects the general noisiness of the facility.

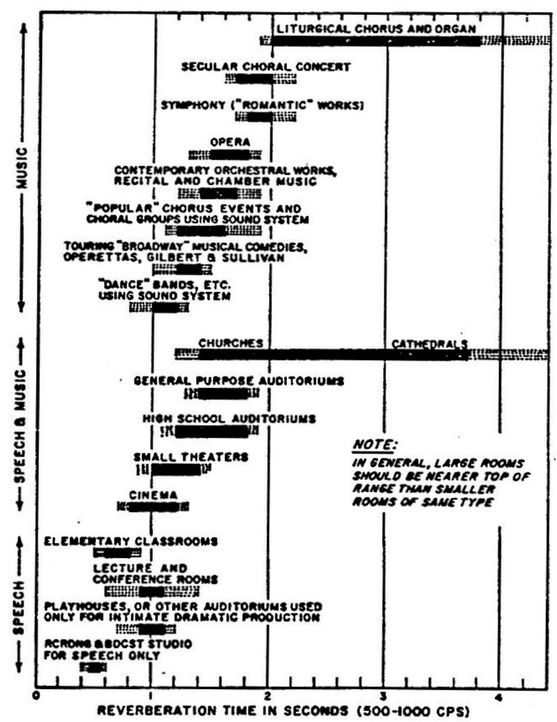
Reverberant sound energy can be either beneficial or detrimental to sound reception. A limited amount of reverberation can add beneficially to the sound level received by the listener and increase intelligibility. On the other hand, excessive reverberation causing one sound to persist or hang over while the next sound is being spoken or generated, therefore acts essentially as noise to confuse the listener.

Reverberation can be controlled through careful selection of interior finish materials and furnishings, so that the combined absorption capacity will result in the desired decay time (RT60). Attention should also be given to the distribution of the absorptive materials, as it is necessary to have proper amounts of absorption in all 3 room dimensional planes, (floor to ceiling, side to side, front to back). For example, installation of a highly absorptive acoustic tile ceiling will not cure reverberation problems in a room which also has four hard walls and a hard floor.

REVERBERATION TIME CRITERIA



Optimum reverberation times for various size areas.

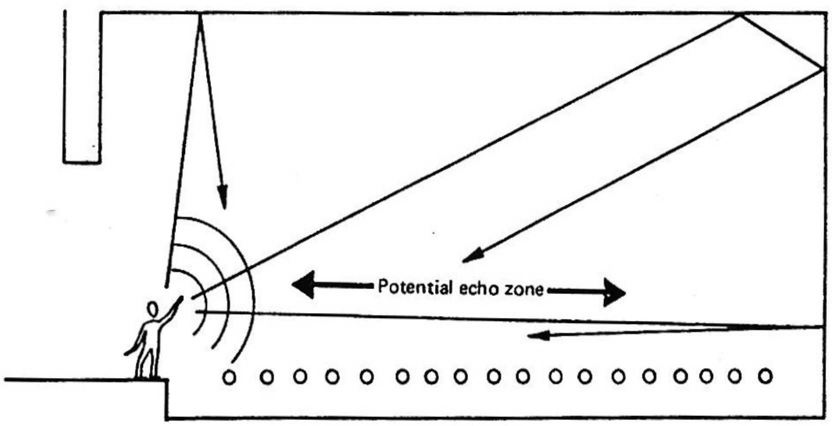


Optimum mid-frequency reverberation times for various facilities.

