NASM

Acoustics for Performance, Rehearsal and Practice Facilities

A Primer for Administrators and Faculties

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I. INTRODUCTION

- Music and acoustics are both science and art.
- Just as the science of music is definable, so is the science of acoustics.
- Yet, acoustics is also an art, like the music it serves.
- No two musical performances, performed in the same hall, will be identical; no two halls will have identical acoustics.
- This Primer reflects all of these positives and explains their relationships.

It is important that all involved in the planning, design and construction of music facilities realize that they are not ordinary building spaces. Not only are they different because of their need to accommodate orchestras, choral groups, audiences and other ensembles, physically they are different because of room acoustic and noise control considerations. Further, the square footage required for musicians with instruments is much greater per occupant than for ordinary buildings. These critically important room acoustics considerations make music facility construction costs higher than those encountered in the construction of "normal" classroom buildings. An adequate construction budget must be assigned if music performance, rehearsal, and instruction are to be satisfactorily housed.

Adequate music facility construction involves building costs beginning at $200 per square foot, and many facilities now under design and construction are more expensive. The ratio of performance vs. instructional space is a principal influence on cost.

II. DEFINING THE ACOUSTICAL PURPOSES OF A SPACE

Since the acoustical attributes of a space are directly influenced by the kind of soloist or ensemble involved, it is essential to define the "mission" of each performance and rehearsal space. This mission statement can assume several forms, but a sampling of questions answered by such a statement might constitute the following:

A. What ensemble(s) will utilize the space?

B. Is the space primarily for rehearsal, performance, or both?

C. What is the size of the anticipated audience, if any?

D. Which function, if any, should be prioritized before the others?

E. What, if any, of the acoustical parameters which follow, are most important:

1. Liveness (reverberance),
2. Warmth,
3. Brilliance,
4. Clarity, or
5. Presence?

III. ACOUSTICS FOR PERFORMANCE

A. Basic Performance Space Considerations

Certain attributes of any performance are necessary or desirable, almost regardless of hall seating capacity. They are:

1. Internal Volume

(directly determines potential for "reverberance," or liveness)

a) Wind Bands (also Jazz and Electronic Music): Approximately 250 CFS (cubic feet per seat).

b) Orchestras: 350 to 450 CFS, depending on clarity vs. reverberance criteria.

c) Choral Ensembles: 350 to 500 CFS, depending on clarity vs. reverberance criteria.

d) Pipe Organs: 400 CFS to 600 CFS.

It should be noted that acousticians have differing philosophies concerning adequate volume. The figures which are given here represent reasonable averages.

Halls which must accommodate more than one of these ensemble types are nominally designed with internal volume as close as possible to the maximum programmed use. For example, a hall which is to be utilized for choral and wind band groups will be provided with choral volume, and adjustable sound-absorbing elements will be provided to satisfy the wind band acoustical criteria. However, economic or other non-acoustical considerations may dictate that a hall with "compromise" volume is best; such solutions typically satisfy neither optimum acoustics for either type of ensemble, and generally do not employ adjustable acoustical devices.

The concept of "reverberance", or liveness, is frequently associated with "reverberation time," which is scientifically defined as the time elapsed for a sound to decay by 60 decibels (dB), as compared to its original level. However, the rate of decay over the first 10 dB, the first 20 dB, or over any other sound level variance we wish to name, influences subjective reverberance just as much as the rate of decay over the entire 60 dB. This one very important fact (among many others, of course) explains why halls with almost identical "reverberation times" may sound completely different.

All halls possess reverberation times which vary depending upon pitch. Reflectivity of surfaces in the bass, middle or treble pitch ranges control reverberance in each pitch range.

Some halls are designed with "reverberation chambers", coupled to their audience chambers to increase potential reverberation time while avoiding very high ceilings. The chambers are coupled to the hall with openings of predetermined sizes, which can be closed with heavy doors or other devices when not in use.

2. **Ceiling Height and Hall Width**

Ceiling height and hall width directly determines "presence," and in live halls, "clarity."

a) These two parameters control the time of arrival of the early sound reflections to the audience and performers themselves. ***Refer to Illustration RA-1***.

b) It is generally agreed in the acoustic profession that the "delay gap" between arrival of direct sound and that of first reflected sounds should lie within the range of 35 to 45 feet. The shorter this gap, the more "presence" will be created. To determine this "gap", follow these steps:

(1) Determine the straight-line distance from the source of sound to a listener location in the center of the hall, approximately at the fifth row of seats.

(2) Determine the total distance from the same sound source, to a side wall, and then to the same listener location.

(3) Subtract (1) from (2).

(4) Determine the same parameter for the early ceiling reflections, using a similar method.

(5) This process can be repeated for any seat within the performance hall, thereby identifying seats which will achieve or lack presence.

The most "presence" is achieved when this "gap" parameter is satisfied from both side walls and ceilings.

c) Within the context of the above-referenced statements, the following general "rules" govern the sound of the hall in terms of its presence:

(1) If a choice must be made, the early acoustic reflections from side walls are more important than from ceiling surfaces.

(2) As the ceiling height increases, the Hall retains presence, but with very high ceilings, excessive reverberance will mask the effect of early side wall reflections.

The use of coupled reverberation chambers (refer to discussion above), if designed and executed properly, can permit the performance hall to achieve both reverberance and presence by lessening requirements for ceiling height.

3. **Ceiling and Wall Surfaces**

Refer to Illustration RA-2.

The construction (mass) of the "core material" of ceiling and wall surfaces directly influences the ability of these surfaces to reflect low-frequency sound energy adequately. Therefore, the core material mass largely determines the potential of the entire hall for good bass response (warmth).

Any construction material will absorb low frequency sound at some range of pitches. But, as the mass of the material increases, the frequency (pitch) at which the material becomes sound-absorbing decreases. Massive materials are therefore required if the hall is to have proper bass response and the resulting warm sound.

If a wall or ceiling system is itself heavy and massive, and another material (wood, plaster, etc.) is applied directly to it, the finish material only adds mass to the core, and further enhances bass sound reflection. If, however, a finish material is separated from the core by an air space, it in itself becomes sound-absorbing at low frequencies.

Low frequency response in a hall is most important for orchestral music; somewhat less so for choral music; and of secondary importance for wind bands and jazz ensembles. Its importance for chamber music and soloists varies depending on the instruments involved, but in general, is the most important for the piano.

4. **Finish Materials**

The porosity of the finish materials on walls and ceiling surfaces significantly influences the high-frequency reflectivity of these surfaces, and therefore determines the potential of the hall for treble clarity and brilliance. Porous materials (for example: brick, concrete block) tend to absorb high frequencies; plaster, sealed wood, gypsum board, sealed laminates, and similar products tend to reflect high frequencies well.

5. **Floor Elevation**

Refer to Illustration RA-3.

The variation in floor elevation (rake of audience), in addition to its obvious influence on audience sight lines to the performance platform, determine the strength and uniformity of the "direct sound" (straight-line sound path) from performers to listeners. The ideal design maintains a line of sight which does not vary significantly from performers to listeners, regardless of listener location. This "ratio of direct to reverberant sound" is extremely important, and should be, to the extent possible, uniform with respect to listener location.

It is important to consider the effect of the Americans with Disabilities Act upon the design of the hall floor slope rate. There are many methods of designing for compliance with this Act; the task of the Designer is to comply with the Act while maintaining optimum sight and sound lines.

6. Side Wall and Ceiling Shapes

The *shaping* of the side wall and ceiling surfaces controls the direction and strength of useful acoustic reflections to the audience (or away from the audience, depending on one's desire). Further, this shaping determines the *uniformity* of sound distribution to the audience by providing diffused (scattered) sound reflections.

Such major hall elements as balconies, large clouds, etc. most influence bass sound dispersion (diffusion).

The "gross" irregularity of the walls and ceiling surfaces (flat, convex, concave, splays) most influences mid-frequency sound dispersion (diffusion).

The surface characteristics of the finishes (rough, relatively small irregularities, smooth) influence the high frequency sound dispersion.

7. Audience Rear Wall

Refer to Illustration RA-4.

The acoustics of any hall are influenced in a major way by the contribution by the audience rear wall to the sound field within the hall. Rear walls in halls with moderate to short reverberation times provide delayed sound reflections (echoes) which damage clarity. In the worst cases, such echoes may be distinguished as audible separate sounds.

Rear wall echoes may be controlled or eliminated by shaping, applying sound-absorbing material, or a combination of both:

a) For orchestral and choral performance, the added ambiance of *diffuse* rear wall reflections is valuable.

b) For wind band and jazz performance, diffuse rear wall reflections are not needed. Absorbing materials provide added clarity.

8. Seating

The effect of seating and audience upon hall acoustics can be summarized as follows:

a) Upholstered, padded chairs are essential in order to make the reverberation time of the hall at least somewhat independent of the audience size. In other words, such chairs act somewhat like people when people are not occupying the chairs. Contrary to the beliefs of some, such chairs do not completely replace the absorption of the absent occupants.

b) Chairs themselves are generally highly sound-absorbing in the mid-range and treble pitch ranges, and less so in the lower frequencies. The primary variables are (1) thickness of padding; (2) porosity of fabric; (3) extent of fabric on seat backs and sides, if any.

c) As the seating becomes more sound-absorbing, the variation in hall liveness becomes less, as a function of audience size.

d) The spacing of seating rows, and the width of each seat, influence the total sound absorption of the blocks of seats.

9. Flooring

Flooring material can have a significant impact on acoustics, even if the surface is apparently hard and sound-reflecting:

a) CARPETING
Carpeting is sound-absorbing; the pitch range at which it becomes sound-absorbing decreases as the thickness of the carpet increases, and the high frequency sound absorption increases as the carpet thickness increases and pile is more porous. Halls with major choral and orchestral use generally do not require, and sound best without carpeting.

b) WOOD SURFACES
Wood surfaces, if adhered directly to a massive core material (such as concrete) are only slightly less reflective than the core material itself. Well-sealed and polished hard materials sometimes are twice as reflective as non-sealed porous surfaces (some tiles are slightly porous, for example).

10. Openings

Openings in the hall which transmit sound to spaces beyond can be selectively absorbing of some pitch ranges, depending on size and spacing of openings, the depth of volume behind the openings, and the sound-absorbing characteristics of finish materials in the spaces beyond the hall. In general, such "coupled spaces" should be avoided unless they are specifically designed for hall reverberation control.

B. Balconies

For many reasons, balconies usually constitute a significant impact on hall acoustics. These effects can be positive or negative, depending on hall size and the configuration of balcony structures. The most important considerations are:

1. Opening into the Underbalcony

The opening into the underbalcony volume areas can be absorbing to sound within the main body of the hall, especially if the depth of the underbalcony seating is significant. This sound absorption varies with pitch (bass, middle, treble), and with the depth and ceiling height of the underbalcony.

The ideal ratio of underbalcony ceiling to underbalcony depth is 1 to 1. Ratios exceeding 1.5 to 1 are not recommended at all. Minimum underbalcony ceiling height should be approximately equivalent to 1.5 times the wavelength of the lowest pitch range wished to be transmitted well to the back row of seats under the balcony (for orchestral music, approximately 16 feet which is 1.5 times the wavelength of sound at approximately one octave below Middle "C"). If the desired propagation of bass sound to the last row under the balcony is lower than this pitch, then the available height to these seats below the balcony should be greater. For reference, 60 Hz, which is approximately two octaves below Middle "C", has a wavelength of 20 feet, with an accompanying balcony height of 1.5 x 20 = 30 feet.

2. Presence of Balconies

The presence of balconies tends to distribute the major sound-absorbing items of the hall (audience and seating) over a wider height than would otherwise be the case. Halls with properly designed balconies tend to have better sound diffusion and uniformity than halls having similar seating capacity with no balconies.

C. Concert Hall or Multipurpose Performing Arts Hall?

1. Principal Acoustic Differences

There are numerous differences between the two hall types. However, the principal *acoustical* differences are:

a) The length-to-width ratio of the seating chamber tends to be smaller in multi-purpose halls (i.e., a wider room than would be the case for concert use only), because of sight line requirements.

b) The performing stage is typically separated from the audience chamber by a framed opening.

c) The volume of the stage chamber is much larger than would be the case within a concert hall (i.e., the fly loft volume).

2. Associated Acoustical Parameter Variances

These differences typically result in three associated acoustical parameter variances. These are:

a) Increase in width usually increases the time required for side wall sound reflections to arrive at the audience seating. The effect of "presence" from side wall surfaces therefore is reduced.

b) Reduced viewing distances from back row seats to the stage may require deeper balcony overhangs than are optimum in concert halls.

c) The stage house volume must be acoustically coupled to the audience chamber by a demountable stage enclosure (commonly called the orchestra shell). Because of reduced mass of demountable panels as compared to concert hall wall surfaces, the bass reflectance of the stage enclosure tends to be not as effective as is the case in pure concert halls.

Within these variance parameters the designers can often still provide acoustical results which are quite favorable, although perhaps not optimum. Demountable stage enclosures do provide a measure of inherent adjustability, which can aid in ensemble musical balance.

