PDHonline Course A176 (2 PDH)

An Introduction to Architectural Design: Theatre and Concert Hall Acoustics and Communications

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An Introduction to Architectural Design: Theatre and Concert Hall Acoustics and Communications

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(This publication is the fifth in a series of five dealing with the design of theatres and concert halls.)

(Figures, tables and formulas in this publication may at times be a little difficult to read, but they are the best available. **DO NOT PURCHASE THIS PUBLICATION IF THIS LIMITATION IS UNACCEPTABLE TO YOU.)**

1. ACOUSTICAL CONSIDERATIONS. A synopsis of the most important acoustical concepts is presented here. Listening requirements determine acoustic parameters for volume, absorption, background noise, partition isolation, reflection patterns and audience-to-performer relationships. These in turn influence design decisions related to building site, Room scale, materials of construction, Room decor, shapes of surfaces, suspended reflector locations, HVAC air velocities and system treatment, location of ancillary spaces and loudspeaker placement. Speech intelligibility is essential for a Drama Room. This can be achieved by keeping the volume of the Room low in relation to seating area and placing reflecting surfaces in locations that will direct early high frequency reflections to all listeners. Background noise must be kept low enough to allow listeners to comfortably perceive average speech sound pressure levels. Continuous background noise from mechanical or electrical equipment can mask speech sounds, making it difficult or impossible to understand performers. Intermittent noise is a distracting element that reduces listening enjoyment. Acousticians have developed standards for preferred background noise level in relation to activities contemplated in a Room. These standards are referred to as Noise Criteria or NC curves. The NC curve specifies permissible ambient sound pressure levels at each frequency. Time delays are appreciable. Sound waves moving through air travel much slower (about 1100 fps) than light. This factor must be considered when designing very large Rooms and amphitheaters.

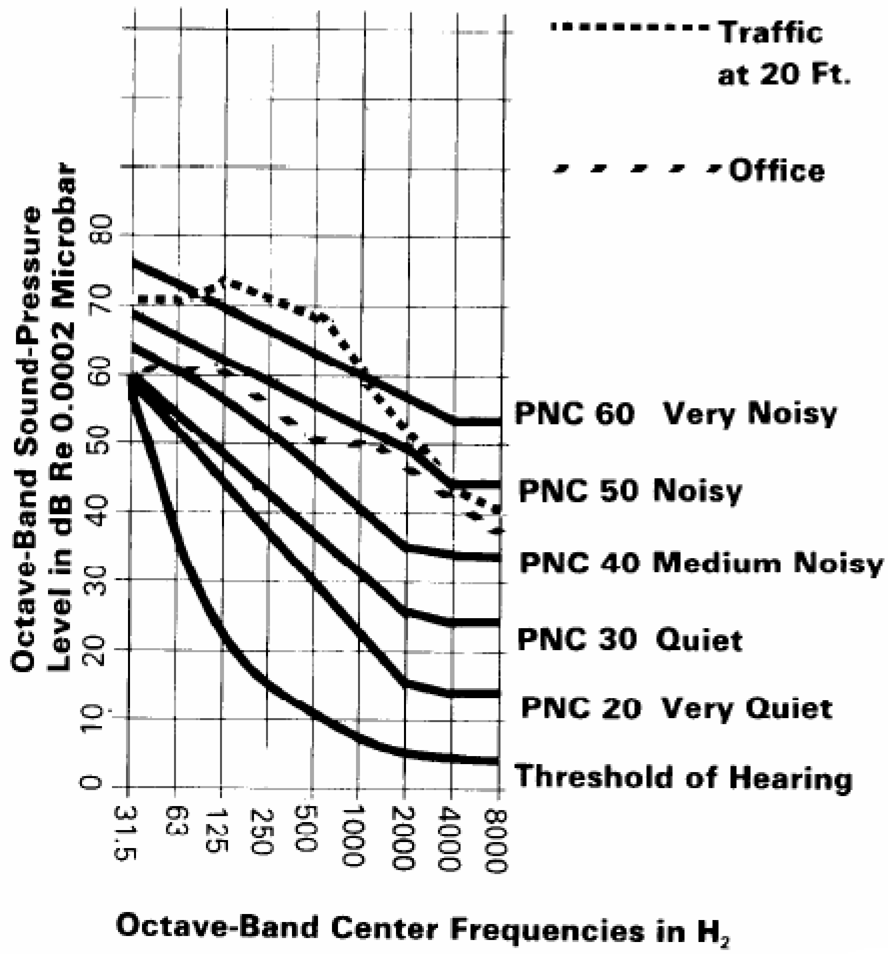


Figure 1

Preferred noise criteria

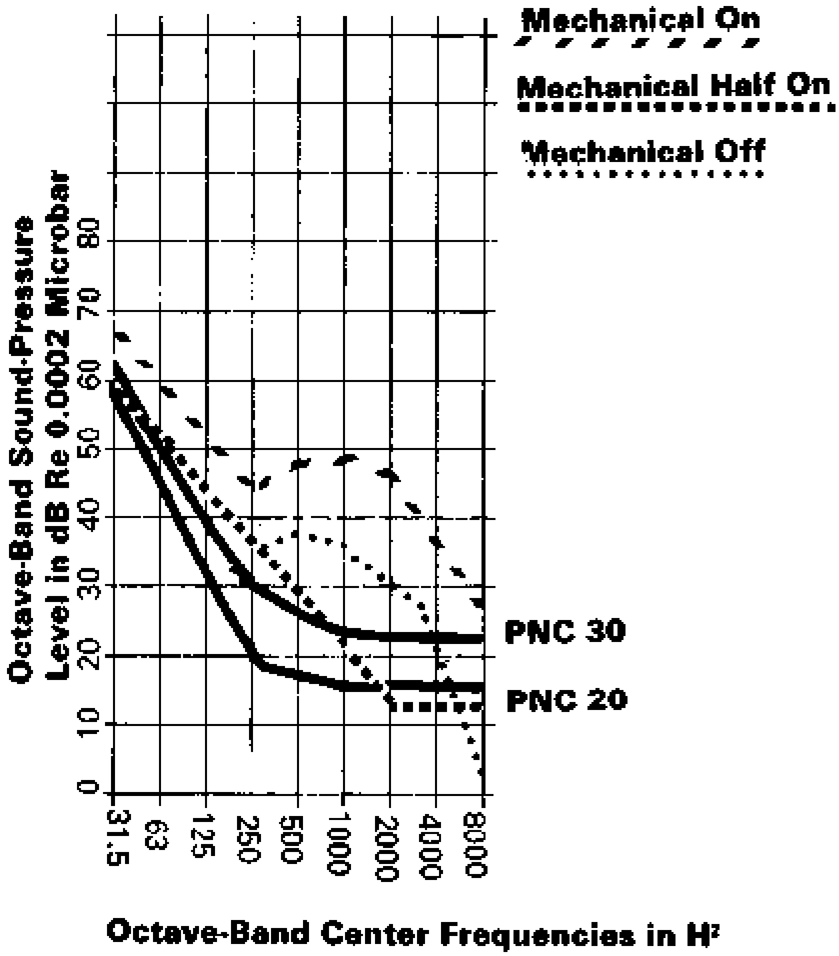


Figure 2

Typical mechanical noise conditions to be mitigated

Aural and visual perceptions will be non-synchronized when the distance between source and listener is too great. Moreover, live and artificial sound will be non-synchronized and garbled when distributed loudspeakers do not incorporate adjustments for time delay. Aural feedback is needed by performers to assess their effectiveness. An acoustically "dead" house will produce excessively late reflections which may confuse the actor, causing hs to slow his speech in order to gain intelligibility. Music-theater requires the singing actors to have good aural contact with their accompaniment. This is usually solved by means of good orchestra pit design.

When drama or musical-theater is amplified, it is essential that the sound console operator be located somewhere within the audience seating area. Mixing live performance is a delicate and difficult assignment. It cannot be done effectively from a sound booth with or without an operable window. Music listening enjoyment is largely derived from the relationship between source sound coming from the musicians' instruments and the reflection patterns heard by the listener over a two to three second period. The perception of both the source and reflected sound fields are related to:

1. *Direction from which sound energy reaches listener.*
2. *Amplitude or intensity of sound energy*
3. *Frequency composition of original signal and each reflection.*
4. *Time intervals between arrival of reflected energy signals and direct sound.*

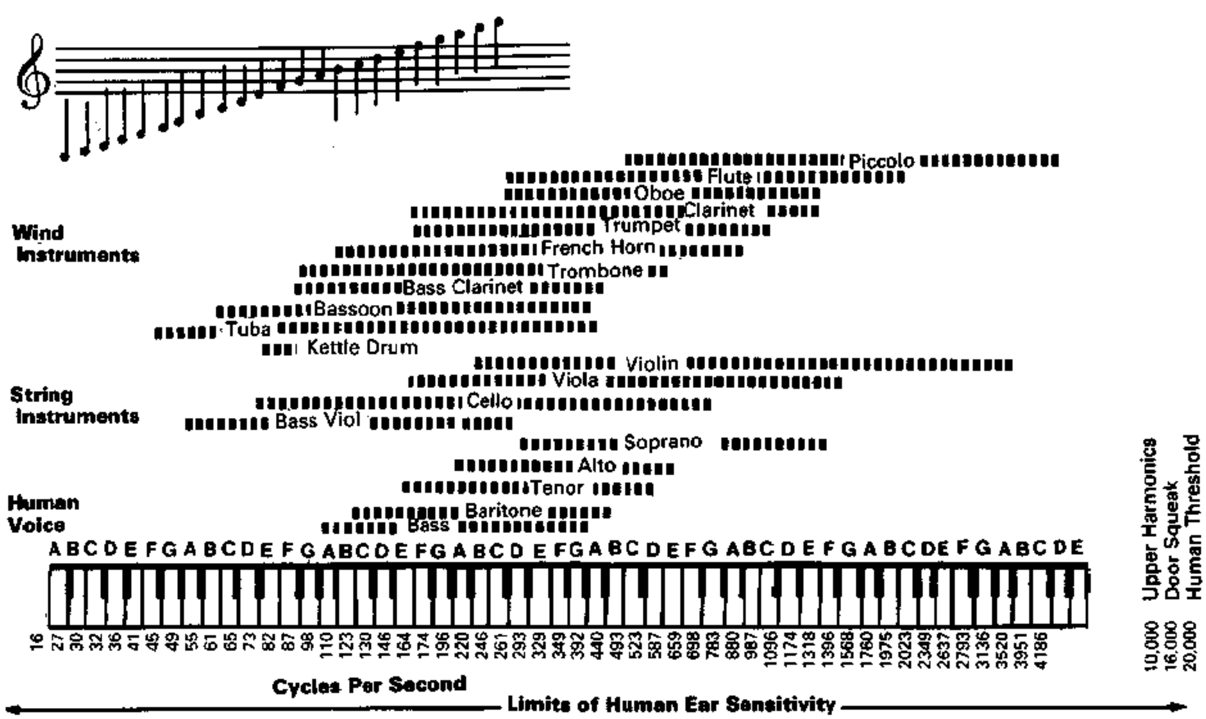


Figure 3

Sound frequency characteristics

Reverberation time has been identified as an important general measure of appropriateness for various uses. It is by no means the only measure, nor a simple one. The standard measure is the time required for sound in the Room to decay by 60 decibels after its source is cut off. It differs with frequency and must be evaluated over a range of octaves (frequency bandwidths) discernible by human ears. The typical reference is 500 cycles per second, or C above middle C. However, the center of average hearing range lies between 500 and 1000 cps. A simplified equation for Rt60 is:

$$T = \frac{0.049V}{Sa + 4mV}$$

T = time in seconds; **V** = volume of air in the Room in cubic feet. This includes House and Stage enclosure for Music Rooms. The stagehouse volume behind a Drama curtain is discounted.

Sa = total Room absorption in sabines; it is a function of individual absorption coefficients peculiar to materials and furnishings, and their surface areas. Obviously, practical estimates are employed for analysis purposes.

M = air absorption coefficient, which varies according to relative humidity, stated in inverse feet. The difference between 70% and 30% RH is nearly a factor of two (at 2000 cps, $M = 0.0006$ and 0.0010 respectively).

Rapid estimates of appropriate Room volume required are made by assuming an "average" Room absorption typical to particular uses, assigning a volume-per-seat factor. This is clearly limited in application to the "typical" Rooms defined. A Surround music hall, for instance, requires a considerably higher volume-per-seat factor.

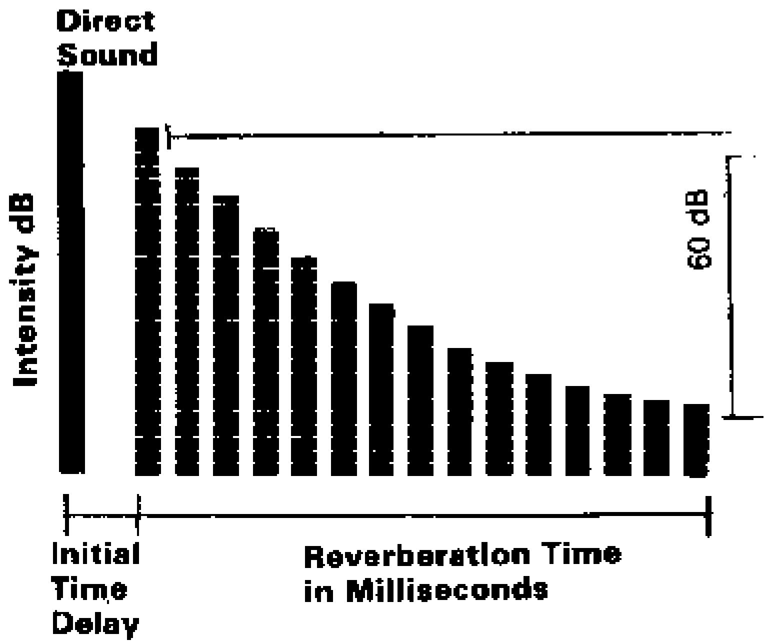


Figure 4

Reverberation time

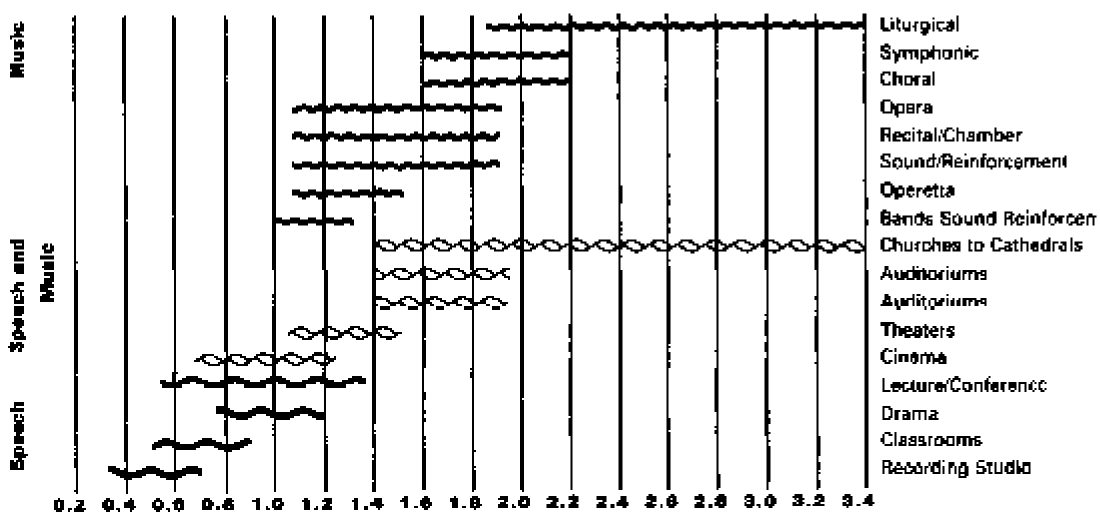


Figure 5

Reverberation appropriate to performance type

MATERIALS	COEFFICIENTS					
	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Brick Unglazed	0.03	0.03	0.03	0.04	0.05	0.07
Carpet Heavy 40 oz. Foam Pad	0.08	0.24	0.57	0.69	0.71	0.73
Concrete Block Coarse	0.36	0.44	0.31	0.29	0.39	0.25
Fabric 10 oz. Velour on Wall	0.03	0.04	0.11	0.17	0.24	0.35
Heavy Velour 18 oz. on Wall	0.14	0.35	0.55	0.72	0.70	0.65
Terrazzo Floor	0.01	0.01	0.015	0.02	0.02	0.02
Wood Floor	0.15	0.11	0.10	0.07	0.06	0.07
Gypsum Brd. ½ in. to 2 × 4 16 o.c.	0.29	0.10	0.05	0.04	0.07	0.09
Ventilating Grilles				0.15–0.50		
Plaster Smooth on Brick	0.13	0.15	0.02	0.03	0.04	0.05
Air per 1000 cu. ft.	—	—	—	0.9	2.3	7.2
Audience Seated per S.F. flr.	0.60	0.74	0.88	0.96	0.93	0.85
Unoccupied upholstered seats per S.F. flr.	0.49	0.66	0.80	0.88	0.82	0.70
Wooden Pews, occupied S.F. flr.	0.51	0.61	0.75	0.86	0.91	0.86

Figure 6

Coefficients of absorption

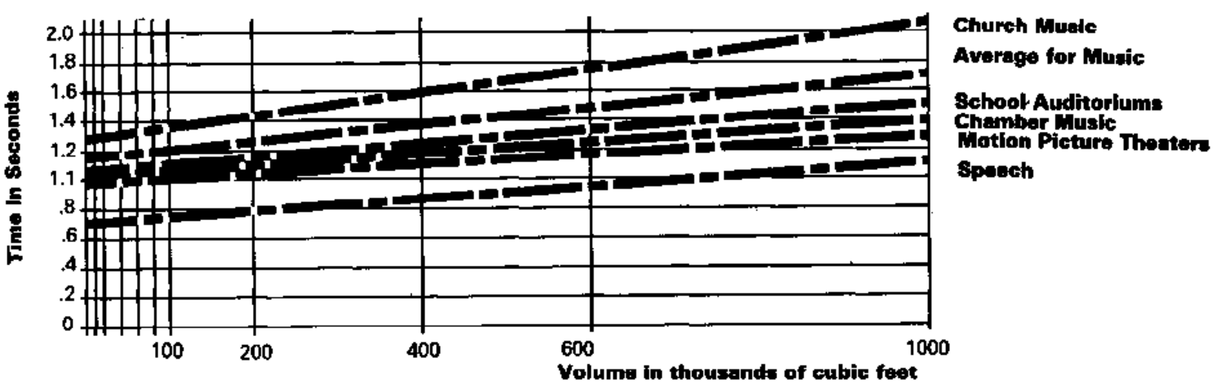


Figure 7

Volume estimate for typical designs

Decibels are not a direct measure of loudness, but of the difference in the level of two amounts of power-namely, 10 times the logarithm of the ratio. By international agreement, the reference sound intensity of human hearing is 10 –16 watts per square centimeter. With that as zero decibels, the range extends to 120 decibels, the threshold of discomfort. Decibels measure the energy in a pressure wave. Loudness is a subjective evaluation. A 10db increase doubles apparent loudness, 20db quadruples, etc. Musicians use their own vocabulary to describe the qualitative aspects of musical sound. It is the role of the acoustician to identify the physical acoustic criteria associated with each subjective parameter and translate these terms into useful architectural concepts. The accompanying charts and diagrams will help define the empirical basis and physical implications of acoustical properties.

2. ELECTRONIC SYSTEMS

2.1 COMMENTARY

This design guide has tended to emphasize natural acoustics for three reasons. First, it shouldbe remembered that no matter what mechanisms intervene, people hear with their ears, naturally, and impart an innate organization and sensitivity to the process. Second, there may be a tendency for design professionals and non-designers alike to assume the existence of equipment that will “fix” malfunctions brought about by lack of attention to and understanding of acoustic principles; this is usually false, and the misunderstanding can be a costly one. Finally, many of the functional criteria and conditions for good listening apply no matter what means is employed for generating sound to be listened to. Electronic audio systems simply introduce a few more steps in the signal path. Audio systems have four parts in common: Input transducer (microphone, tape head, phono cartridge), signal processor (tuning, filters, mixing, volume, delay), amplifier, and output transducer (loudspeaker). Signal processing accounts for major differences in application.

2.1.1 ELECTRO-ACOUSTIC ENHANCEMENT: This system’s purpose is to increase the reverberation time of a Room by introducing very small delays between the input and output by way of a digital processor. It may have one or more predetermined settings appropriate to various Room uses. Ideally, it will not alter the characteristic frequency response spectrum of a well-designed auditorium or provide acoustic gain (increased loudness). But in cases where a portion of the spectrum drops out of reverberant field, the processor can selectively strengthen that part. This corrective function (called equalization) can be useful when it is desirable to shorten natural reverberation time by adding absorptive material to the volume; the material tends to absorb certain frequencies more than others.

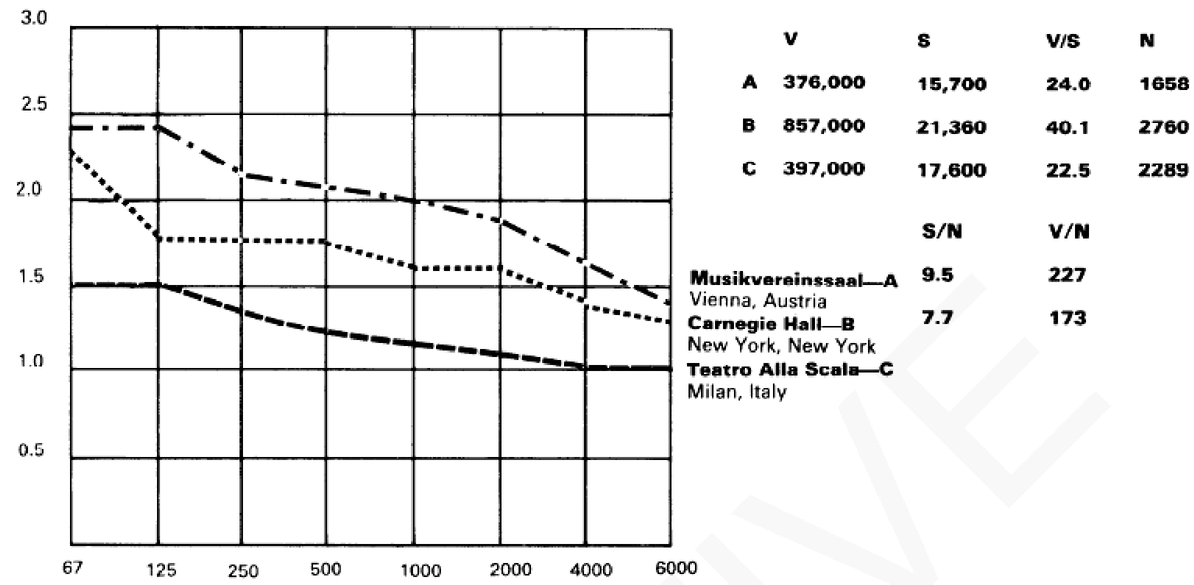


Figure 8

Reverberation time comparison

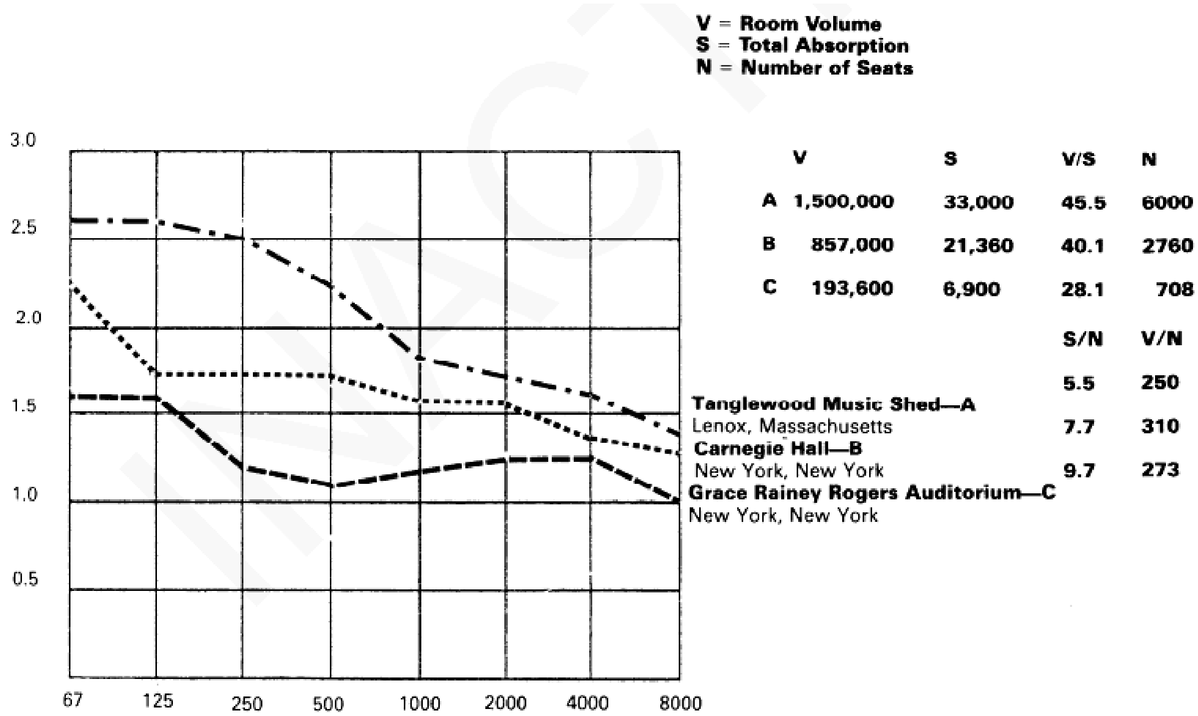


Figure 9

Reverberation time comparison

Symphonic Acoustics	Acoustical	Recital Hall	Music Pavilion	Surround Hall
Warmth-Bass Response	Rich late arriving low frequency reflections	Hard roof cap	Coupled overhead chamber	Coupled moat chamber
Articulation—Definition	Early mid and high reflections (20 ms)	Side walls	Forestage canopy	Forestage canopy
Presence—Intimacy	Early mid and high reflections (20 ms)	Side walls	Forestage canopy	Forestage canopy
Liveness—Reverberation	Proper R/Ts through frequencies	Volume/Absorption Ratio	Volume/Absorption Ratio	Volume/Absorption Ratio
Transparency—Clarity	Smooth R/Ts—Proper stage diffusion	Good diffusion, proper volume, shaping, no echo, no focusing	Good diffusion, proper volume, shaping, no echo, no focusing	Good diffusion, proper volume, shaping, no echo, no focusing
Balance—Sectional Relationships	Stage Design—Orchestral placement	Proper volume, shaping stage, stage risers	Tunable shell and risers	Tunable reflectors and risers
On Stage Hearing—Clarity	Stage Design—Orchestral placement	Proper volume, shaping stage, stage risers	Tunable shell and risers	Tunable reflectors and risers

Figure 10

Musician to scientist translation system

System design can result in two modes of operation: fixed, unattended, on-off operation; and variable, controlled, programmable operation. For some facilities, the second system is not recommended, as it requires a fully trained, fulltime system operator entirely familiar with its workings and the science of microphone and loudspeaker placement. Although it offers optional control over the widest variety of performance types and conditions of performer and audience arrangement, it will be wiser to build in the quality of selected configurations without reliance on expert operating personnel. The recommended approach to “assisted resonance” requires a carefully worked out pattern of installation designed for a given Room. Since it is the non-directional reverberant field that is energized, a large number of individual inputoutput channels may be employed, each covering a limited frequency bandwidth, the total of which cover the low- and mid-range spectrum. One microphone mounted in a selective resonant chamber (usually in the reverberant reaches of the Room near the ceiling) feeds one processor- amplifier that drives one carefully located speaker. In some instances, individual signalsoriginating at the stage or orchestra pit may be

mixed and fed to a number of full-range speakers in the house ceiling and balcony soffits. An enhancement system will probably not be required for some new facilities; good natural acoustic design is preferable at the scale of Rooms and production types anticipated. It will more likely be applicable to found space conversions where acoustical limitations are inherent
in the existing construction.

2.1.2 SOUND REINFORCEMENT. Amplification raises the level of direct sound sent into the Room, which can have several purposes. It can ensure sufficient loudness (or balance of loudness between stage and pit sources), intelligibility, naturalness, and directional realism if properly designed. It will be an important requirement of multi-use programs especially when absorptive material is used to reduce reverberation time and where (perhaps in conjunction with enhancement) a stagehouse shell has not been provided for music uses. System design will depend on conditions of use and Room configuration. There are four basic approaches related to loudspeaker locations. The most common arrangement employed by touring companies using a Room without adequate installed reinforcement is the temporary placement of speakers on each side of the proscenium. Apart from. ease of set-up, there is sometimes the advantage of reaching into underbalcony recesses. However, for the majority of the audience, unnatural amplification will be evident and in many instances distracting, due to directional conflicts between eyes and ears. In extreme cases, sound from the more distant speaker will be heard as echo. The most common installed system utilizes a central loudspeaker cluster directly over the proscenium. This very simply eliminates split system problems by positioning the speakers in a complementary spatial and temporal relationship to the onstage source; the sound arrives from the same direction and at the same time. The only exceptional circumstances would be dialogue across a very wide proscenium, down a very deep stage, or in a Thrust or Surround arrangement. In other words, it assumes a dominant central focus. Its only physical disadvantage may be the difficulty of reaching under deep balconies from an especially high proscenium position. A variation of the central cluster scheme responds to the first exception by locating three to five clusters across the width of the proscenium, with corresponding microphone inputs so that apparent sound direction moves with its source. Either the microphones or the wireless receivers (if used) must have directional qualities while the speakers do not, to avoid differential delays caused by source distance across the stage. Alternatively, fixed omnidirectional microphones may incorporate preset time-delay feeds to each speaker, the longest to the most distant speaker, along with a scaled level adjustment. Often only the central cluster is used for speech presentation, and the others turned on for large choral or orchestral groups, stereophonic effects, or high level amplification (rock or popular music) that would overpower and distort the normal central cluster elements. Finally, carefully designed directional side clusters or a distributed loudspeaker system may be installed supplemental to the central system, for deep under-balcony spaces or for unusually “dead” or uneven Rooms encountered in found space conversions. The distributed system always incorporates time-delay processing, not to provide reverberation but to ensure that live sound arrives, establishing directional realism, closely followed by reinforcement sound. Criteria include low gain relative to stage and central sources, and required proximity to the affected audience to avoid echo perception at the front of the house. A slightly greater (+2 db) gain can be obtained if under-balcony sound arrives about 15 milliseconds after the cluster sound. The central cluster arrangement is the most likely choice for some facilities described in this guide. In fact, it is probable only the large (1400 seat) House will require a reinforcement system for multi-use programming, to increase speech intelligibility for drama presentation and enable popular entertainers, using electronics as part of their art form, to effectively function in the space. The main components would be a central cluster three-way loudspeaker system with separate low, mid, and high end speaker components. Each of these components should be amplified separately and balanced with electronic crossover networks. The design of such a system requires an experienced professional. While this preferred system utilizes a limited number of loudspeaker outputs, it requires a multitude of input microphone receptacles in the stage area and current practice is to provide a 40-pair shielded cable from the stage to the control location in the house and the main control booth. It is essential that the sound reinforcement console be operated from a position in the house. It is impossible for an operator to achieve good balance of either speech or music programs when operating the system in a closed booth, or in a booth having an operable window. For this reason, the tie lines are split at the stage with one set going to an in-house console location, and another set going back to the control room. Since it is necessary to move the console from the control room to the house position frequently, it might very well be advisable to purchase standard commercial reinforcement consoles in modular sections of 8 to 12 input channels each. Three 8-input channel boards can be plugged together to form a 24-input channel mixer, a reasonably sophisticated device for a 1400-seat house. Please bear in mind that if the 1400-seat house has high drama use, additional output channels and speaker delegation switches will be required. The normal sound reinforcement system console does not include these components as a standard part of its design.

2.1.3 THEATRICAL SOUND EFFECTS. An effects system is conceptually the opposite of a reinforcement system. It would usually have a limited number of inputs, 4 to 12, with a large number of outputs. Output delegation switches allow the operator to feed the signal to the loudspeaker of his choice in a wide variety of locations both on stage and in the house. Obviously, in such a situation each speaker must be fed by its own individually controlled amplifier. This system should be independent of the reinforcement system because directional realism may demand that sound effects such as doorbells, thunder, sirens, shots, etc., appear to originate off stage or even in the house. Therefore, it is advisable to keep the design flexible and just provide receptacles for loudspeaker leads in a variety of locations. One left and right on the proscenium and three or four on the backstage wall would be sufficient. Sometimes a receptacleIn terms of the House we may find that the director would like to provide a sound effect that is directionally oriented in relation to the seating area. In other words, sound coming from the left to the rear or from the right of the audience, or perhaps a sound that would be panned across the audience in either direction or panned around the audience from one direction to another. In this instance it is good to put a series of small speakers of bookshelf or studio monitor type around the auditorium in certain locations. A minimum arrangement would be one on both the left and right, which would be located about one third of the way from the proscenium to the rear, and one in the rear. The inputs of effects systems are usually tape recorders, turntables, cassettes and/or voice announcements over a microphone. The intervening electronics are fairly straight forward in terms of a simple mixing console with the required number of output channels to feed the various loudspeaker locations. This console is often remote from reinforcement controls, with a separate operating technician receiving cues from the stage manager on the loading gallery and pinrail is advisable. In terms of the House we may find that the director would like to provide a sound effect that is directionally oriented in relation to the seating area. In other words, sound coming from the left to the rear or from the right of the audience, or perhaps a sound that would be panned across the audience in either direction or panned around the audience from one direction to another. In this instance it is good to put a series of small speakers of bookshelf or studio monitor type around the auditorium in certain locations. A minimum arrangement would be one on both the left and right, which would be located about one third of the way from the proscenium to the rear, and one in the rear. The inputs of effects systems are usually tape recorders, turntables, cassettes and/or voice announcements over a microphone. The intervening electronics are fairly straight forward in terms of a simple mixing console with the required number of output channels to feed the various loudspeaker locations. This console is often remote from reinforcement controls, with a separate operating technician receiving cues from the stage manager.

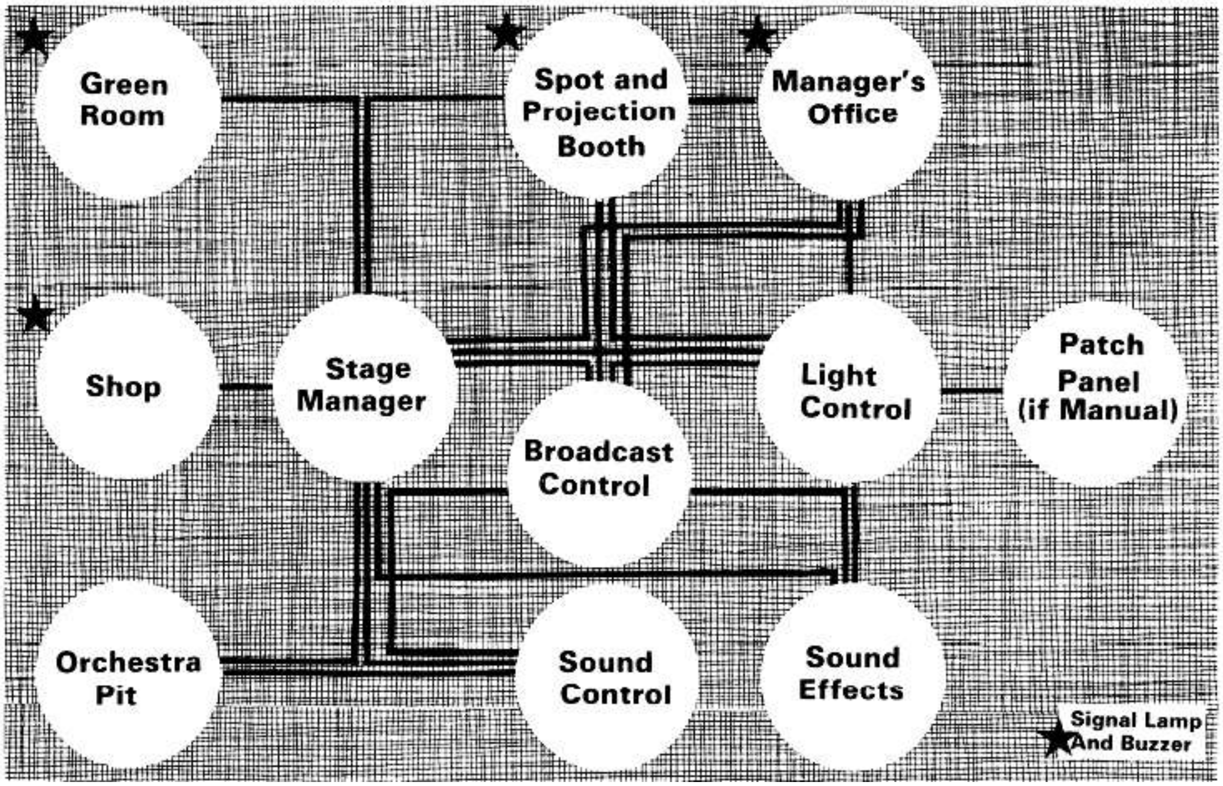


Figure 11

Intercommunications

Music reproduction for plays and dance is usually handled through an adptation of the effects system using all of the same equipment heretofore discussed. Stereo and quadraphonic material can be reproduced as long as four input channels and four output channels are available. In some circumstances the reinforcement speaker clusters may be brought into play. The reinforcement system will have been carefully adjusted to suit the Room acoustics. However when sound does not originate on stage, dancers and other performers may have difficulty hearing it in the stagehouse. In this situation the music should also be played on stage. When live music from the pit is miked through the reinforcement system to balance a weak pit orchestra, the above method may need to be modified so that music played on the stage does not arrive in the house too long after the direct and cluster sound. The onstage speakers should be located just behind the proscenium, directed to the actors. Directional pit mikes will minimize feedback. If actors on stage are miked (musical drama) voice/music channel separation becomes very important. A facility with minimal reinforcement capabilities may find it necessary to place a small orchestra itself on stage behind the action, where music and speech sound is picked up by reinforcement microphones.

2.1.4 MICROPHONES. The selection and placement of microphones for various activities is an art in itself and too difficult to describe in this discussion. It is recommended an experienced professional be retained to assist in this area. Most touring drama and professional music groups are familir with microphone setups and can usually instruct the house crew as to their preference. It is good to have a variety of microphones on hand for various purposes and a good mix is suggested.