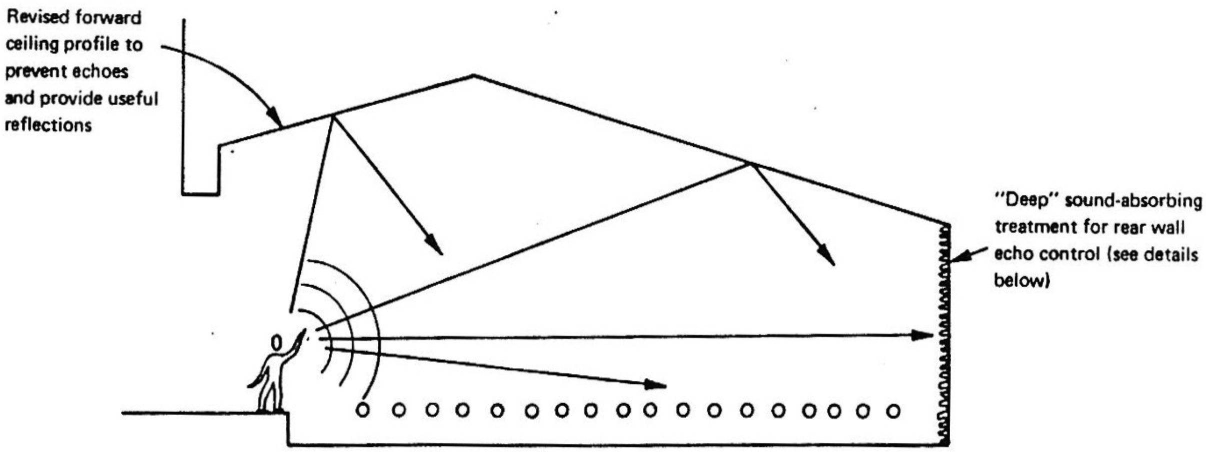
ECHO ELIMINATION

An echo is a reflected sound that reaches a listener approximately 1/17 of a second or more after the first initial direct sound. A sound path differencial greater than 50 feet can cause an echo. Echos cause distinct problems for listeners as their blurring effect can greatly reduce speech intelligibility and degrade sound and program reception. Echos should be minimized by reviewing the facility design and acoustically treating any reflecting surfaces which might cause echos.

Potential echo-producing surfaces should be treated with efficient sound-absorbing materials or shaped as shown below, where the forward ceiling is lowered and reoriented to provide useful reflections.



Potential echo-producing surfaces



Revised ceiling profile

TRANSMISSION ISOLATION

Transmission isolation refers to the ability of a particular facility to isolate itself from adjoining facilities or outdoor areas. Walls, floors, ceilings, windows and doors comprise the barriers through which sound can be transmitted. Each material and element of the perimeter construction has a sound transmission loss rating usually specified as an STC rating. The composite or overall sound transmission rating of a facility is only as good as the weakest element. All potential sound paths, including air gaps, must be considered. The chart below shows the optimum sound isolation ratings for various types of facilities.

The appropriate sound isolation rating should be specified for each facility so that the ambient noise level within the facility, including sound received from adjacent areas, will not cause undesirable interference with speech and program reception.

Suggested Sound Transmission Class (STC) Ratings for Partitions

Source Room \ Receiving room	Audio-visual facilities	Classrooms	Gymnasiums	Kitchens	Laboratory work spaces	Libraries	Music practice rooms	Reception areas
Audio-visual facilities	50	50	15	15	50	50	50	50
Classrooms	20	35	–	–	35	35	–	35
Gymnasiums	35	50	–	–	20	50	20	20
Kitchens	50	65	15	–	50	65	35	50
Laboratory work spaces	15	35	–	–	–	35	15	15
Libraries	–	–	–	–	–	–	–	–
Music practice rooms	50	50	–	–	15	50	65	15
Reception areas	15	35	–	–	35	35	–	–

WORKING WITH AN AUDIO CONSULTANT

It is recommended that the services of a professional audio consultant be retained to aid in setting design priorities, establish acoustical design specifications, and aiding in the accomplishment of those objectives.

Through the wonder of computers it is now possible and practical to predict performance results based on complex mathematical computations. By working with the design team during the blueprint drawing stage the audio consultant can recommend the most practical and economical means to accomplish the design objectives.

If the facility is already constructed the audio consultant can make necessary onsite tests to determine the exact nature of the existing acoustical environment. He can then recommend various methods of modifying the room acoustics to allow for optimum performance conditions.

IS A SOUND SYSTEM REQUIRED?

Once the acoustical design has been finalized it can easily be determined whether or not a sound system will be required in a facility. Expected natural audio performance can be compared to desired audio performance specifications, the difference being the needed amount of sound system supplementation. A competent sound system consultant can recommend a complimentary sound system design to satisfy the user's needs.

SAMPLE ACOUSTICAL DESIGN WORKSHEET

Attached is a sample acoustical design worksheet to aid in establishing acoustical design objectives and design specifications. A successful project will require attention to each item.

ACOUSTICAL DESIGN WORKSHEET

Facility Name:______________________________ Ref.#___________________
Owner: _____________________________________ Agent:___________________
Prepared For:_______________________________ Date:____________________

Type of Classification of Facility:____
Intended Use:___Speech___Music/Program___Other:____

Design Objectives

indicate	___Achievement of AUDIO COMFORT
priority	___Achievement of SPEECH INTELLIGIBILITY
ranking	___Achievement of OPTIMUM MUSIC & PROGRAM RENDITION
	___Achievement of EASE OF FACILITY OPERATION
	___Achievement of a BUDGETED COST OBJECTIVE

Design Specifications

Ambient Background Noise Criteria: Conform to NC_____________________
Room Reverberation Time: RT60____________ sec.
Sound Isolation Rating: Floor___________ Ceiling______________
Walls____

Speech Intelligibility: Alcons____________% or better
Special Music & Program Requirements: ____No ____Yes

Comments: