Chapter X

Music Building Acoustics

Charles Bonner, Acoustician, President
BAi, LLC

Introduction

Typically in music buildings, faculty and administrators (to say nothing of students) only experience a building's acoustics when the building is occupied and in use. Music administrators and faculty are sometimes not even a part of the design and construction team, and frequently they are astonished by decisions that are made before they become involved and occupy their buildings.

The purpose of this chapter is to present to the music executive tools that may be useful in communicating to provosts, university architects, presidents, and facilities personnel the essence of music and performing arts buildings; why rooms are sized in specific ways; what acoustical amenities are required to enable their buildings to perform for their intended purpose; and finally to enable them and their faculty representatives to have a basis for useful dialogue with architects, whether or not such architects are experienced with this building type. Acoustics for truly multipurpose music/theater/dance venues can also be important for the music executive to understand. Therefore, this chapter will discuss the following primary topics of "pure" and amplified acoustics in music buildings that may or may not be shared with theater and dance facilities, and also in multipurpose performing arts centers:

- Internal room acoustics
- Acoustic separation between rooms
- Noise control within rooms
- Acoustics and sound systems relating to multipurpose performing arts centers
- Acoustics for rooms for theater and dance within music buildings or shared performing arts facilities

Selection of the Design Team, Including Acoustician

The design team comprises, at a minimum, an architect, a structural engineer, a mechanical/electrical/plumbing engineer, a civil engineer, a code consultant, a cost consultant, a landscape consultant, an acoustical consultant, and a theater consultant (if theatrical elements are included in the project. These specialists may or may not be included in teams assembled by architects, depending on the university's approach in selecting all the design professionals. The team approach seems to be the most common, although because of frequently mandated interview time constraints, the architect that assembles the team may elect to bring to the interview only themselves and one or two of the important specialty consultants. The team approach brings with it some disadvantages to the music executive:

- The selection of an entire team implies that all team members are chosen as one entity. Sometimes an architect may elect to have the University select some or all of the specialty consultants..

- Interviews with teams may last 90 minutes or less. Some may be restricted to 20 minutes for presentations and 15 minutes for a question and answer period. Such an approach allows insufficient time to get to know the architects' project approaches, to say nothing of those of special consultants.

More useful methods for interviewing architects and particularly special consultants such as acousticians are as follows:

- If using the team approach, allow 90 minutes for presentations and 30 minutes for Q&A.
- Consider requiring architectural teams to come to the interview table with a list of acousticians with whom they have successfully worked on previous applicable projects. Then the university can select from this list, interview each acoustician separately, or express no preference. In the latter case, the architect would make the selection.
- Because good acoustics are difficult to communicate verbally, try to allot time to visit one or more of the referenced projects presented, and hear concerts/recitals and rehearsals in these facilities.
- Ask who, specifically, at the acoustician firm will be assigned to your project, from programming through building completion, together with his or her specific experience in this project type.

Irrespective of selection methodology (and assuming that adequate time is allotted), your acoustician should provide specific references for other similar projects, and be prepared to undertake the following:

- Sit in on faculty/administration meetings during all project design phases, especially programming.
- Ask specific questions during programming and design about your specific academic mission. Is your mission primary devoted to orchestra? bands? chorus? jazz? percussion? voice? teaching or performance emphasis? all of the above? some of the above?
- If determined useful, acoustically benchmark other similar facilities for acoustical positives and negatives. Describe the methodology that will be employed to ascertain causes for positives and negatives.
- Present specific design approaches aimed at helping your facilities meet your academic mission.
- Present specific approaches to acoustical commissioning of your building.

It is highly useful for the music executive to appoint a faculty or staff member to act as a continual interface between the design team and the entire faculty, including the executive. This person attends all meetings and is involved in the construction process, and therefore has frequent opportunity to interact with the acoustician.

Acoustics for Performance

Most university concert halls and recital halls are, by the very nature of music curricula, acoustically multipurpose in nature. Recitals and concerts featuring various types of soloists, chorus, orchestra, wind bands, and jazz, percussion, and chamber ensembles typically take place in such halls, and each requires its own acoustical environment. To audiences, music critics, teachers, and performers, such differences are critical for the public experience and affect the education of student musicians and the audience. The design team must be able to respond to these differences. A "short list" of acoustical amenities influences whether a hall will accommodate its intended purpose. Some of these elements are debatable in terms of magnitude in purely acoustical terms and importance; all are almost universally recognized as of primary importance ("almost" will be discussed in somewhat more depth).