2.1.5 PRODUCTION COMMUNICATIONS. A production communication system is one which allows the individual in charge of the production to communicate with members of the technical staff. A minimal system would be a single channel system with the main control position at the stage manger's desk in the stage wing areas. The lighting control operator, the sound effects console operator, the spotlight operators and the crew chief at the stage, pinrail and loading catwalk would all be in communication on this single channel. Several commercial systems are available. The most popular for theatres is a lightweight headset with single earpiece and boom mounted microphone, connected to a separate belt pack that will jack into a wall receptacle. On-stage crewmen sometimes do not like the constriction of this arrangement and prefer their communications in an integral wall mounted unit so they are not trailing any wires. A more sophisticated version of this same system would be a two channel system in which the technical lighting people would be on their own separate cue channel. This is recommended for Drama with more than minimal scenic support. The actor cue call and program monitor system is usually combined as a single cable loop system starting from the stage manager's desk and going to all the dressing room areas, manager's office, cast bathrooms, assembly areas, technical crew chief's office and general crew offices and staging areas. All of the rooms which are wired to the system will have a single speaker and a wall mounted volume control. A microphone hung just behind the main act curtain on stage will continually feed program and rehearsal material to all of the stations. Concurrently, whenever there is a specific cue call for an actor, orchestra, chorus members, corps de ballet, etc., the announcement emanating from the stage manager's console and activated by a push button will override the program material and announce the cue to all concerned. Should the program material be bothersome at any given time, the control knob on the wall will allow those in the room to reduce the volume to an inaudible level. However, under no circumstances will this deactivate the override actor cue capability. Therefore, even when the control knob is at its lowest position cue calls will always be audible in the various rooms. In certain rooms it might be desirable to eliminate cue calls; rooms such as the manager's office, the stage manager's office, etc. In these cases the cue call override wire can be snipped and only program material will be fed into these designated spaces. Quantities depend on specific circumstances. Add to these as required (the equipment can be rented) and have on hand at least half as many portable "bookshelf" speakers as there are effects output channels if not permanently mounted. Since the basic house central cluster reinforcement system is of minimal scope for some program, it is suggested the designer furnish sufficient on-stage A.C. power so that touring groups utilizing their own portable sound systems can set them up rapidly, allowing sufficient time for their technical personnel to conduct pre-performance sound checks. This provision is highly desirable for the 650 Seat Drama Room and 1400 Seat Music Room having no reinforcement systems.

2.2 ILLUSTRATIVE DETAILS. Following are tables and figures that illustrate equipment lists and construction details.

300 Seat Drama

- Actors call—main plus — 12 stations basic minimum, 20 stations recommended
- Program monitor— 16–24 stations
- Intercom—main plus 10–15 stations
- Effects/reproduction system— 4 input/16 output minimum
- Articulation/ reinforcement— not likely needed

650 Seat Drama

Same systems as 300 seat, more stations likely.

- Actors call — 24 stations extended/touring
- Monitor — 35 stations
- Intercom — 20 stations
- Effects — 8 input/20 output

650 Seat Music

Very little sound equipment is required for a small Music Room.

- Actors call—main plus — 8 stations basic, 12 stations recommended
- Monitor — 15–20 stations
- Intercom—main plus 7–10 stations
- Announce system—portable or built-in, 4 mike locations

1400 Seat Music

Same systems as 650 seat, more stations likely.

- Actors call — 24–30 stations
- Monitor — 36–40 stations
- Intercom — 12–15 stations
- Announce booth plus — 6–8 plug—in receptacles

Multi-Use/Musical Drama

- Actors call — 24–30 stations
- Monitor — 36–40 stations
- Intercom — 24–30 stations
- Effects — 12 input/20–30 output
- Articulation/ Reinforcement — 24–40 input channels

Microphone Assortment, Modest Inventory

- 16 High quality cardioid microphones, either dynamic or condenser type (used for general purpose pickup.)
- 3 Super cardioid microphones (used for difficult situations and for stage floor pickup).
- 3 Omni-directional microphones (especially designed for close-up vocal work).
- 1 Medium quality cardioid microphone with built-in switch (used for off-stage announcements).
- 2 Lavalier microphones (used for lectures, etc.).

Figure 12

Suggested audio/communications equipment

Qty.	Description	Manufacturer	Type
	1. Articulation System		
2	Loudspeakers	Custom	
3	Microphones	Special	
6	Pre/Summing Amplifiers	Spectra Sonics	110
3	Transformers	" "	T67
3	Power Amplifiers	" "	701
1	Card Holder	" "	202fc
1	Card Holder	" "	201C
1	Regulator	" "	411
1	Power Supply	" "	404RS
1	Rack	Soundolier	300-42
1	Control Panel	Custom	T07
	2. High Level System		
2	Loudspeakers	Spectra Sonics	3000
12	Power Amplifiers	" "	701
2	Electronic Filters	" "	505
2	Transformers	" "	T66
2	Card Holders	" "	202PC
1	Power Supply	" "	404RSD
1	Limiter	" "	610
1	Processor	UREI	567
2	Microphone Plugging Box	Custom	
1	Rack	Emcor	
	3. Effects System		
6	Loudspeaker	JBL	4350
12	Power Amplifier	Spectra Sonics	701
2	Card Holder	" "	202PC
1	Power Supply	" "	404RSD
6	Transformer	" "	T66
2	Patch Panel	ADC	PJ-738
24	Patch Cord	ADC	PJ-712 TL
	4. Stage Monitor System		
2	Loudspeaker	Bozak	CM-209-11CH
4	Power Amplifier	Spectra Sonics	701
1	Card Holder	" "	202 PC
1	Power Supply	" "	404RS
2	Stage Speaker Plug Box	Custom	

Figure 13

Sound system equipment specified for a 1200 seat musical drama open stage

	5. Backstage System		
20	Loudspeaker	Soundolier	C10T70
20	Enclosure	"	95–8
20	Baffle	"	51–8
10	Priority Volume Control	"	AT10PA
2	Power Amplifier	Spectra Sonics	701
1	Line Transformer	" "	T70
1	Power Supply	" "	404RS
1	Card Holder	" "	203 PC
2	Microphone	Electro-Voice	621
1	Fly Microphone	" "	RE–10
2	Mixer/Preamplifier	ALTEC	1589B
1	Stage Manager Control Panel	Custom	
	6. Lobby System		
30	Loudspeaker	Soundolier	C10T70
30	Enclosure	"	95–8
30	Baffle	"	51–8
2	Power Amplifier	Spectra-Sonics	701
	7. Production Intercom		
1	Main Station	Clear-Com	ES–200K
12	Remote Station	" "	RS–100A
12	Headset	" "	CC–240
12	Extension Cable	" "	IC–25
2	King Biscuit	" "	KB–111
	8. Miscellaneous Equipment		
1	Control Console	Tangent	1602a
16	Microphones with Accessories		
1	Tape Recorder	Ampex	AG–440
1	Phono Reproducer		
2	Monitor Speaker	Bozak	CM–200–2
2	Rack	Emcor	

Figure 13 (continued)

Sound system equipment specified for a 1200 seat musical drama open stage

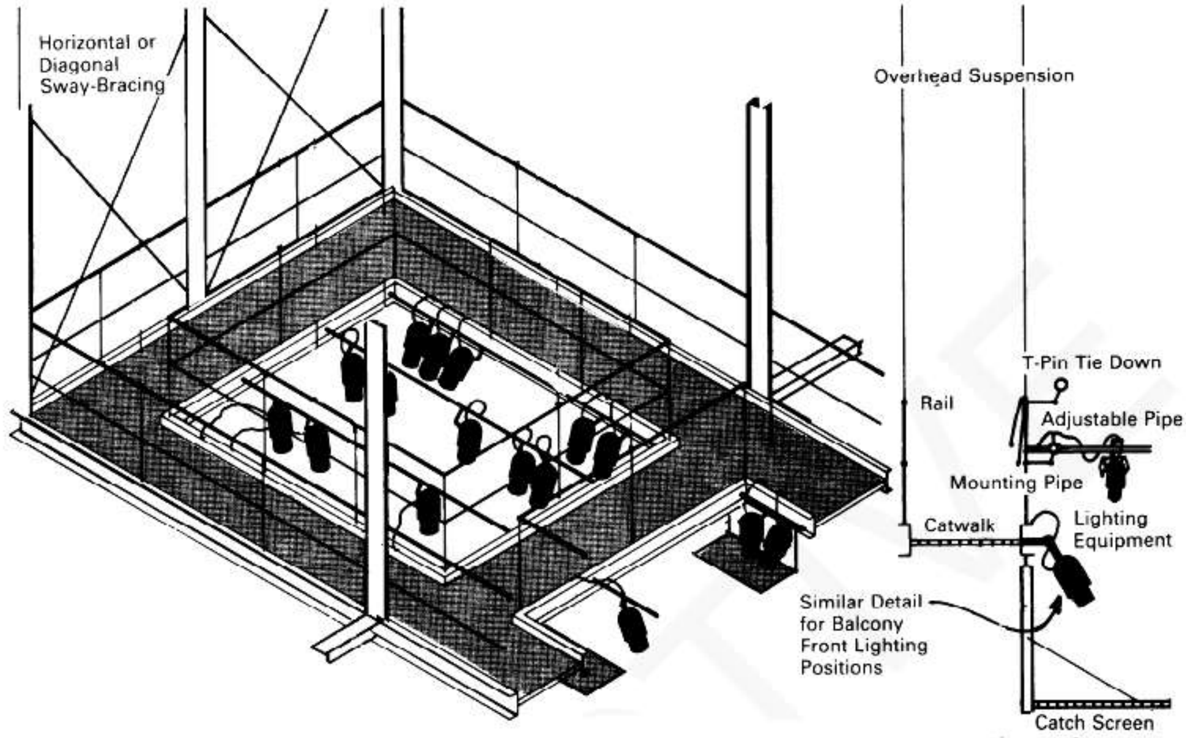
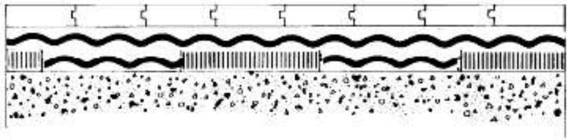