D. Designing Halls for Pipe Organs and Other Uses

Reverberation times which are considered optimum for the pipe organ may also be appropriate for choral ensembles, depending upon the degree of clarity desired for sung voices. When pipe organ performances are to occur in a hall which is also programmed for orchestral, wind band, jazz, or chamber music, however, the acoustical physics of reverberation time simply do not permit sufficient adjustability to present optimum acoustics for all of these functions. However, when a hall must accommodate all event types from pipe organ to jazz ensemble, the following guidelines may be useful:

- Audience chamber volume should not exceed 320 cubic feet per seat, if the organ function is to be emphasized as compared to jazz ensembles.
- Audience chamber volume should not exceed 280 cubic feet per seat, if the jazz ensemble function is to be emphasized.
- Adjustable acoustical devices are mandatory, and should be planned to achieve reverberation time range of 1.0 second to 1.8 seconds; these values can vary depending on seating capacity, and are offered for a sample case of an 800- to 1200-seat hall.
- Adjustments in reverberation times within this range in such halls can permit such multipurpose environments to be acoustically adequate, although perhaps not ideal.

E. Adjustable Acoustical Device System

All acoustical materials have varying sound absorption rates, depending on material thickness, density, air space behind the material, and a host of other factors. For easy adjustability, it is frequently desirable to use acoustical curtains which draw or raise into enclosures when not in use. The planner must be aware of the effects of these material systems and their placement. The principal variables are:

1. **Thickness**

   Thickness controls how much bass sound absorption is achieved. Thin materials (thin curtains, for example) absorb trebles and overtones well, but are not effective in bass pitch ranges. Thus, a room which is said to have "adjustable" or "variable" reverberation time may essentially sound more "muddy", since only the higher pitch ranges are absorbed by the material.

2. **Air Space**

   Air space which may be created between the adjustable material and the wall or ceiling surface may create additional bass absorption. This is desirable when a uniform rate of reverberation decreases is expected.

3. **Placement Locations**

   Placement locations (i.e., walls, above ceilings or catwalks) have a significant impact on the strength of individual sound reflections from room surfaces, and thus can influence not only reverberation time, but also presence and overall ambiance. The ideal solution is always to spread the adjustability over as many different surfaces as possible.

IV. SOUND TRANSMISSION CRITERIA AND CONTROL

Note: This narrative is supplemented by *Illustrations "SS"*, for "Sound Separation."

A. Introduction

1. The Acoustical Separation

The acoustical separation of music practice, teaching, rehearsal and performance spaces is an extremely complex subject. Fortunately, it can be simplified into an easily understood set of principles and processes. Unfortunately, the science of acoustics (note: this part of acoustics is very much a science) originally developed terminology for acoustic separation by using the human spoken voice as the sound source. All of the terms used and widely heard by architects to describe the acoustical performance of walls, ceilings, and materials essentially ignore four primary musical factors:

a) That music contains acoustic information which is tonal in nature.

b) That music contains information far lower in pitch than any human voice.

c) That the generation of music by various instruments is of essentially uniform loudness, as a function of pitch, where in the human voice, loudness is less in the lower frequencies than the higher pitches.

d) That music within these rooms is frequently generated at very loud sound levels. In typical piano practice rooms, for example, we frequently find sound levels approaching 95 dB at the floor under the piano. By comparison, most voice sound levels in a typical office are in the 60 and 70 decibel range.

It is these four considerations that make music buildings unique among all academic building types. Wall systems, floor systems, mechanical systems, and structural systems which work well for other academic buildings simply will not work well for music buildings. For illustration, a pair of faculty music studios which are separated by a standard drywall partition would be analogous to building no wall at all between two administrative offices in any other department.

2. Systems of Construction

It has become incumbent upon the acoustic design profession to develop systems of construction which essentially ignore the spoken voice criteria. Through the years, these systems have been developed and field-tested to the extent that the profession has come to know exactly how a given construction will perform.

B. Familiar Rating Systems Used for Voice Only

1. Two Primary Rating Systems

There are two primary rating systems which we tend to avoid, or modify:

a) Sound Transmission Class (STC).

b) Noise Isolation Class (NIC).

Refer to Illustration #SS-1

2. STC - Sound Transmission Class

a) This is a single-number system which defines within certain limits the number of decibels of sound reduction a given construction will produce.

b) In very general terms, this system allows the low frequency sound reduction to be about 20 dB less than the high frequency reduction, to achieve the STC single number rating.

c) This term applies only to walls and floors tested in a calibrated acoustical laboratory, without consideration for ducts, doors, windows, and other circuitous sound transmission paths.

3. NIC - Noise Isolation Class

a) This is a single number rating system, very much like STC, but which is used to describe the sound reduction actually achieved in a real building. The NIC rating curves are depicted in ***Illustration #SS-1***.

b) Again, the low frequencies are de-emphasized by about 20 dB.

c) The on-site measurement techniques are able to distinguish between the acoustic reduction for the separate components of a system. If one component (for example, a duct) degrades the rating, then that component is identified for improvement. In the planning process, the design is executed in such a way to permit all the components of the system to work together to achieve one suitable rating.

C. Typical Rating System Modifications

Acoustical designers use the part of the STC-NIC rating system that measures high frequencies (starting from one octave above middle "C" on up). The construction types actually used are designed with equal consideration to bass pitches but without reference to the STC-NIC ratings.

The tonal sounds produced by music are more audible to a listener on an opposite side of a wall from the sound-producing instruments then to a listener closer to the source. The criteria, therefore, for sound separation, exceed those which would be permissible for the spoken word. Acoustical designers use pink noise measurements and intelligent listening with long years of experience to determine adequate ratings for sound separation.

D. Paths of Sound Transmission

Refer to Illustration #SS-2.

1. Potential Paths for Sound Transmission Between Rooms

Consider two rooms which share a common wall system, a common floor, and a common roof or structure above. The potential paths for sound transmission between the rooms are as follows:

a) Directly through the common wall.

b) Flanking around the wall through common exterior or corridor wall systems.

c) Flanking below the wall through the floor.

d) Flanking through ductwork.

e) Movement through degraded construction with electrical boxes and conduit.

f) Flanking around the wall through corridor door systems.

2. Effect of the Background Sound Level

Consider also the effect of the background sound level which is generated within each room by the building air delivery system. With today's variable air volume delivery systems, the background sound level within the room varies as does the air velocities. Thus, one cannot depend on any appreciable background sound to partially cover, or mask, the intruding music from the adjacent space.

3. Sound Transmission Through Corridor Door Systems

The sound transmission through corridor door systems can seriously compromise the acoustical rating of any wall, especially if the doors are close to one another. ***Refer to Illustration #SS-3.*** This design is to be avoided wherever possible.

E. The Effect of Building Structural Type Upon Acoustical Separation

Refer to Illustrations #SS-4 and #SS-5.

For acoustical discussion purposes, there are two primary building structural system types which influence sound transmission: (1) steel frame and (2) concrete frame.

1. Steel Frame

a) This type of system is fairly lightweight and flexible, and is composed of floor and roof cores which are fluted steel deck with either lightweight or normal weight concrete fill and topping. The deck system is supported by steel beams and lightweight joists. The joists are spaced fairly close together (approximately four to six feet apart, depending on the system).

b) Since this system involves the use of multiple steel beams and small joists (most of which must penetrate the wall systems between rooms), and corrugated steel deck, it is difficult to impossible to seal the joints between the top of the wall system and the structural system above.

c) Therefore, it is normally the case that acoustical designers do not even attempt to make these seals. Instead, a horizontal sound barrier, composed of two layers of drywall (gyp board), is installed immediately below the steel beams or joists, creating a double ceiling system (noise control ceiling). This solution works for many applications, but still has serious shortcomings with respect to low frequency sound energy. The "finished" ceiling visible to the room occupant is not shown in the illustration.

2. Concrete Frame

a) In this design, a flat concrete slab is poured onto a temporary form, the form is removed and the concrete slabs are supported by large concrete beams spaced rather far apart (usually 20 to 30 feet).

b) This design permits the common wall systems to be completely sealed against flat surfaces and is ideal for all music sources.

c) However, this kind of structural system is more expensive than the steel frame design. When the cost of the double ceiling system is compared against that of the concrete frame, the double ceiling system is always judged more economical.

The concrete frame design is always preferred for best sound transmission control.

F. The Design Steps for Sound Transmission Control

For purposes of this discussion, we consider any pair of rooms which share a common wall and floor system.

1. The Wall System

a) Wall systems generally fall into three categories:

(1) Stud and drywall systems.

(2) Masonry (concrete block) systems.

(3) Composite systems using both drywall and masonry components.

b) Drywall systems control high frequency sound energy better than masonry systems.

c) Masonry systems control low and mid frequency sound energy better than drywall systems.

d) Composite systems control all pitch ranges to a predictable degree, depending upon wall thickness and air space depth between wall elements.

e) Complete inaudibility of sound transfer depends upon the pitch range under consideration and the level of the sound being generated. In general, however, for piano, most winds, and acoustic strings, the goal for inaudibility is at least 65 dB of sound reduction. For percussion and very loud brass, 70 to 80 dB of reduction is desired. The reader should note that for simplicity, the amount of sound reduction is stated in dB without reference to the pitch characteristics of the sound reduction. To properly describe sound reduction, the frequency spectrum of this noise reduction must also be stated.

f) Frequently, the criteria for complete inaudibility are simply not achievable with limited construction dollars. In such cases, acoustical sound transfer criteria are prioritized by the design team and the owner. It is also possible, during the design process, to demonstrate acoustically to the owner exactly what the acoustic results will sound like. In cases where a music department or school is relocating to renovated or new facilities, it is reasonable to measure the sound transfer performance of the existing construction, and compare it to what will be achieved with the renovated or new design.

g) The left portion of ***Illustration #SS-6*** shows a typical drywall partition with two layers of gyp board on each side of a set of metal studs. This construction carries a rating of NIC-45, but it is weak in the bass and lower midrange pitches (at and below one octave below middle "C", its sound reduction is only 25 dB).

This construction is below minimum acoustical standards for music practice or teaching applications.

h) The right portion of ***Illustration #SS-6*** shows a drywall partition with two adjacent sets of metal studs and double gyp board each side.

This construction carries a rating of NIC-53, and still is 20 dB weak at one octave below middle "C".

This construction is considered to be the minimum acoustical standard for student practice rooms.

i) ***Illustration #SS-7*** shows a drywall partition similar to the previous one, except that a larger air space is created between the sets of metal studs. This construction carries a rating of NIC-58, and is only about 10 dB deficient at one octave below middle "C".

This construction is considered to be above minimum acoustical standards for student practice rooms, and at minimum standard for faculty studios.

j) ***Illustration #SS-8*** shows a composite wall, in which studs and sheet rock are combined with concrete block to form a system that carries a sound rating of 58, the same as the previous illustration. However, this wall system is superior to SS-7, in that the pitches below one octave below middle "C" are better reduced; this does not show up in the standard rating.

This construction is above minimum standards for faculty studios, but not optimum.

k) ***Illustration #SS-9*** shows a composite wall in which studs and drywall are provided on both sides of the concrete block, instead of just one side. This construction carries a sound rating of NIC-60, and is still more effective at low frequencies, which are not depicted within the standard rating system.

This construction is the best that can be done when two adjacent rooms share a common, non-isolated floor, and is always initially recommended for faculty studios.

However, it should be noted that some common, non-isolated floors can reduce the overall isolation to below a rating of NIC-60, even though the wall construction will produce the 60 rating.

2. The Floor System

a) The conduction of sound through the common floor systems prevents the wall construction from achieving any sound rating exceeding 60 and begins to reduce the effect of any wall construction at lower NIC ratings (55). This is particularly true for floors above grade (i.e., not resting upon the earth). Any wall construction beyond that shown in ***Illustration #SS-9*** is not productive, unless it is accompanied by an isolation system within the floor.

b) There are three generic methods which are used to provide this structural isolation:

(1) Structural expansion joint method; all buildings must have expansion joints somewhere, so that structural systems can move with temperature and soil variations. Typically, however, these expansion joints are few in number, and are not practical when large quantities of rooms are involved (faculty studios and practice rooms). Also, this method of isolation may not be possible for floors above grade.

(2) A lightweight isolating floor system, consisting of isolation pads and a plywood floor and finish material. ***Refer to Illustration #SS-10***. This is a reasonably economical way to increase the horizontal sound transfer reduction by 5 points or more. It also aids in vertical sound transfer control. This system is recommended for studios where the piano is a primary sound generator.

(3) A lightweight concrete isolating floor system, consisting of isolation pads, insulation, and three inches of lightweight concrete. ***Refer to Illustration #SS-11***. This system is sometimes used for less critical locations than noted in Item "4" below, and where building structural considerations dictate a somewhat lighter concrete isolated floor system.

(4) A heavy, concrete isolating floor system, consisting of isolation pads, insulation, and four inches of normal weight concrete. Refer again to ***Illustration SS-11***. This is an expensive construction, and is used to increase the horizontal sound transfer reduction up to a rating of NIC–70, with only a 10 dB decrease in the lowest octave. This system is recommended for percussion and electronic music suites, and occasionally for special purpose rooms such as marching band.

c) There are numerous variations of wall and floor isolation types for different applications. However, the constructions described in this narrative are the basic systems.

d) Where severe vertical sound transfer requirements are found, additional measures are needed, including spring-isolated drywall ceilings, concrete floating floors on each level, and other systems.