Floor Plan Dimension Ratio (i.e., Length vs. Width)

It is generally recognized that the concept of musical "presence" is controlled first by the time sequencing between the "direct" sound from performer(s) to audience and then by the "first reflections" that arrive at the audience shortly thereafter, primarily from the hall side walls and secondarily from the ceiling(s). The length-to-width ratio controls this acoustical amenity. Values between 3:2 and 2:1 are recommended. For example, a hall that is 100 feet long (including platform) would be assigned a width of 50 to 70 feet. For halls of extreme sizes (very large or very small), this guideline becomes somewhat murky but generally still applies.

Volume in Cubic Feet (i.e., Length x Width x Height)

This value determines the potential of a hall to achieve a specific reverberation time (this differs from the term "presence"). Figure 1 shows a graphic representation of reverberation time. Since reverberation time requirements differ for various ensemble and soloist performances, it is advisable to plan for a cubic footage that allows for the *longest* reverberation time required (i.e., for choral and orchestral ensembles). If a music unit concentrates solely on jazz or wind band performance, then cubic footage appropriate to orchestral performance would be an economic and acoustic waste. The values presented apply to this topic and are given in terms of cubic feet per occupant. Divide the volume of the hall by the number of occupants (including platform musicians). In the absence of a specific quantity of occupants, assume 9.5 square feet per audience occupant, and 20 square feet per occupant for the concert platform.

Choral and orchestral ensembles:	350 to 400
Wind bands, percussion ensembles:	280 to 320
Jazz:	250 to 280
Organ performance:	600 to 800

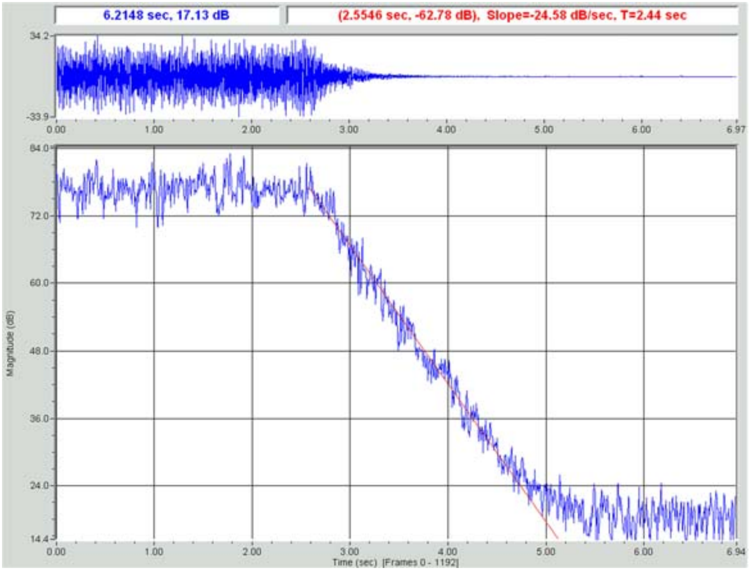

FIGURE 1 Illustration of a hall reverberation time. Measurement one octave above middle "C," 2.44 seconds

Most music buildings' pure concert halls are required to accommodate more than one of the above, and accommodation for all of the above is frequent. In such cases (except for organ performance, which will be discussed as a separate topic), the higher volumes would apply, using adjustable acoustical devices to reduce reverberation time for other types of presentations.

The inclusion of a balcony does have an effect on volume determination. If the balcony is small in depth (i.e., no more than 3–5 seating rows), the effect may be addressed by calculating the volume separately for the orchestra seating and balcony seating, summing the two volumes, then dividing by total occupancy. Large, deep balconies should be avoided.

Acoustical "Warmth"

The acoustical "warmth" of a performance hall is influenced primarily by the weight (i.e., mass) of the wall and ceiling surfaces. This effect is related to the bass response of the hall. The specific weight of these surfaces is selected to enhance bass energy for the hall's intended purpose. Depending on the function of the hall, the surfaces may be constructed from multiple layers of drywall, wood, thick plaster, concrete, or other dense materials. Thin materials with air spaces behind them should be avoided. Wood is considered to be an excellent acoustical material, but only if its thickness measures at least two inches or it is mounted to a massive substance.

A hall with a "diffuse" sound field normally has acoustics that are fairly uniform in loudness and music response. Acoustic diffusion may be achieved with (1) geometrical irregularity within wall and ceiling surfaces (see figure 2); (2) balcony, loge, or box seating elements; or (3) a combination of both. Halls with significant seating sections surrounding the upper levels sometimes require less wall shaping. Acousticians hold differing viewpoints on the importance of this topic.

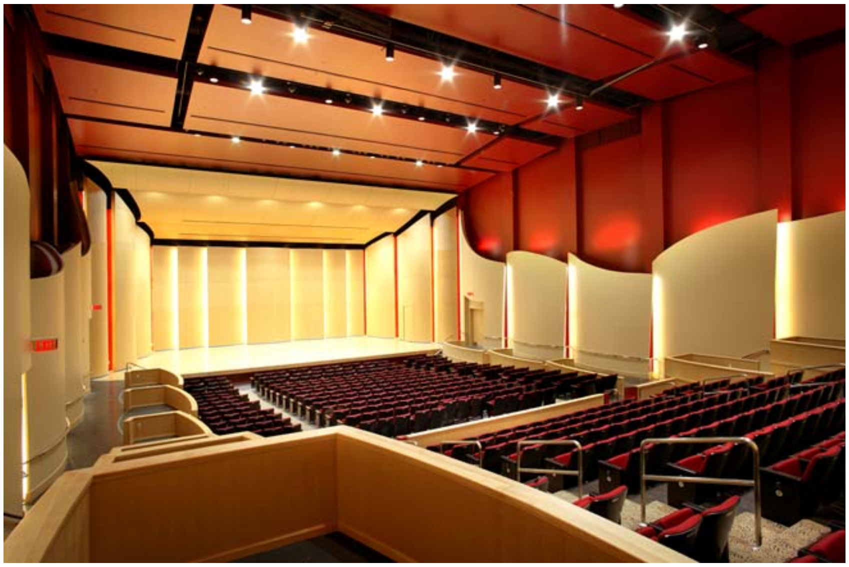

FIGURE 2 Illustration of a hall with geometrical shaping to achieve acoustical diffusion

Acoustical "Clarity"

Acoustical "clarity" frequently is judged to be as important as reverberance. In a reverberant hall, clarity can be optimized using the simple design tool of audience floor elevation changes ("rake", "step," or "slope"). Floors with minimum slope typically generate less clarity compared with slopes or steps that gradually increase with distance from the platform.

Adjustable Acoustical Systems

When a hall's volume is selected to meet the most reverberant function needed, its users frequently seek to reduce reverberation time for concerts that require less. Such "passive" methods commonly rely on vertically or horizontally deployed sound-absorbing curtains or heavy fabric, either exposed when deployed or concealed behind sound-transparent surfaces such as metal mesh, thin fabrics, or wood latticework. Other, more esoteric materials are also used occasionally, but all of the systems use materials that are sound-absorbing. Deployable materials that are exposed are typically more effective than those that are concealed, depending upon the sizes and dimensions of wall or ceiling openings that conceal such materials. Most sound-absorbing materials are more efficient at higher pitches than lower ones, and therefore the degree of acoustic adjustability is greater or lesser, depending upon the pitch. A "more active" approach to acoustical adjustability includes acoustically coupled "reverberant chambers," which are dedicated, nonoccupied volumes that are acoustically connected to the hall. Heavy doors, either automatically or manually deployed, expose or conceal the chamber volume from the hall. This approach adds reverberation to the acoustics.

For true multipurpose concert halls, there is never "too much" adjustability when jazz, electronic music, or pop concerts occur. The "ideal" is approached when 50 percent of the available side wall area is covered by sound-absorbing materials when deployed. In addition, acoustical adjustability is advisable within the concert platform envelope as well as within the audience chamber. This may be achieved with traditional curtainage or other deployable systems, or with portable sound-absorbing devices.

Variants on the "Traditional" Approach

The historic "traditional" design model maintains a wrapped hall concert platform, with hard wall surfaces surrounding the musicians. One variant gaining in popularity is that of wrapping the upper areas above the platform with seating, so that those audience members view the musicians and conductor from the rear and sides. This approach produces a different acoustic on stage and within the audience, because the "early" acoustic reflections from upper platform walls arrive later than with the traditional model. A second variant, more encompassing than any other, is that of the "hall in the round" model. Examples of this model are found in Berlin, Denver, and Los Angeles (the Disney Hall). The acoustics of such halls are again different from the traditional model, due primarily to ceiling surfaces being the most valuable contributors to early sound reflections. The scope of this narrative is not to express preferences for one approach over another. The reader is encouraged to hear performances within each of these design approaches when possible.