Figure 14

Lightweight stage grid



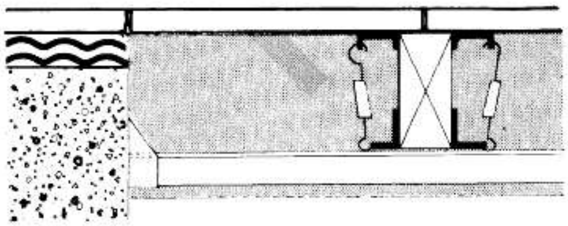


Figure 15

Stage and rehersal floor construction

Trap construction

AIR-BORNE NOISE ORIGINATING IN THE THEATER

Source	Method of Prevention
Radiators	Heat the house entirely by circulated air, or wall or floor radiation. On stage 1. Radiator Return line graded to avoid condensate and resultant banging. No valves to hiss. 2. Circulate hot water rather than steam. 3. Use radiators for rehearsals and pre-performance only.
Stage Wagons, Turntables (Noise magnified because of reverberant stage floor)	1. Well-made ball or roller bearing casters running on level tracks installed over stage floor. 2. Revolving stage on its own support structure. 3. Slow hydraulic elevators are quiet; the screw-jack type are noisy. 4. Remote isolated elevator machine room.
Audience (Talk, shuffling)	1. Make crossover sound absorbent. 2. Lobby doors opposite aisles used for exit, not during show. 3. Divide rear crossover from house. 4. Carpets. 5. Silent seats.
Orchestra Pit	1. Rubber feet on chair legs and stands. 2. Prearrange and rehearse placement.
Telephones	Locate only where one open door will not permit sound to reach house or stage. Light instead of bell on stage.
Backstage Noise	Minimize personnel on stage, rehearse cues thoroughly. Minimize loose tools, properties.

SOLID-BORNE NOISES

Source	Method of Prevention
Train or Street Rumble	Vibrant-isolating mounts under columns, vibration-isolating joints in walls. Compliant substance between grade walls and back fill. In case of excessive vibration, float interior walls and floors.
Air-Handling Units	Locate remote. Isolation mounting and soundproof room, regular maintenance.
Vibration from non-theater functions of building	1. Locate in remote building with independent structure. 2. Float the floor of the facility at which the vibration originates. 3. Structurally discontinuous sound-lock connecting passages only.
Motors, Machinery	Vibration isolating mounts, gearless transmission.
Plumbing	More than one wall between house and facility. Isolate from structural members. Silenced flush valves, vestibule doors.

AIR-BORNE NOISES ORIGINATING OUTSIDE THE HOUSE

Ingress	Method of Exclusion
Doors	Airtight fit (A hairline crack will raise the transmitted sound level 6 db.) Double-door systems are necessary to isolate the scene shop, lobby, street, etc. from the stage. (Doors opening on alleys or halls may be less of a problem than if they open on the street. Open only into spaces which can be kept reasonably quiet.)
Windows	1. Prefer none. 2. Double where used and not capable of being opened.
Ceiling Slots	Exclude sound from loft by roof insulation, solid catwalks, tight doors.
Projection Booth	Quiet machines. Sound absorbent walls and ceiling in booth. Glass in viewing ports.
Ventilation Ducts	1. No metal connection between blower and steel structural members, or blower and duct. 2. Ducts and diffusers sized for PNC when blower operates at full speed (above normal operating speed). 3. Sound-insulated ducts. 4. Long run-out to first diffuser.
Roof	A massive slab with a tight ceiling below it, if necessary. Hang ceiling on resilient mounts.
Alternator, for Motorized Rigging	Locate in soundproof vault outside the theater.

Figure 16

Typical corrective measures for noise control

	Slot Speed at Terminal	10′ of Duct Before Opening	Next 20 Ft.	Next 20 Ft.
NC–15 Supply	250 Ft/Min.	300	350	400
NC–15 Return	300	350	400	450
NC–20 Supply	300	350	425	500
NC–20 Return	350	400	500	650
NC–25 Supply	350	425	550	700
NC–25 Return	425	500	650	800

Maximum Duct Velocities (feet/minute)

Figure 17

Suggested HVAC criteria, noise control

CONSTRUCTION	TRANSMISSION LOSS AT LISTEN FREQ. H,						
Walls	125	250	500	1000	1000	4000	STC
2" Solid gypsum. Sand aggregate plaster 18 PSF	31	32	33	38	45	53	38
4 in. Pumice block, unpainted 16 PSF	18	19	26	32	35	40	38
4½ in. solid brick plastered both sides 45 PSF.	24	35	40	51	57	60	46
2×4 wood studs, ½ in. sand aggregate plaster on ⅜" gypsum lath both sides 16 PSF	27	25	31	44	34	50	34
3⅝ in. sheetmetal stud ½ in. gypsum board both sides 2½ insulation in airspace 16 PSF	27	36	48	56	50	46	46
2½ in. wire studes ½ in. sand aggregate plaster on ⅜ in. gypsum lath on ½" resilient metal clips 12 PSF	30	57	43	48	43	60	45
4 in. hollow concrete block 24 PSF painted ½" gypsum board on resilient furring channels 1" insulation	27	44	57	64	61	55	51
Two wythes of plastered 4½ solid brick 2" air space sound absorbing mtl. air space 90 PSF.	43	50	52	61	73	78	59
Floor Ceiling							
Finish & subfloor on wood joists gypsum lath and plaster below 15 PSF	74	32	40	48	51	54	43
Oak flooring on ½" plywood sub 2×10 joists 6" o.c., ⅝" gypsum board on resilient mtl. furring channel.	35	39	45	52	58	63	50
Doors							
1¾" hollow door hung, ½" undercut	7	9	13	14	13	12	13
1¾" special double panel sound absor. flu	31	33	37	40	44	44	40