G. Special Acoustical Adjacencies

1. Structural Expansion Joint Method for Floor Isolation

Music buildings frequently include multiple performance and rehearsal venues, which sometimes by necessity must be close to one another. In such cases, it is useful to consider the structural expansion joint method for floor isolation, possibly in addition to floating floors, multiple composite wall systems, intervening corridors and other design elements.

2. NIC Ratings Needed for Adjacent Music Building Spaces

Typical NIC ratings which are needed for adjacent music building spaces are recommended as follows:

a) Instrumental Rehearsal to Choral Rehearsal: 70.

b) Marching Band to Performance Stage: 95 (note: such a construction involves at least two systems with a rating of 70, separated by at least an 10-ft. corridor).

c) Percussion to Percussion: 70.

d) Faculty Studio to Faculty Studio: 60 to 65.

e) Practice Room to Practice Room: 56.

H. Considerations for Value Engineering

1. Value Engineering (VE)

The term "value engineering" or "VE" has come into being in recent years. The goal of value engineering is to provide the desired building results for some portion of the building or building system, but at a lower cost. Value engineering when properly applied can be a useful tool; however, in the building trades it is often used as a term to describe cost cutting when a project is over budget. When budget problems occur, the design team is faced with a number of choices:

a) Reduce square footage from the building.

b) Reduce the quality of the mechanical systems.

c) Reduce the quality of the acoustical systems.

d) Reduce the quality of architectural finishes, lighting or other parts of the building.

2. Acoustical Quality

Acoustical quality often comes under scrutiny when projects are over budget. While it is appropriate to think of acoustics as the "most important consideration" in music building planning, it is incumbent upon the design team and the acoustical consultant to inform the owner and users as to the possibilities for acoustical quality reductions and cost savings versus acoustical value. In this way, acoustical designers show good stewardship of the owner's funds, while maintaining good acoustical quality.

For example, an acoustical designer might consider the following cost reductions:

a) Eliminate most concrete block construction in faculty studio and student practice rooms. Use drywall construction with large air spaces instead.

b) Consider steel instead of concrete frame construction, except within percussion and electronic music areas.

c) Use structural expansion joints wherever possible, in lieu of expensive concrete floating floor systems.

d) Avoid adjacencies incorporating very loud sound generating rooms, such as instrumental music, marching band, and similar areas. Separate these spaces by as much physical distance as possible.

I. The Effect of Ductwork on Sound Transmission within Practice Rooms and Faculty Studios

Refer to Illustration #SS-12.

1. Supply Ductwork

Supply ductwork must be brought in from the corridors adjacent to the rows of studios and practice rooms. Common walls between studios must not be penetrated with ductwork. Since this is the case, the spaces above corridor ceilings must have enough height to contain this ductwork, together with all of the other system devices which may include variable air volume boxes, light fixtures, roof drain piping and other elements. In some cases, duct silencers may be required at wall penetrations into the corridor ceiling plenums.

2. Air Delivery Return Systems

Air delivery return systems must at least be ducted from the individual rooms into the corridors. The corridor ceiling plenum can sometimes be used as a return air path without the need for return air duct.

3. Internally Bare Ductwork

In some projects, there are requirements for internally bare ductwork; that is, no liner inside of ducts. This requirement has resulted from air quality concerns, even though there is no factual information that lining or lack thereof presents an air quality problem. With internally bare ducts, there is essentially no sound transmission control within ducts. Because of these changes, the development of air delivery systems in music buildings is now undergoing re-evaluation to assure acoustical success under new requirements.

J. The Effect of Other Building Systems on Sound Transmission Control

1. These systems may be designed as part of the building, or may be provided by the Owner at a later time:

    a) Electrical conduit and wiring systems.

    b) Temperature control conduit and wiring systems.

    c) Telephone cabling systems.

    d) Roof drain piping systems.

2. All of these systems employ devices which could compromise sound transmission control. Be aware that the design team should implement measures to insure that this does not happen. Musicians should require backup information from the design team that documents attention to these issues.

V. REHEARSAL ROOM ACOUSTICS

A. Mission

The purpose of acoustics within a rehearsal space is to enable the sound of an ensemble to be heard by musicians and conductor within an area and volume which is not coupled to an audience chamber, and which frequently has a floor area and ceiling height much different than a performance stage.

In the absence of newly developed electronic technology, rehearsal spaces are designed to enable good ensemble, intonation, and definition to occur. Within this criterion, reverberation may vary within certain limits.

B. Acoustical Needs Common to All Large Rehearsal Rooms

1. Floor Plan: Approximately 20 square feet per musician, with a ratio of 1.25:1 to 1.6:1.
2. Internal Cubic Volume: Approximately 400 cubic feet per musician.
3. Ceiling Height: 16 to 24 feet, depending on square footage. Heights exceeding 24 feet are not necessary or desirable.
4. Acoustical diffusion, or scattering, needed in the ceiling system.

C. Ways to Achieve Acoustical Ceiling Diffusion

Refer to Illustration #RH-1.

1. The simplest and most economical way to achieve diffusion and scattering of sound is to provide a flat or sloping suspended ceiling, composed of a mixture of acoustically reflective and absorbent surfaces. This solution is common within economical secondary school rehearsal spaces.
2. The preferred manner of providing diffusion is to utilize geometrical irregularity within the ceiling design. This is often accomplished by installing a flat and suspended sound-absorbing ceiling with relatively large sound-reflecting and diffusing elements suspended beneath the absorbing ceiling.

D. Reverberation Times Desired

1. Wind Ensemble: 0.7 to 0.9 seconds, depending on desires of conductor and size of ensemble.
2. Orchestra: 0.9 to 1.5 seconds, depending on desires of conductor and size of ensemble.
3. Choral: 0.9 to 1.5 seconds, depending on desires of conductor and size of ensemble.
4. For any rehearsal room, the reverberation time should be uniform at all pitch ranges.

5. This requirement influences the selection of sound-absorbing materials in a major way. If we see a rehearsal space with a flat acoustical tile ceiling, carpeted floor, and thin acoustical material of any sort on the walls, we can expect that room to be boomy and lacking in clarity.

E. Wall Shaping

1. Wind Ensemble: Short reverberation times require a great deal of acoustical wall material. Consequently, undesirable reflections between parallel walls are eliminated and nonparallel walls become less critically needed.

2. Orchestra, Choral: Less acoustical treatment on walls is needed for reverberation control, since reverberation times are longer. Hence, nonparallel side walls are desirable.

F. Multipurpose Rehearsal Room Acoustics

1. Some rehearsal rooms can be planned quite well for more than one purpose. Choral and orchestral requirements are fairly similar, as are Wind Ensemble and Jazz rehearsal requirements.

2. Other less compatible ensembles can be accommodated well in one rehearsal space with adjustable acoustical devices. Such devices must, however, employ the thickness and types of sound-absorbing materials necessary to achieve the uniform reverberation time requirements.

G. Marching Band Rehearsal Acoustics

1. In rehearsal rooms which must accommodate marching bands of 100, 200 or even 400 instruments, the general guidelines for acoustics in wind ensemble rooms still apply.

2. However, there is another acoustical consideration which is just as important: that of hearing loss. A marching band of 200 instruments playing fortissimo in an enclosed room, even if the room is sufficiently large, will generate sound levels up to 115 dB within the space. With repeated exposure to such levels for time intervals of 30 minutes or more, the conductor's and musicians' hearing will gradually deteriorate. This effect has been brought to light within the past five to seven years by alumni who, at age 50 or later, complain of loss of hearing as a result of this sound exposure.

3. It is therefore incumbent upon designers to produce rehearsal spaces for bands which have reverberation times as close to outdoor conditions as possible. There are ways to achieve this condition which are considered beyond the means and materials within acoustical design standards; however, such treatment needs to be considered, and might include fiberglass insulation up to two feet thick, fiberglass wedges, and other nonstandard devices.

4. It is important to note that any rehearsal room properly treated for marching band will be acoustically unsatisfactory for any other use, unless adjustability is provided.

VI. NOISE LEVELS PRODUCED BY AIR DELIVERY SYSTEMS

A. Standard Noise Criteria

Refer to Illustration #NC-1.

1. The acoustical design profession uses several rating systems to describe the noise levels produced by air delivery systems. The one most commonly used is the "noise criterion", or "NC" system. This single number rating system attempts to relate the noise levels with what we, as humans, hear, and allows louder low frequency noise for a given rating to be compared with high frequency noise. Refer to the chart showing NC contours (illustration #NC-1). The correlation between comparative musical pitch and octave band center frequencies in Hz are as follows:

63 Hz:	Two octaves below Middle "C"
125 Hz:	One octave below Middle "C"
250 Hz:	Middle "C"
500 Hz:	One octave above Middle "C"
1000 Hz:	Two octaves above Middle "C"
2000 Hz:	Three octaves above Middle "C"
4000 Hz:	Four octaves above Middle "C"
8000 Hz:	Five octaves above Middle "C"

2. The noise level requirements are generally more stringent for performance spaces than for rehearsal, although in projects with essentially unlimited funds, the rehearsal spaces could be designed equal to performance areas.

3. The criteria which are currently used for various spaces are as follows:

   a) Recording Studios: NC-15

   b) Concert Halls: NC-15 to 20

   c) Rehearsal Rooms: NC-25 to 30

   d) Faculty Offices, Practice Rooms: NC-30 to 35. Note, however, that variable air volume systems produce noise levels which are not regularly predictable.

B. Components of Noise Control

Refer to Illustration #AC-1.

1. A detailed description of all components and solutions for noise control is beyond the scope of this narrative. However, it should be realized that, particularly for concert halls and other performance spaces, the effect on the human emotions of the music's dynamic range, from the softest pianissimo to the loudest fortissimo, is lost in a room which is too noisy.

2. It is extremely important to note that the background noise level of mechanical and electrical systems is comprised of multiple noise sources, which combine together to create one ambient noise level. These sources, beginning with the supply and return air diffusers and working back towards the fans, are the following:

a) Airflow noise through the diffuser or grille vanes or perforations.

b) Airflow noise through the diffuser necks.

c) Airflow noise within the ducts between the secondary branch duct intersections and the diffuser necks.

d) Airflow noise around air volume control dampers.

e) Airflow noise within the remainder of the ductwork system.

f) Noise radiated by ductwork within a ceiling space.

g) Noise created by the fan blades and motors.

h) Noise created within the building structure by the fan units and variable speed drives associated within these units.

i) Noise created by water supply piping.

j) Noise created by electrical devices such as transformers.

The design of a quiet air delivery system must and does include attention to all of these noise sources. Any technical reports submitted should address each one (a-j). Be aware that all of the noise sources combined must not create overall total noise exceeding the NC criteria.

Refer to Illustrations #AC-1 through #AC-6.

3. These illustrations describe in a conceptual manner a typical air delivery system for a concert hall. An air handling room is located on a mezzanine level, adjacent to the performance stage. Supply ductwork is routed from the units to the stage and audience areas above the ceilings. Return air ductwork is routed from vents located low in the hall, under the floor and up to the units. The supply duct routing is depicted in ***Illustration #AC-1***; the return routing, in ***Illustration #AC-2***.

4. ***Illustration #AC-3*** depicts a conceptual method of isolating the portion of the noise source which is emitted by the fan unit. Note that the solution involves structural separation of the fan unit room from the hall structure, and multiple masonry wall elements.

5. ***Illustration #AC-4*** depicts a conceptual method of isolating the portion of the noise source which is emitted by the fan unit room. This solution can involve packaged sound traps and/or duct enclosure methods.

6. ***Illustrations #AC-5 and #AC-6*** depict typical supply and return airflow schemes, which include a high supply, low return, low air velocities, and internally lined ductwork. The methodology is conceptual in nature, but will serve as a guide in evaluating the mechanical system configuration for your concert hall.

Please note that there may be other mechanical system equipment such as chillers, pumps, and air compressors which can create noise problems. Such equipment must also be considered by the building design team to assure that suitably quiet building spaces will be provided.

VII. CONCLUSION

Acoustics and music are inseparably linked. Rehearsal and performance spaces are instruments. Pursuit of the musical arts requires attention to many details in many areas. It is hoped that this Primer will indicate the need for serious care with acoustic issues when building or renovating music facilities. In educational institutions, acoustical results have serious impacts on the quality of teaching and learning. Decisions made at one point in time affect quality for years afterward. The results of inattention or wrong choices are often hard to correct. The basic instruction contained in this Primer is intended to be a springboard for wise and thoughtful decisions, for seeking and working with acoustics professionals, and ultimately for supporting the fullest possible development of music and musicians.