Multipurpose Performing Arts Center Hall Acoustics

In this model, an audience chamber is separated from the performers by a framed stage (proscenium) opening. The acoustics of such a space must accommodate performances ranging from symphonic ensembles to musical theater, opera, lectures, and a host of other event types.

The principal element provided for music ensembles on stage is an enclosure that both visually and acoustically surrounds the performers (i.e., a shell). Both the top and sides of the enclosure must be moved offstage and stored when not in use. This can be accomplished in any number of ways, including "flying" the ceiling panels and "nesting" wall elements offstage, complete movement of the enclosure into "garages" behind the stage house, and other more exotic plans. Various acousticians have differing design philosophies that govern their enclosure designs, ranging from "airtight" systems to individualized panel systems that tend to allow some sound energy to escape into the fly tower or through openings above the proscenium opening walls. All of these approaches have acoustical, structural, space, and economic advantages and disadvantages.

The weight of the enclosure units must be sufficient to reflect low-frequency (bass) energy. Since it is not commonly cost-effective to replicate the weight of the audience chamber walls and ceilings, acousticians and enclosure manufacturers tend to maximize the weight of the enclosure elements, while facilitating rapid storage deployment.. The enclosure must be shaped in such a manner that acoustic energy is dispersed into the audience chamber properly.

The audience chamber acoustical design criteria are similar to those of a pure concert hall. The reverberation time requirements for musical theater and lectures are not significantly different than those for jazz performance in a concert hall.

Acoustics for Organ Performance

This specialized area of acoustics carries perhaps more caveats than any other topic within acoustical performance. Nevertheless, what follows is an attempt to quantify some of the possible variables.

- When designing a concert or recital hall, never increase cubic footage purely for the sake of organ acoustics. This practice would risk poor acoustics for all other concerts.
- Halls built purely for organ performance can be optimized for the function, with the following generalities.
  - Volume per occupant should not be less than 500 cubic feet and can be as much as 1000, depending on the size of the instrument and the occupancy. The optimum target is 600.
  - The weight of the room surfaces is more critical than in a multifunction concert or recital hall, because pitches as low as 30 Hz (represented by the 32-foot pipe length) must be reflected and enhanced.
  - The instrument should be small in comparison to the room size, to avoid overpowering of the hall by the instrument. The "ideal" configuration features long, narrow, and tall rooms with the instrument at one end. The casework and pipes themselves are sound-absorbing; therefore, large instruments positioned near the center of small halls typically do not perform well.
  - Acoustically "hard" materials all possess some minuscule amount of sound absorption. Brick and concrete block, for example, tend to be acoustically porous and can be quite sound-absorbing at very high harmonics.
  - Acoustical diffusion is important, particularly at the walls behind the audience.
  - No sound-absorbing materials, such as carpeting and upholstery, should be used on the floor, audience seating, or anywhere else.

Acoustics for Rehearsal

Should rehearsal room acoustics somehow replicate those of performance halls? If so, to what extent? How can this be achieved in much smaller rooms, if at all? Are clarity and definition more important than liveness, and if so to what extent? How can rehearsal rooms work for multiple ensemble types (never mind scheduling difficulties)? This section discusses the typical rehearsal space required for music buildings and ways to resolve these kinds of questions.

Instrumental and Choral Rehearsal

A number of elements common to many instrumental and choral rehearsal rooms can take care of many of the acoustical concerns that arise when designing rehearsal space. The design process should follow these guidelines:

1. Determine maximum occupancy. Multiply that number by 25 square feet (assuming no built-in instrument storage), 35 square feet with significant permanent storage. This will produce the room's square footage value.

2. Set floor plan ratio (length to width) at approximately 3:2. This will determine the room shape.
3. Assign cubic feet per occupant at approximately 400. This calculation will determine the gross ceiling height (usually 18 to 23 feet in most large rehearsal rooms for instrumental and choral work).
4. Enable deployable sound-absorbing materials (such as heavy curtains) to cover 50 percent of all walls (usually 100 percent of walls above a height of 10 feet).
5. Lower walls (from floor to about 10 feet) should not be parallel, or should contain significant geometrical shaping elements.

This design concept enables the conductor to adjust the room reverberation for "dry" acoustics maximizing clarity and definition or "live" acoustics that will more closely approximate the environment of a live performance hall. However, since rehearsal rooms are much smaller than performance venues, exact replication is never achieved.