Figure 18

Typical sound transmission losses

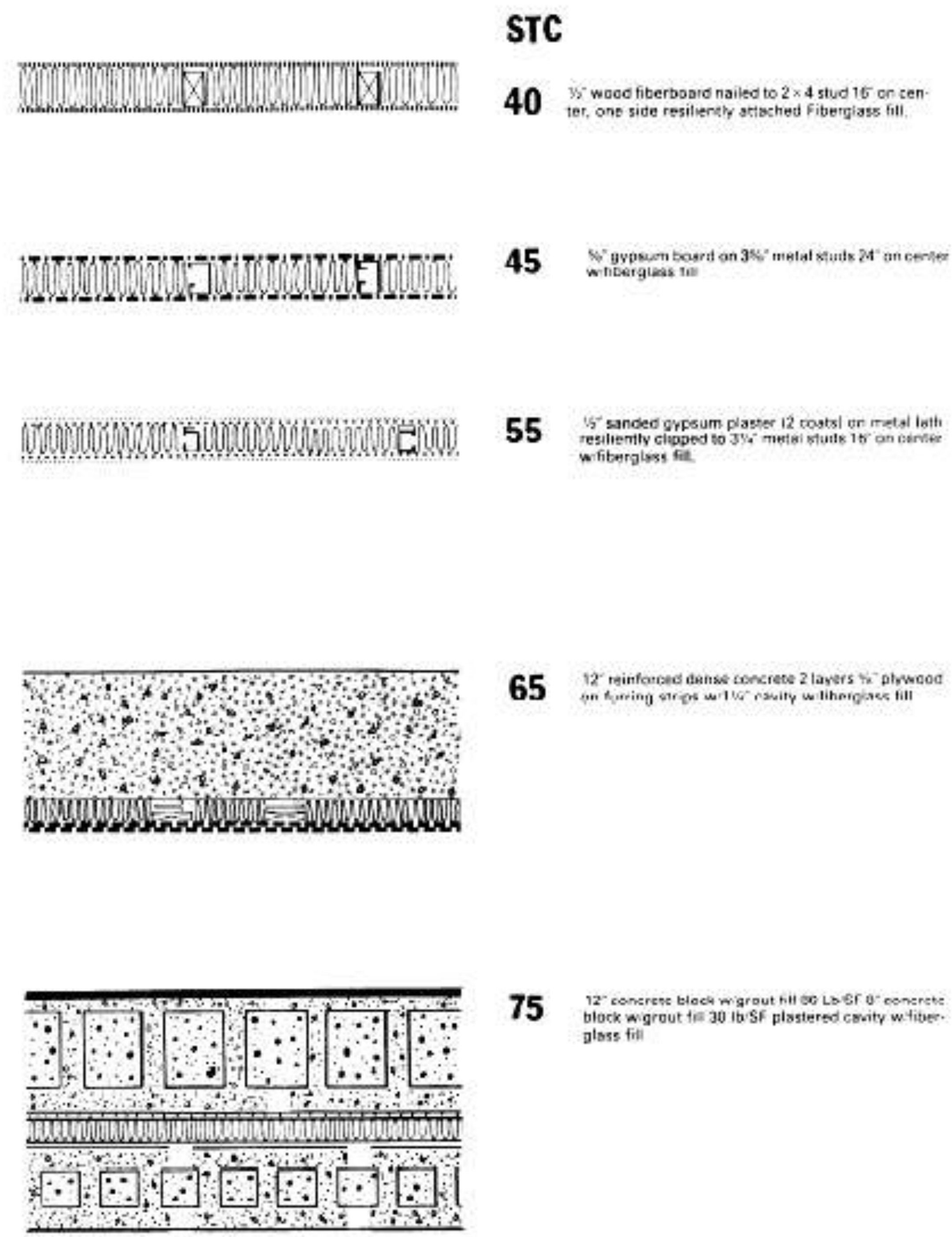
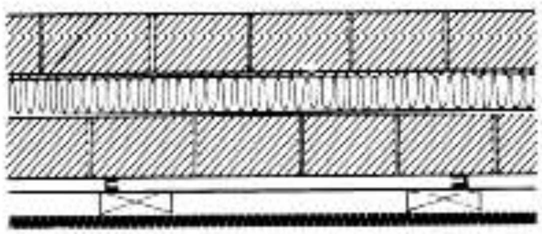


Figure 19

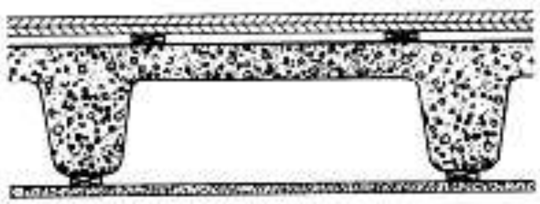
Ceiling and floor construction, noise control



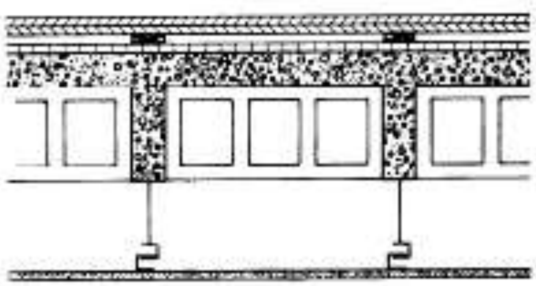
70 — 2 wythes brick w/4" air space plastered cavity w/ fiberglass fill 2 layers ⅝" gypsum board on metal furring strips resiliently attached.

FIGURE 4–6.6 WALL AND PARTITION CONSTRUCTION, NOISE CONTROL

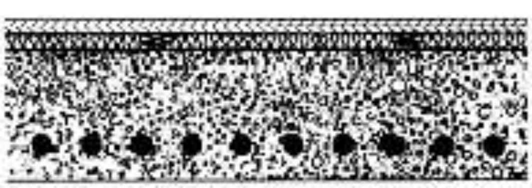
STC



55 — Finished & subfloor on wood sleepers on 2½" concrete slab w/6" ribs 2'0" o.c. 55 Lb/SF w/Ridgidly furred ceiling skin



75 — Finished & subfloor on wood sleepers on resilient fiber board (or eqv.) on 2" slab on 6" hollow filler block 80 lb/SF w/suspended ceiling on resilient runners



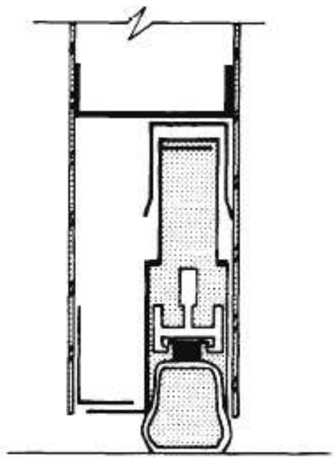
65 — Finish & subfloor on wood sleepers resiliently attached to 8" reinforced concrete 95 lb/SF w/fiber glass fill.

Figure 19 (continued)

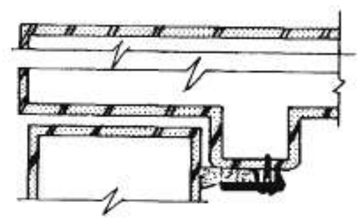
Ceiling and floor construction, noise control

DOORS

Construction	Thickness	Weight Lb/SF	STC Rating
Hollow core wood	1–3/4"	3.5	19
Solid core wood	1–3/4"	5	29
Hollow metal	1–3/4"	5	30
Packed metal	1–3/4"	7	32
Special Acoustical	1–3/4"	6	35
Sound core wood	2–1/4"	7	32
Special Acoustical	2–1/2"	8	38



Threshold



Head/Jamb

Figure 20

Door construction, noise control

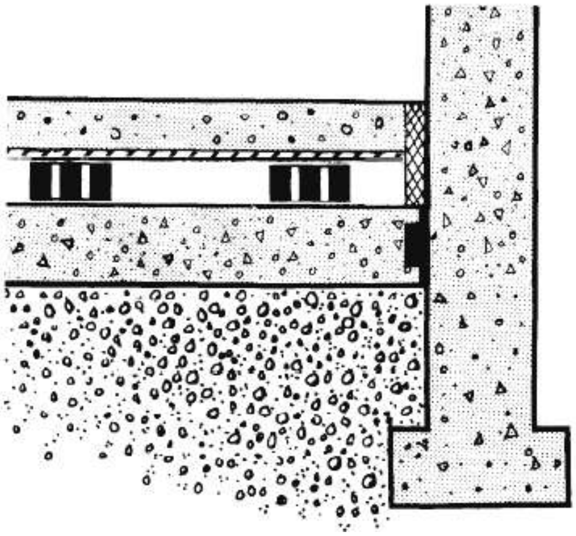


Figure 21

Mechanical room and equipment mounts, noi