VIII. ILLUSTRATIONS

ILLUSTRATION #RA-1
NOT TO SCALE

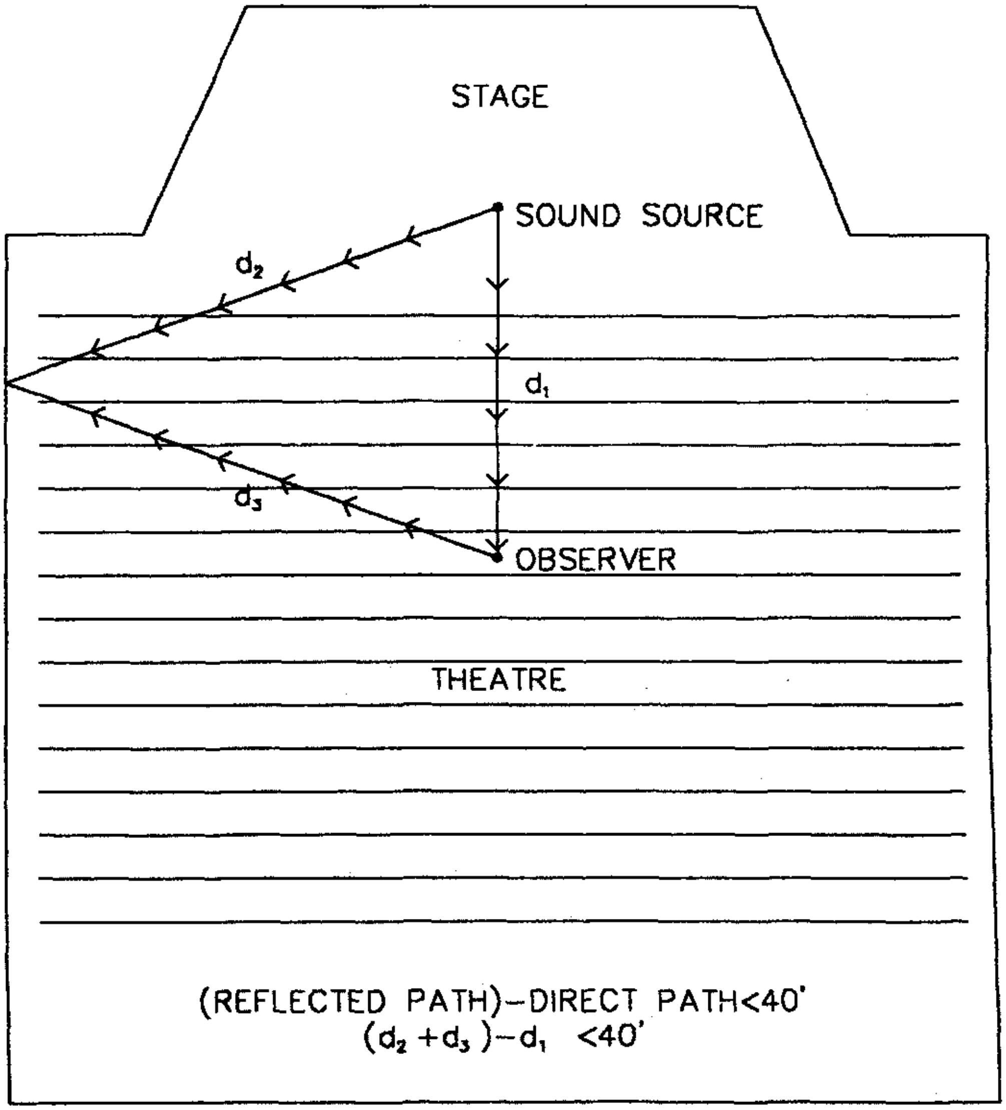
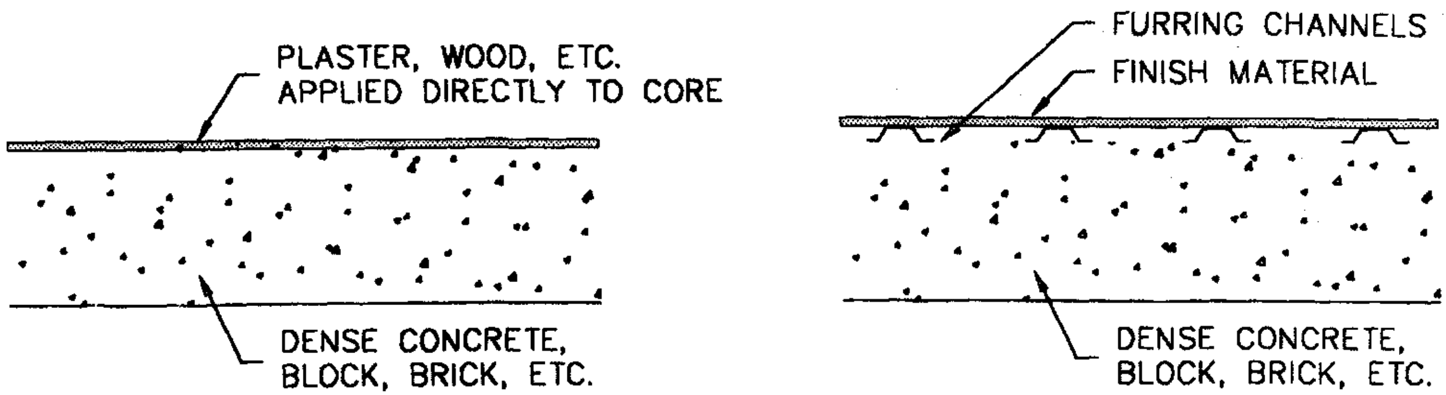