Jazz or Music Technology Rehearsal

Square footage calculations for instrumental/choral rooms also apply to jazz spaces, although using 35 square feet for the calculations will permit conductors to set up the musicians in flexible ways. The cubic feet per occupant should be set at 250–300.

These rooms must be acoustically very "dead," in order to preserve occupants' hearing and to achieve maximum clarity. Almost all of the room surfaces must be highly sound-absorbing. It is important to interview jazz faculty to ascertain whether any acoustical adjustability is required.

Acoustics for Private Music Instruction

Faculty teaching studios should be sized to accommodate the instructor and one or more students. Most of these rooms contain at least one small grand piano or upright, one or more chairs and music stands, furniture, and private music libraries. Faculty occupants of these rooms spend several hours each day in private instruction, and many prefer to personalize their rooms with area rugs, artwork, and the like. Ceiling heights must be sufficient to permit sound waves to properly fill the space and not be "constricted" by insufficient cubic volume. Suggested room dimensions for a single-piano room are 14' W x 17' L x 11' H. Hard-surface floors are suggested, to enable the faculty occupant to choose the appropriate floor coverings. Selectable hanging sound-absorbing wall elements are also suggested, to enable the faculty member to select the acoustic environment desired. These elements may be interspaced amongst artwork and furniture.

Acoustics for Student Practice

Perhaps because of the quantities of rooms that must be devoted to practice, and also because of economic considerations, many of student practice rooms are acoustically undersized. Rooms of 50 square feet or less are frequent, presenting the students with the "small cubicle" approach to practice. Prefabricated practice modules are frequently too "dead" acoustically to enhance the practice experience. Available options include prefabricated vs. built by the contractor "dead" vs. "resonant" acoustics, electronic enhancement of sound within an acoustically "dead" space, and subvariants of these.

The balance between the quantity of rooms and the quality of the practice experience should be uppermost in the minds of building planners. The music administrator and faculty are in the best position to offer advice. Some maintain that practicing in a lobby or stairwell is better than in a small cubicle, saving "woodshedding" for small, confined spaces.

With due respect to these considerations, the following approach is suggested:

- Ceiling height should be a minimum of 9 feet. In the author's opinion, the lesser height offered by prefabricated rooms represents an acoustical disadvantage.
- Minimum room size of 60 square feet is suggested. If absolutely necessary, include a minimum quantity of 50 SF rooms.
- Consider rooms designed with varying acoustical environments.
- Consider prefabricated vs. contractor-built rooms carefully, taking into account economics and acoustical separation (refer to the "Acoustic Separation Between Spaces" section of this chapter), along with the value of electronic acoustic enhancement functions.

Acoustics for Audio Recording Technology

This topic is one of the more esoteric and complex in the industry, and the specifics are beyond the scope of this discussion. Facilities for recording may include one or more of the following:

- A small, simple control room intended for audio reference recordings originating within one or more performance or rehearsal spaces. Internal room acoustics are designed to be very dry.
- A larger, more complex control room intended both for reference recordings and for multitrack recording, editing, and mixdown functions. Within such rooms, reverberation times are typically extremely short (less than 0.4 second), dedicated bass absorbers are provided, and special acoustic diffusing and wall-shaping elements are provided.
- A dedicated recording studio, accommodating a specific musician occupancy, designed as a stand-alone "open mic" space for recordings serving specific ensemble/soloist functions. Such rooms, depending on the mission, are designed for either very dry or adjustable acoustics.
- A "voice-over" room, typically used for narration and other "spoken word" functions, typically very dry acoustically.

Associated ancillary rooms for storage, digital/analog libraries, faculty offices, and the like. The scope of the department's need for such facilities, if any, should be determined during the initial programming phase. This task is a simple one if the music unit includes one or more faculty members who either teach this technology or use it themselves. Sometimes a staff member, either full- or part-time, executes the technology during rehearsals and performances. In the absence of any faculty or staff input during programming, the music executive would assist in the programming in an advisory capacity.

Sound Transmission Between Spaces

Music buildings are unique compared to other university building types, for two primary reasons. First, unlike speech, which is the mode of communication within classroom buildings, libraries, science buildings, and the like, music is "tonal" in nature and is therefore heard much more easily by the observer in adjacent, nearby, or even more remote rooms in a building. Second, music, also by its nature, can be extremely loud, particularly in confined spaces such as teaching studios and practice rooms, but also within rehearsal and performance venues. Whereas typical instructors' amplified or nonamplified voice loudness levels are 65 to 75 decibels (dB), music can approach levels of 100 dB. Both of these elements, in creating the acoustic challenges in music building design and execution, tend to make these construction projects much more expensive than other university building types.