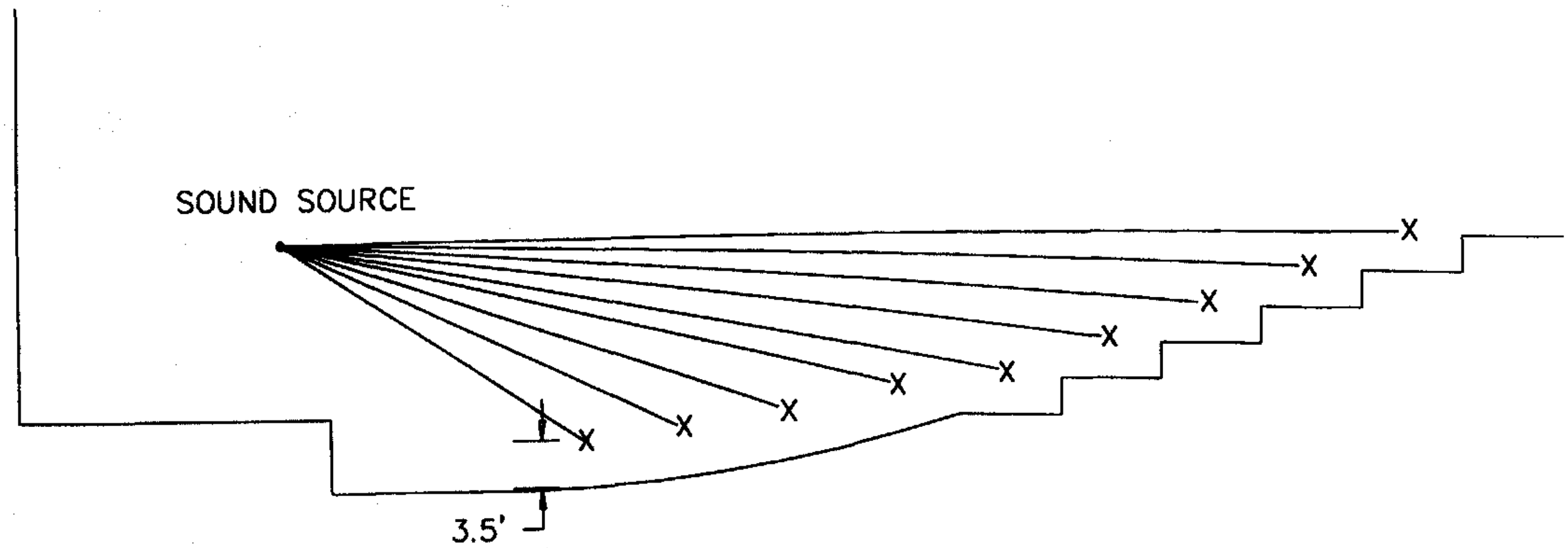
ILLUSTRATION #RA-2
NOT TO SCALE



GOOD CONSTRUCTION FOR BASS REFLECTIVITY

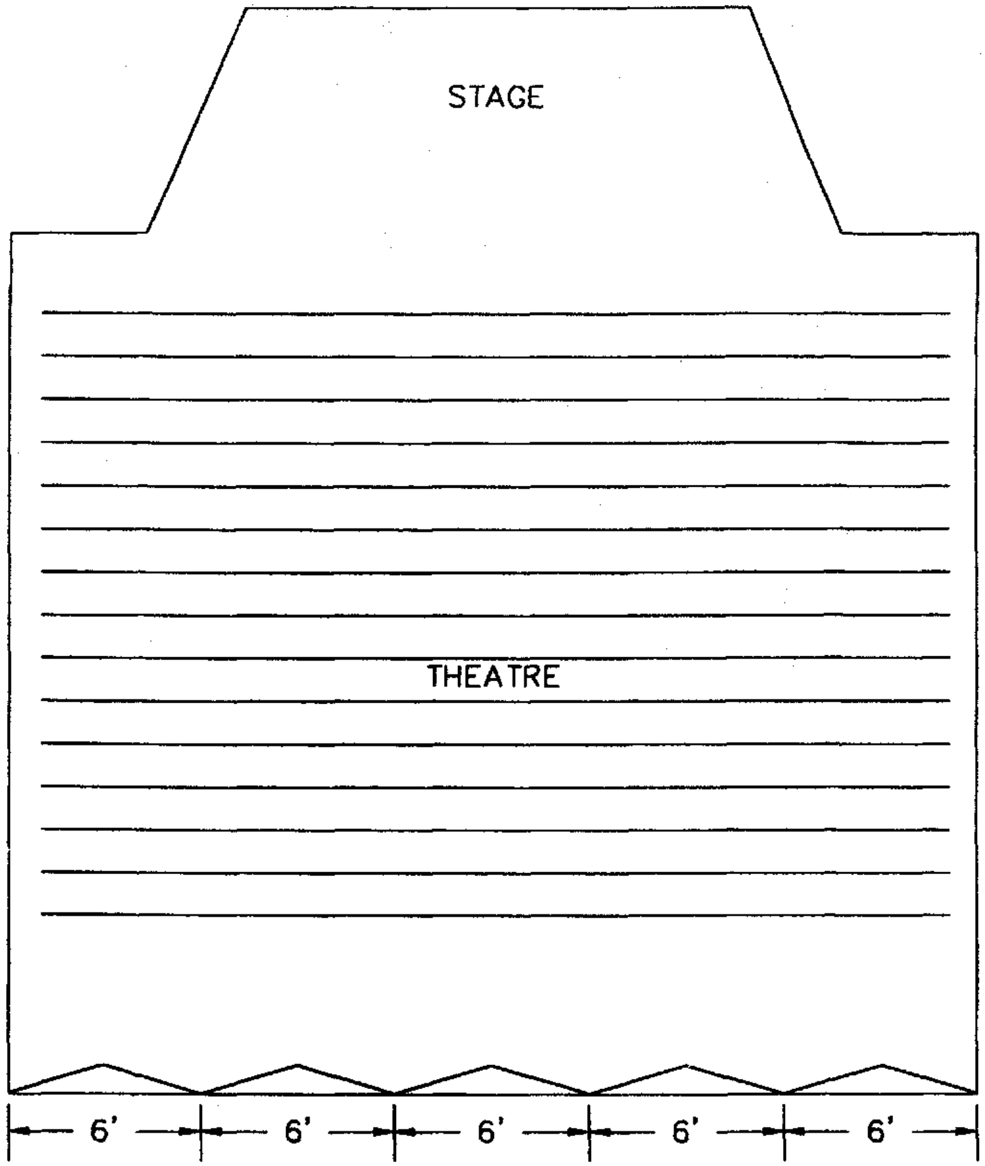
POOR CONSTRUCTION FOR BASS REFLECTIVITY

ILLUSTRATION #RA-3
THEATRE SECTION: NOT TO SCALE



LINE OF SIGHT FROM SOURCE TO RECEIVERS

ILLUSTRATION #RA-4
NOT TO SCALE



ONE EXAMPLE OF AN ACOUSTICALLY DIFFUSE REAR WALL

ILLUSTRATION #SS-1

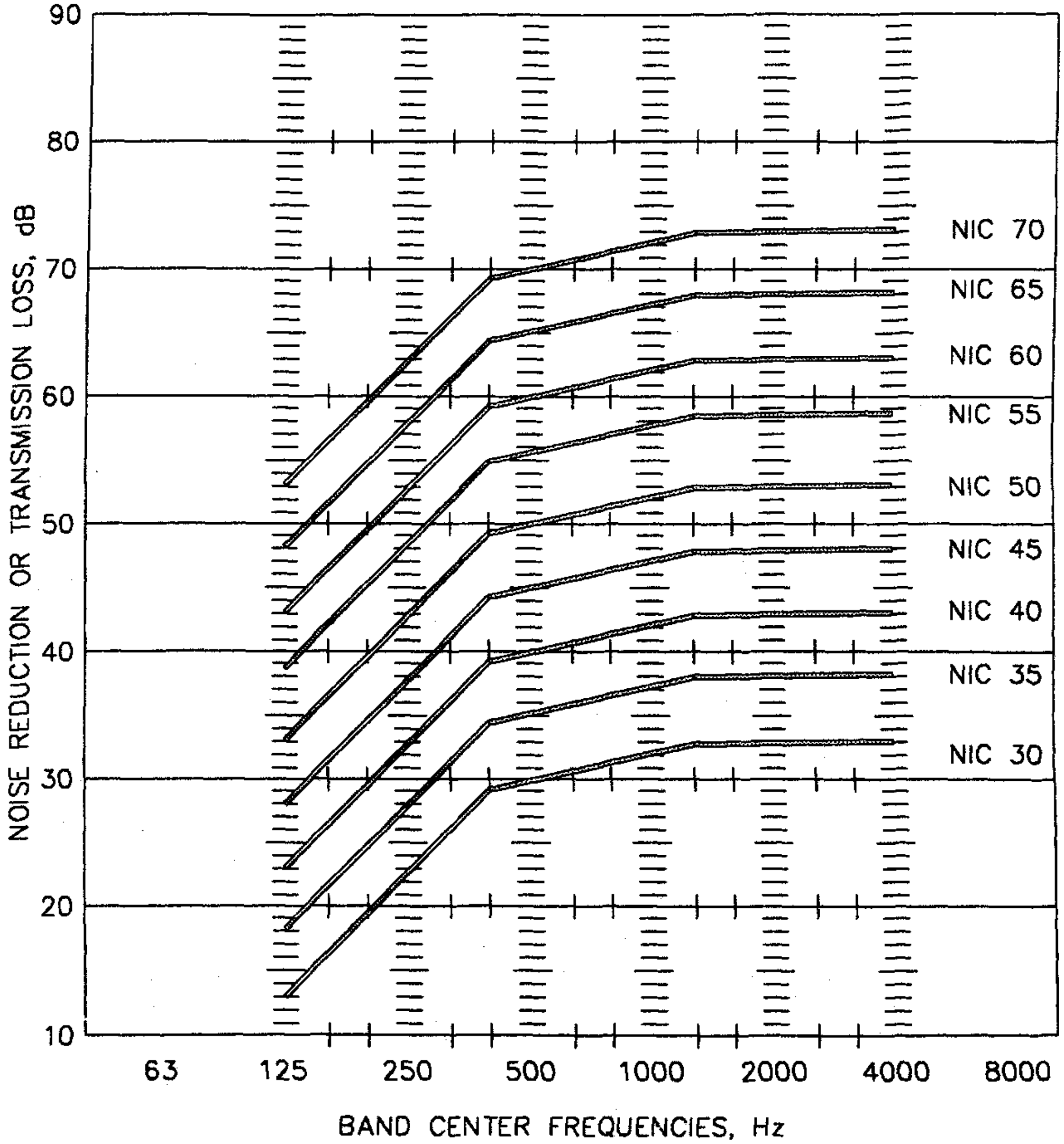
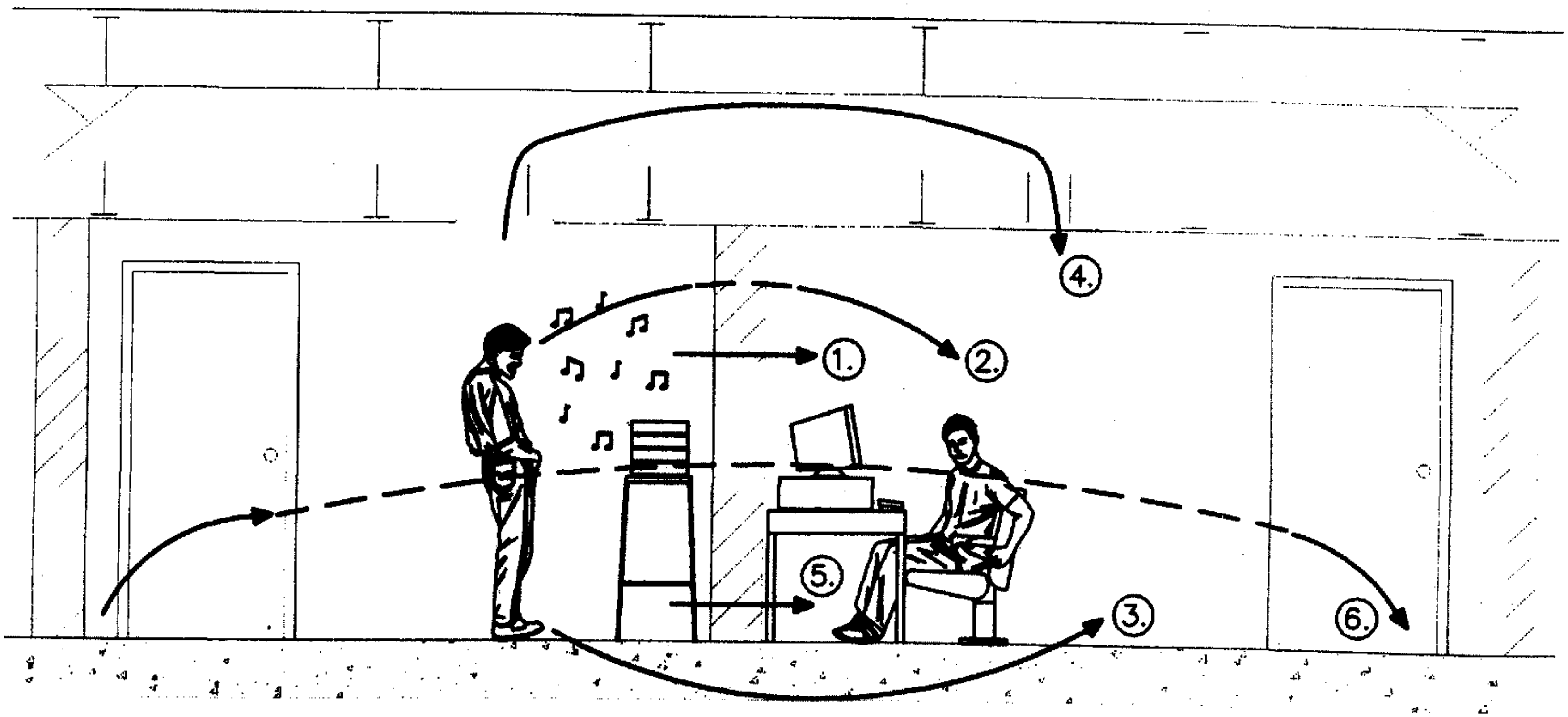
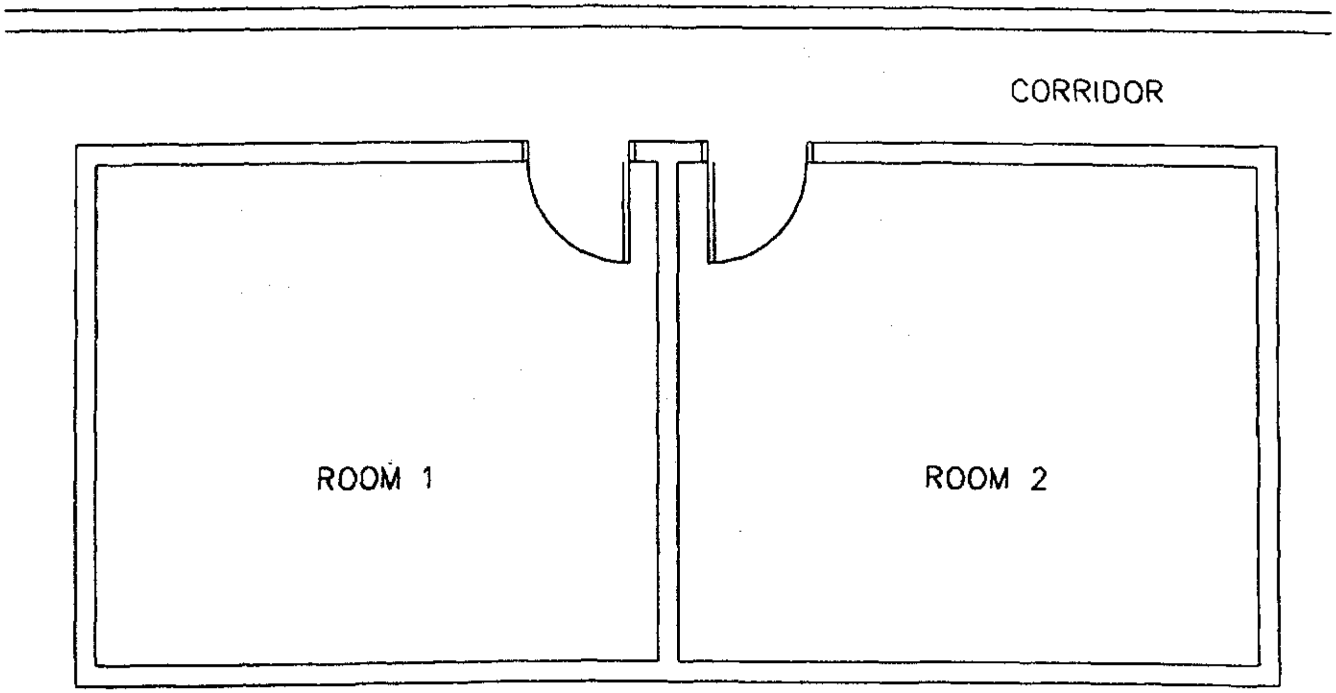


ILLUSTRATION #SS-2
NOT TO SCALE



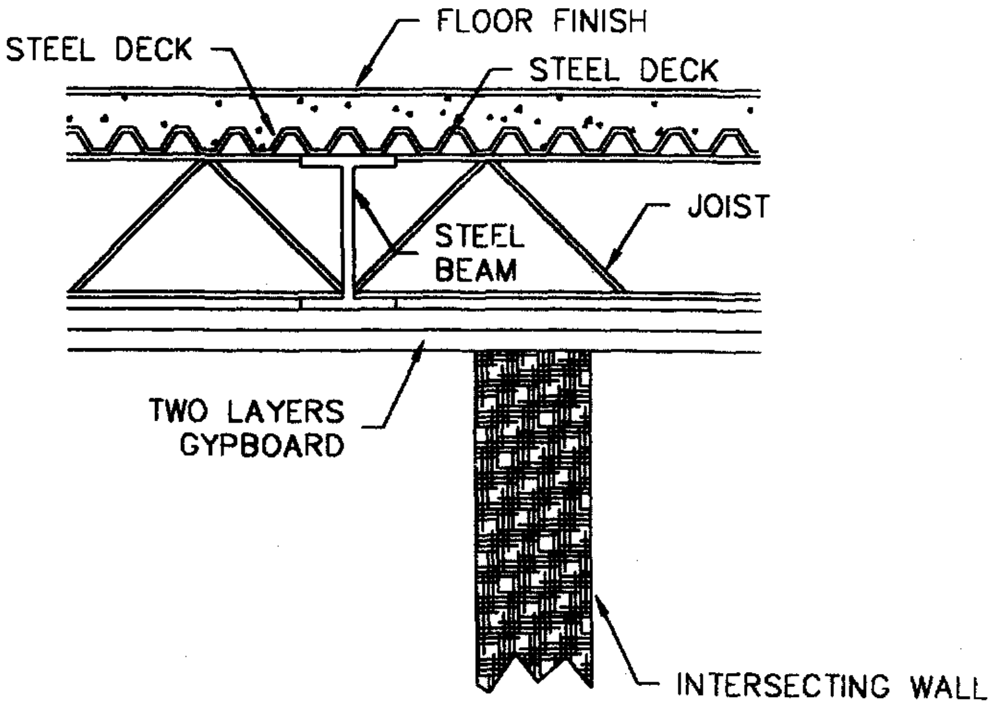
POTENTIAL PATHS FOR SOUND TRANSMISSION
BETWEEN TWO ROOMS

ILLUSTRATION #SS-3
PLAN: NOT TO SCALE



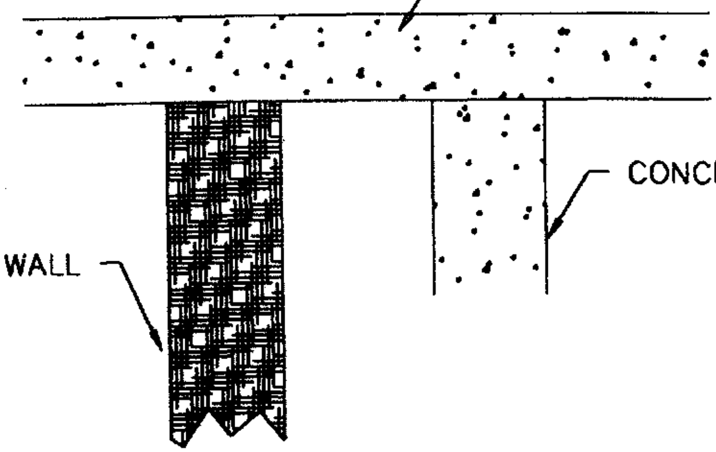
POOR DESIGN: DOOR SYSTEMS COMPROMISE
RATING OF WALL

ILLUSTRATION #SS-4
SECTION: NOT TO SCALE



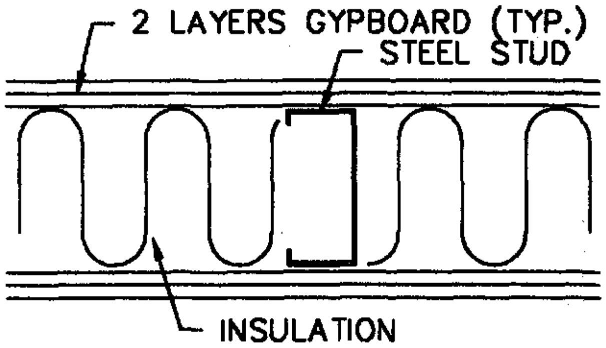
STEEL FRAME CONSTRUCTION

ILLUSTRATION #SS-5
SECTION: NOT TO SCALE

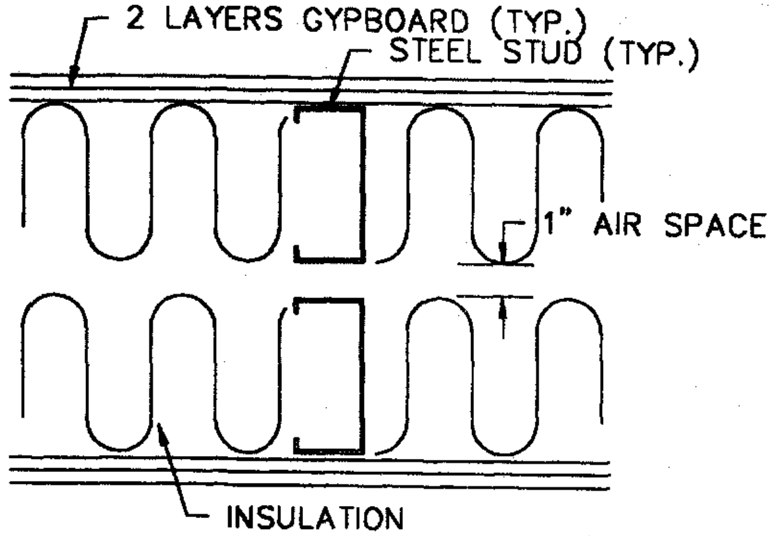


CONCRETE FRAME CONSTRUCTION

ILLUSTRATION #SS-6
PLAN VIEW: NOT TO SCALE

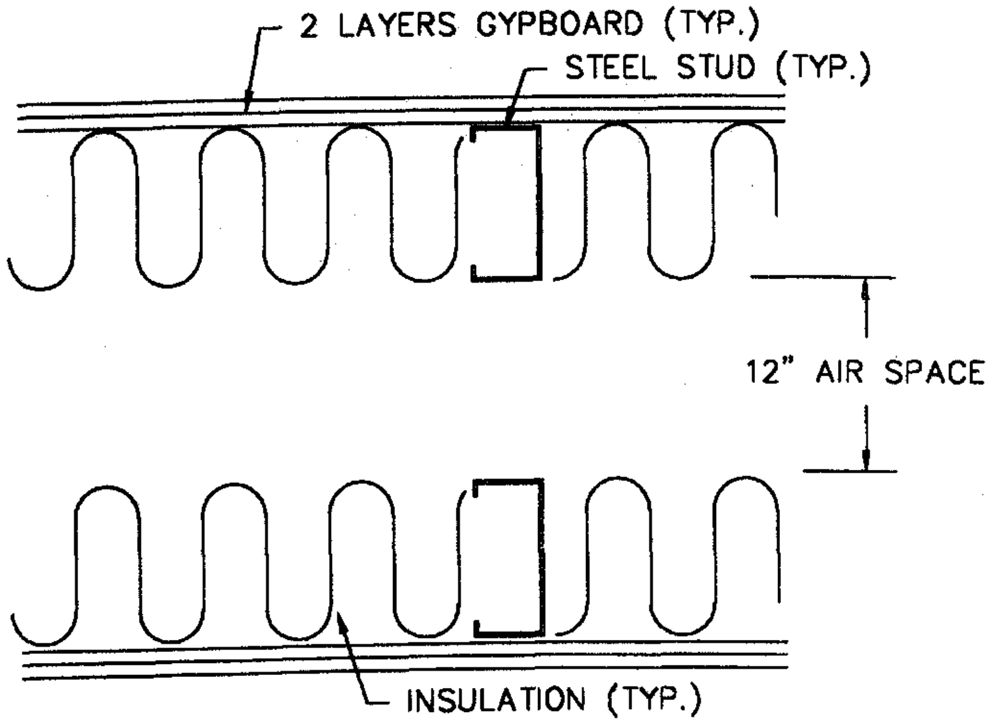


NIC 45 WALL CONSTRUCTION



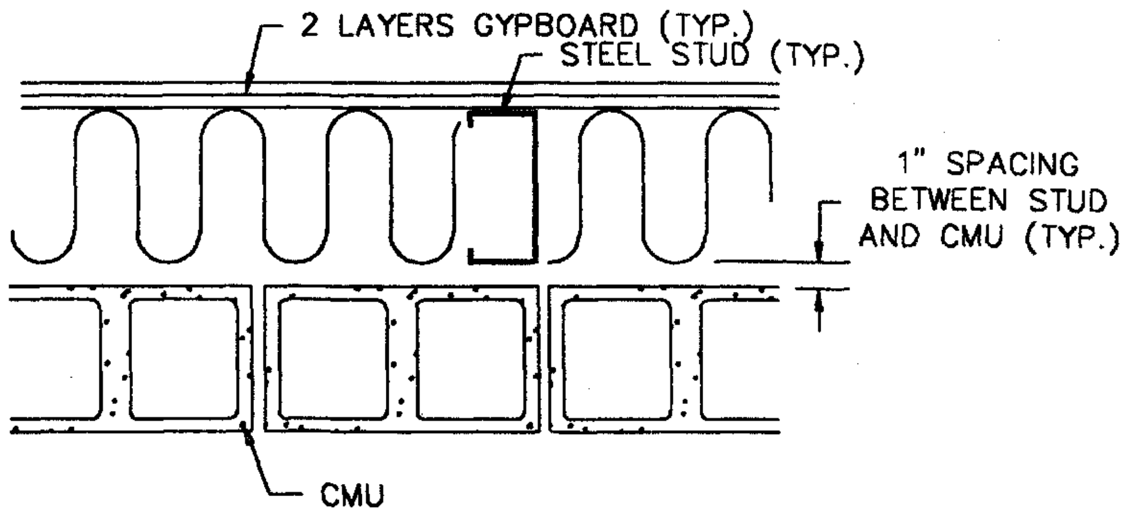
NIC 53 WALL CONSTRUCTION

ILLUSTRATION #SS-7
PLAN VIEW: NOT TO SCALE



NIC 58 WALL CONSTRUCTION

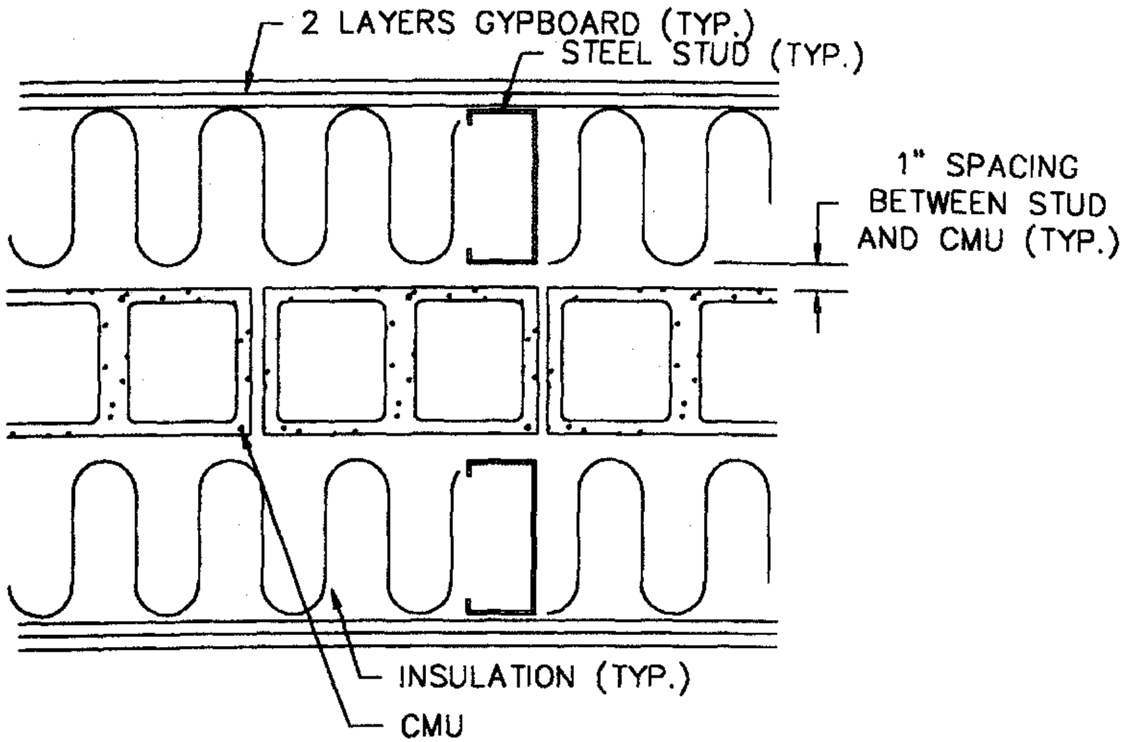
ILLUSTRATION #SS-8
PLAN VIEW: NOT TO SCALE



NIC 58 WALL CONSTRUCTION

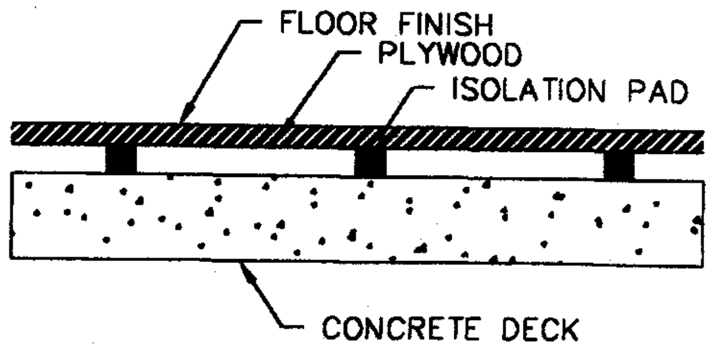
ILLUSTRATION #SS-9

PLAN VIEW: NOT TO SCALE



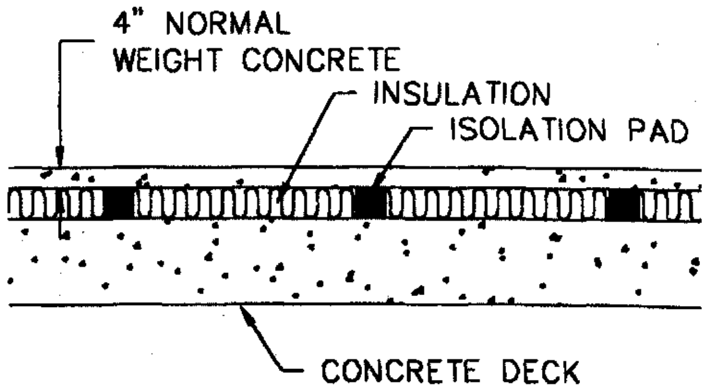
NIC 60 WALL CONSTRUCTION

ILLUSTRATION #SS-10
SECTION: NOT TO SCALE



LIGHT WEIGHT ISOLATING FLOOR SYSTEM

ILLUSTRATION #SS-11
FLOOR SECTION: NOT TO SCALE



NIC 70 FLOOR CONSTRUCTION:
RECOMMENDED FOR SPECIAL PURPOSE ROOMS

ILLUSTRATION #SS-12
NOT TO SCALE

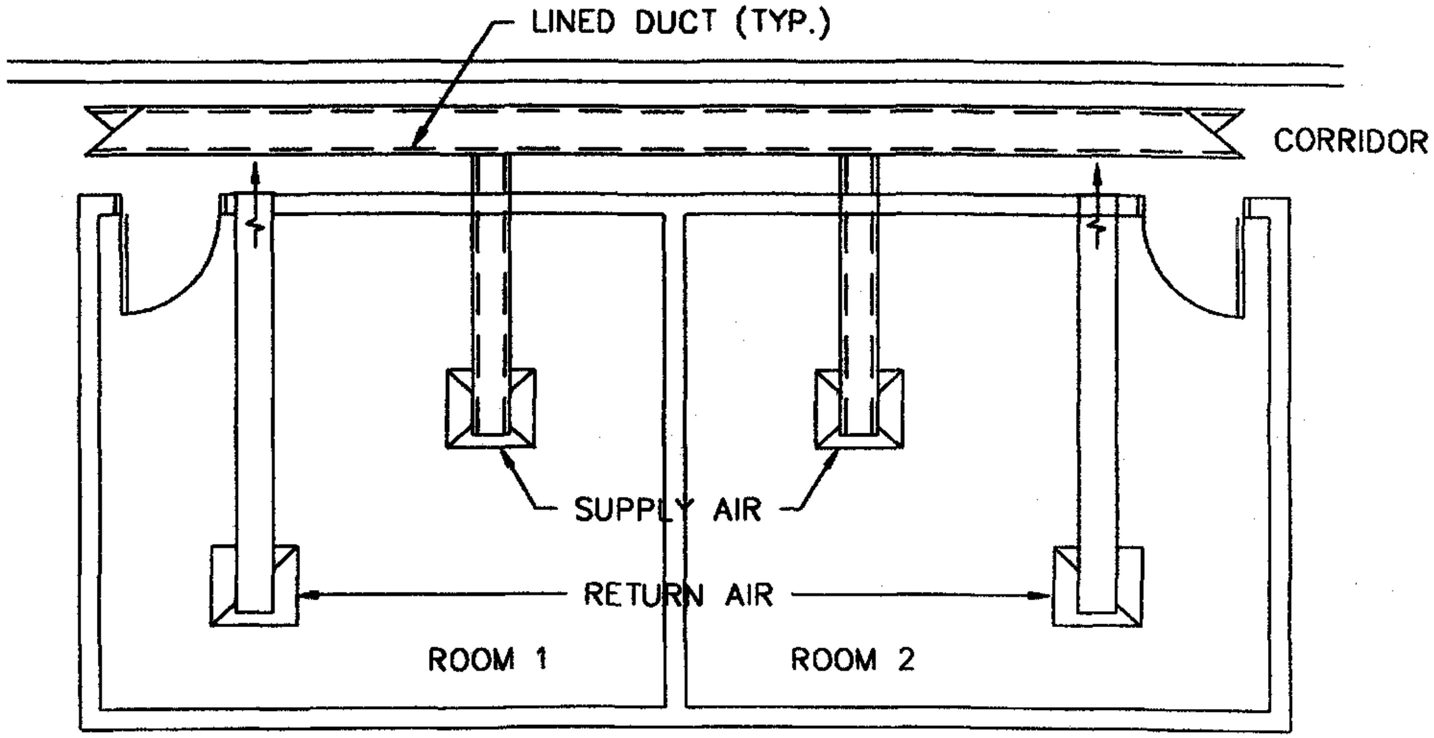
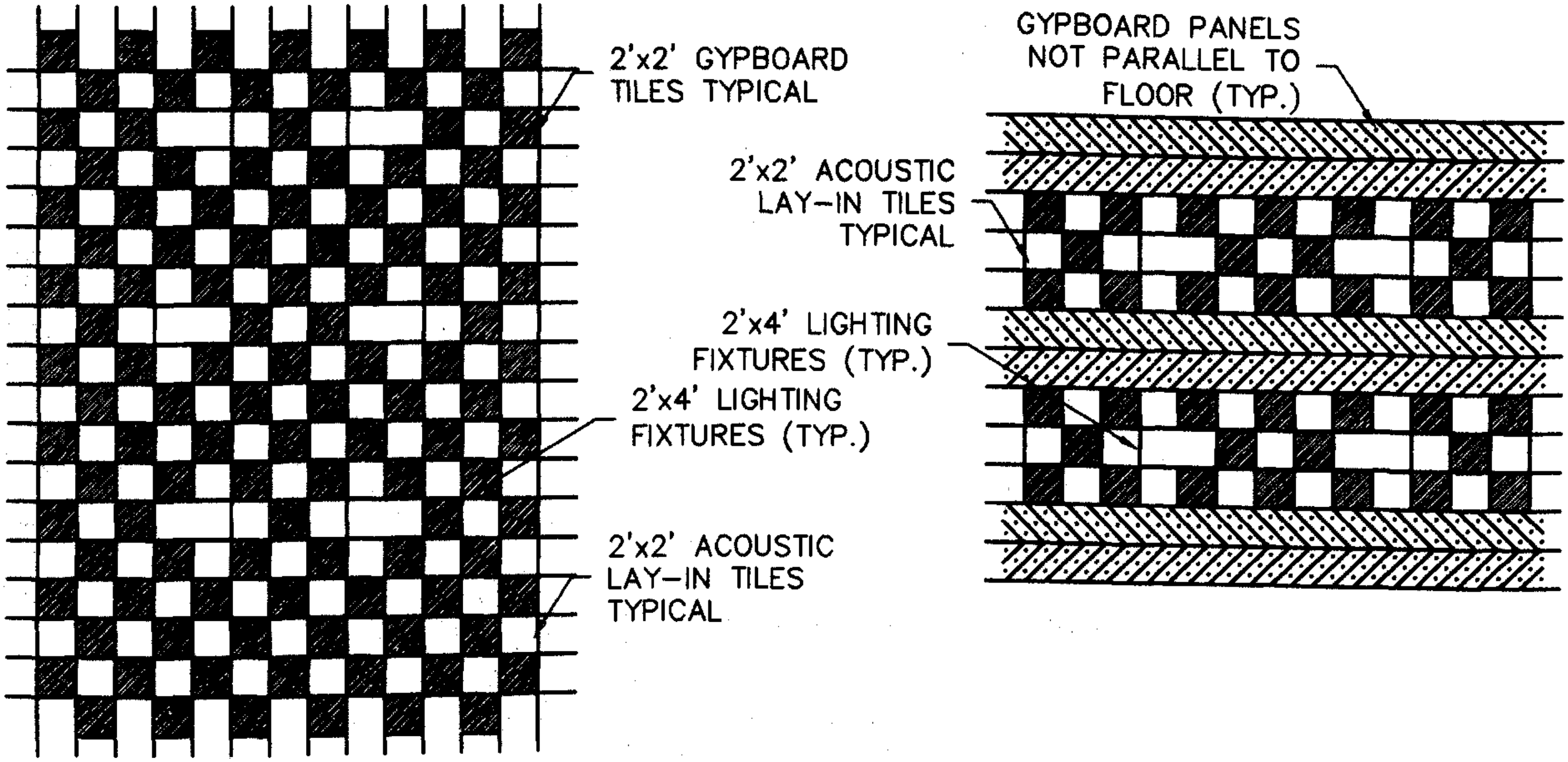


ILLUSTRATION #RH-1
REFLECTED CEILING PLANS: NOT TO SCALE



TYPICAL REHEARSAL ROOM
REFLECTED CEILING PLANS

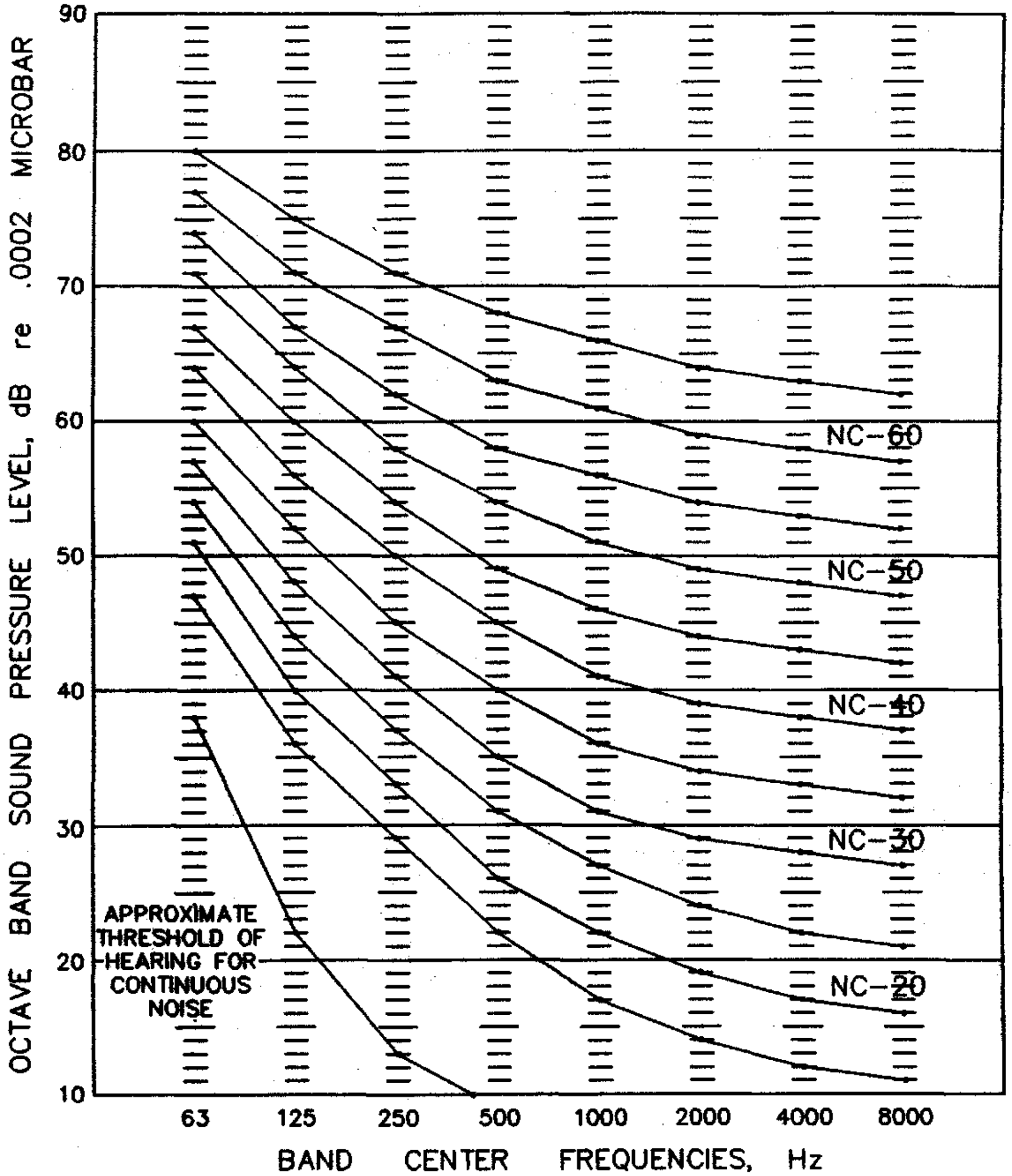


ILLUSTRATION NC-1

CONCEPTUAL SUPPLY AIRFLOW DIAGRAM
(DUCTS ABOVE CEILING)

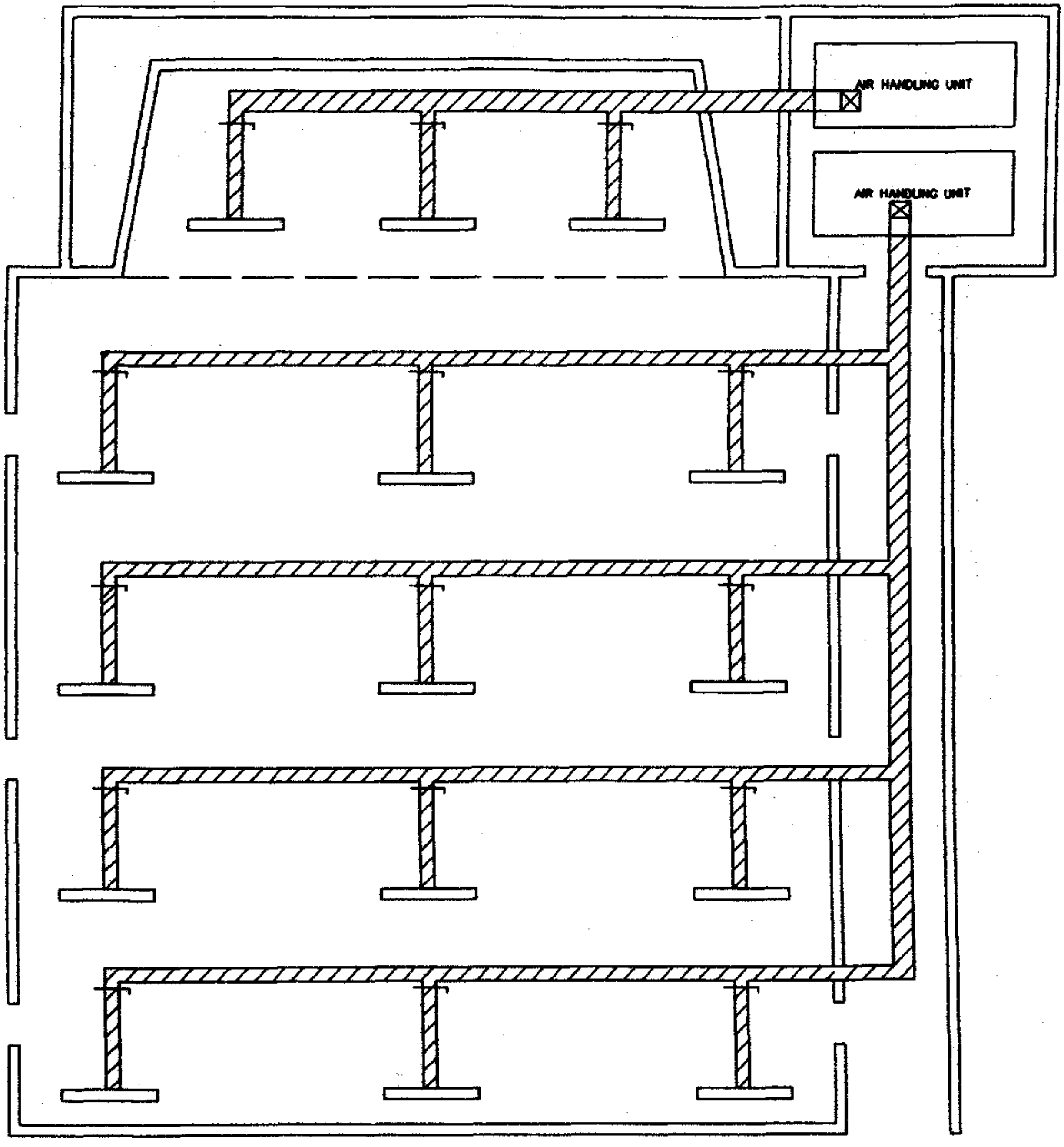


ILLUSTRATION AC–1

CONCEPTUAL RETURN AIR DIAGRAM

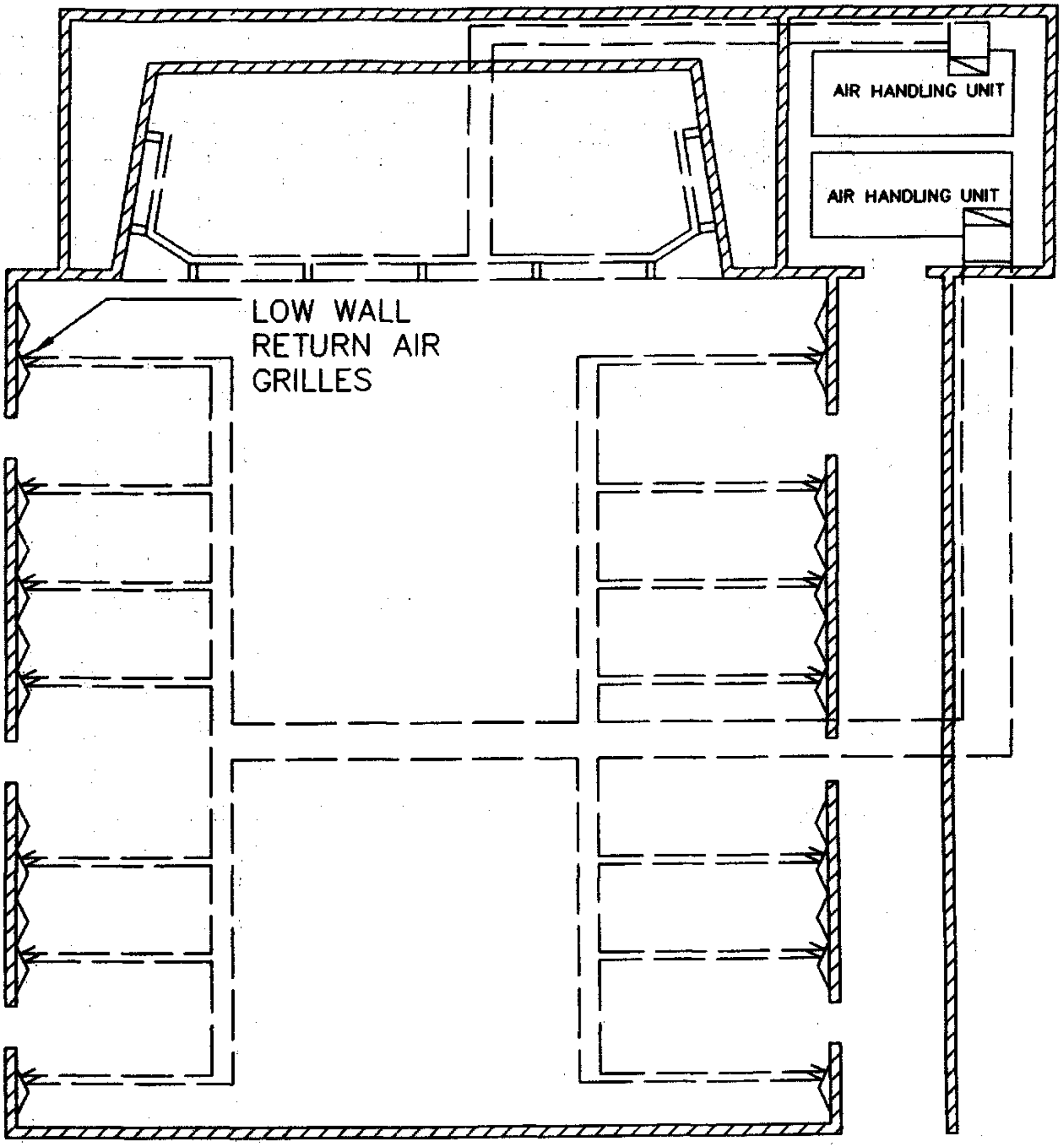


ILLUSTRATION AC-2

CONTROL OF AIR HANDLING UNIT RADIATED NOISE

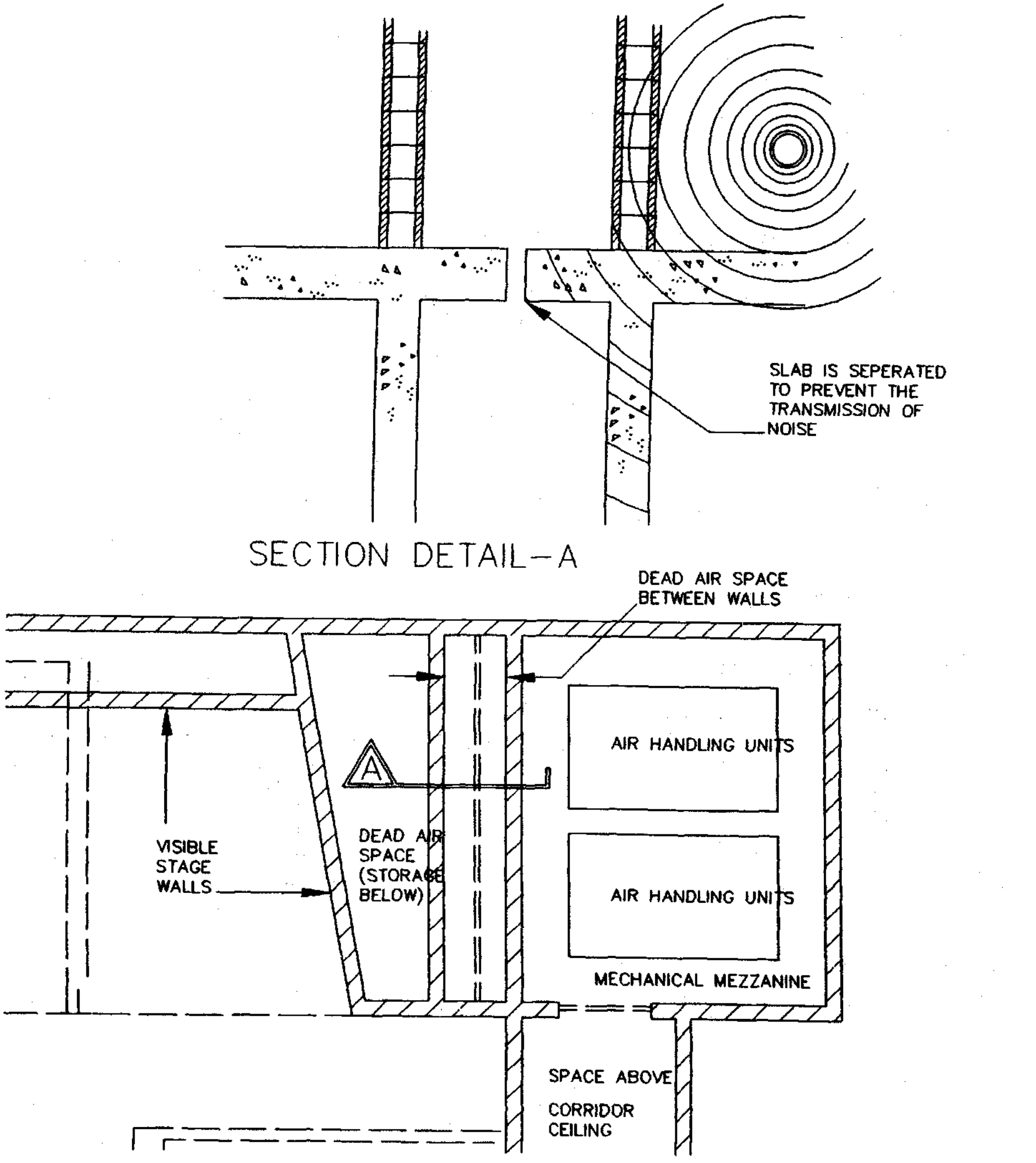


ILLUSTRATION AC-3

UNDERGROUND RETURN AIR DUCT SYSTEM

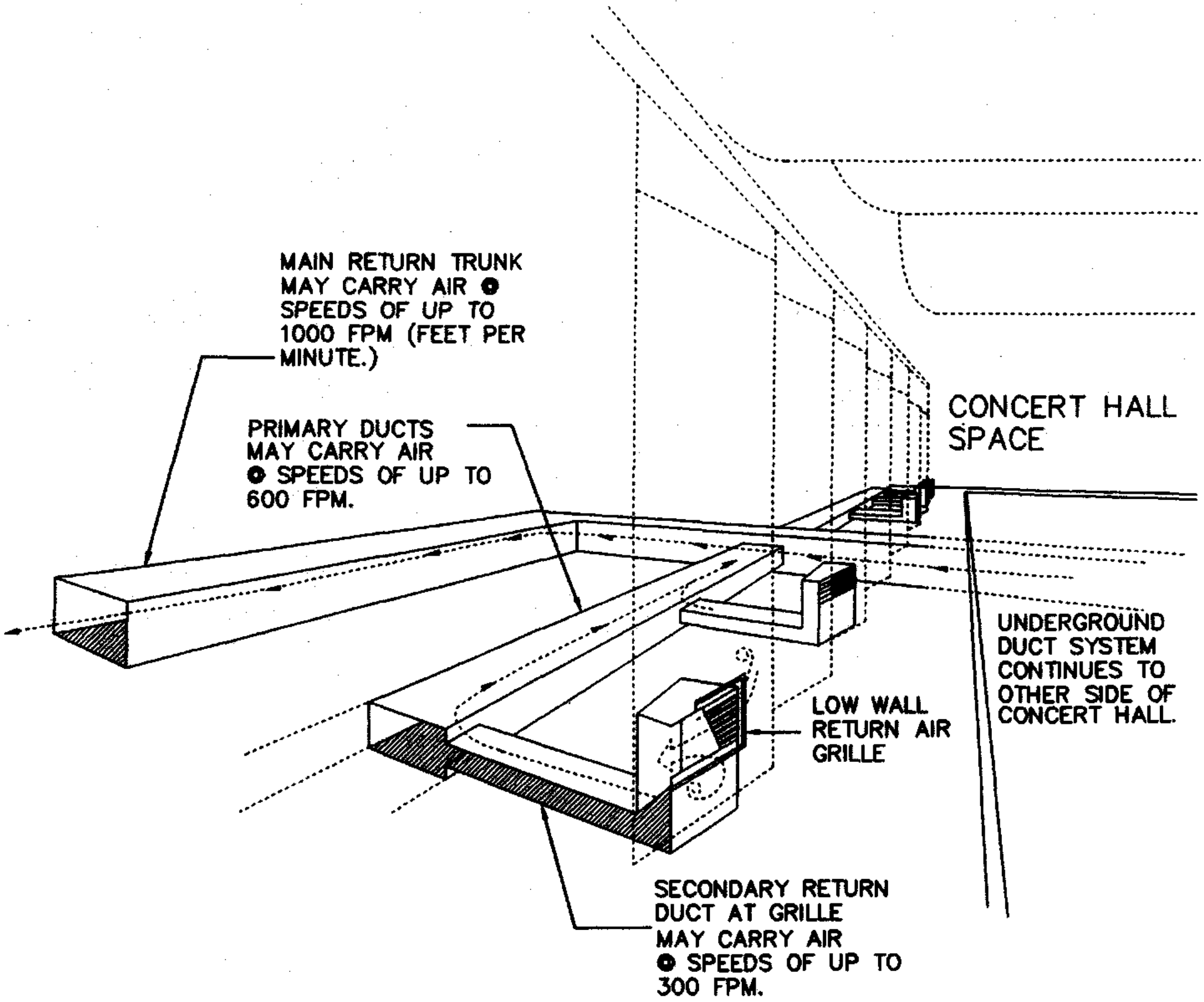


ILLUSTRATION AC-6