Building Efficiency

The ratio of net (i.e., assignable) square footage to gross (i.e., assignable added to unassignable square footage) is called building efficiency. Examples of unassignable square footage include hallways, mechanical rooms, restrooms, unassigned storage rooms, and floor area concealed by walls. Typical classroom buildings are approximately 75 percent efficient (i.e., for every 100 SF of building, 75 are assignable). However, music buildings typically fall between 60 and 65 percent efficient, primarily for the following reasons:

- Hallways are wider, in order to facilitate the movement of large musical instruments between various parts of the building.
- Walls are much thicker, in order to attenuate sound between and among spaces.
- Because music buildings require that heating, ventilation, and air-conditioning (HVAC) systems be extraordinarily quiet, ductwork, air handling units, and mechanical rooms are all much larger than in a typical university building.

Typical Paths of Sound Transmission

In a music building the ways in which sound frequently travels from one part of the building to another include:

- Through walls, floors, ceilings, and doors via the air
- Underneath and above walls via floors and roof structures
- Through and around ductwork, piping, conduit, and the like
- Through building structures, either originating in air (as in sounds presented by percussion instruments) or by direct connection to floors by musical instruments (e.g., piano, percussion)

Design Tools for Acoustic Separation Between and Among Spaces

The tools that an acoustician will choose to achieve acoustic separation depend heavily upon the types of rooms and adjacencies required. For example, a jazz rehearsal space directly adjacent to a performance hall would require more isolation than a pair of teaching studios for applied music performance. Similarly, percussion rooms require greater isolation from surrounding spaces than other sets of rooms. The following tools are available to the acoustician:

- Walls containing concrete block, multiple layers of drywall, air spaces, and/or various combinations of these elements
- Building expansion joints
- Simple floor slab breaks
- Suspended spring-isolated multiple drywall ceiling systems
- Floating wood floor assemblies
- Floating concrete floor assemblies
- Heavy, sound-retarding doors
- Corridors separating sound-sensitive spaces
- Acoustically "benign" rooms such as music libraries and storage rooms separating sound-sensitive spaces
- Sound/light locks
- Special sound-retarding window assemblies
- Special duct routing and treatments
- Special pipe and conduit treatments
- Specially designed HVAC systems to generate some "masking" or white noise within practice rooms and teaching studios

Design practices for the various space types are assumed as follows:

- Acoustic isolation between teaching studios should be as complete as possible.
- Corridor walls and door systems should be such that sound is audible in the corridors but room-to-room isolation is not compromised.
- Student practice rooms may be designed to be similar to teaching studios. However, for economic reasons this equality may not be achievable; generally practice rooms will achieve less isolation.
- Percussion room isolation should be at the maximum level with respect to all surrounding areas; some reduction in isolation is permissible at corridors only.
- Performance halls should be completely isolated from each other and from nearby rehearsal rooms.
- Rehearsal rooms should be completely isolated from each other and from surrounding spaces.
- Audio recording studios and control rooms should be completely isolated from surrounding spaces (including corridors).

Some or possibly all of the elements that influence acoustical isolation are applicable to each architectural element in the building, depending upon adjacencies and STC ratings. For example, adjacent teaching studios require either wood or concrete floating floor systems, to prevent transmission of sound through floors under walls to the adjacent rooms.

Routing of ductwork within the building must be designed to avoid "cross-talk" between spaces. For example, ducts serving teaching studios must be routed from adjacent corridors rather than across dividing wall systems. Internal lining or other sound-absorbing ductwork must be provided in all cases to avoid such short-circuits around wall and other demising building elements. Figure 3 shows an example of proper duct design for a series of practice rooms.

Sound transmission class (STC) is a single-number rating that describes the level of acoustic separation between spaces. The term is similar to dB; higher numbers indicate greater sound separation. The STC ratings for music building spaces should achieve the following values:

Between teaching studios:	65–70
Teaching studios to corridors:	50–55
Between practice rooms:	55–60
Practice rooms to corridors:	40–45
Performance halls to rehearsal halls:	75–85
Rehearsal halls to performance halls:	75–85
Recording rooms to all spaces:	80–85
Performance/rehearsal halls to public areas:	55–60

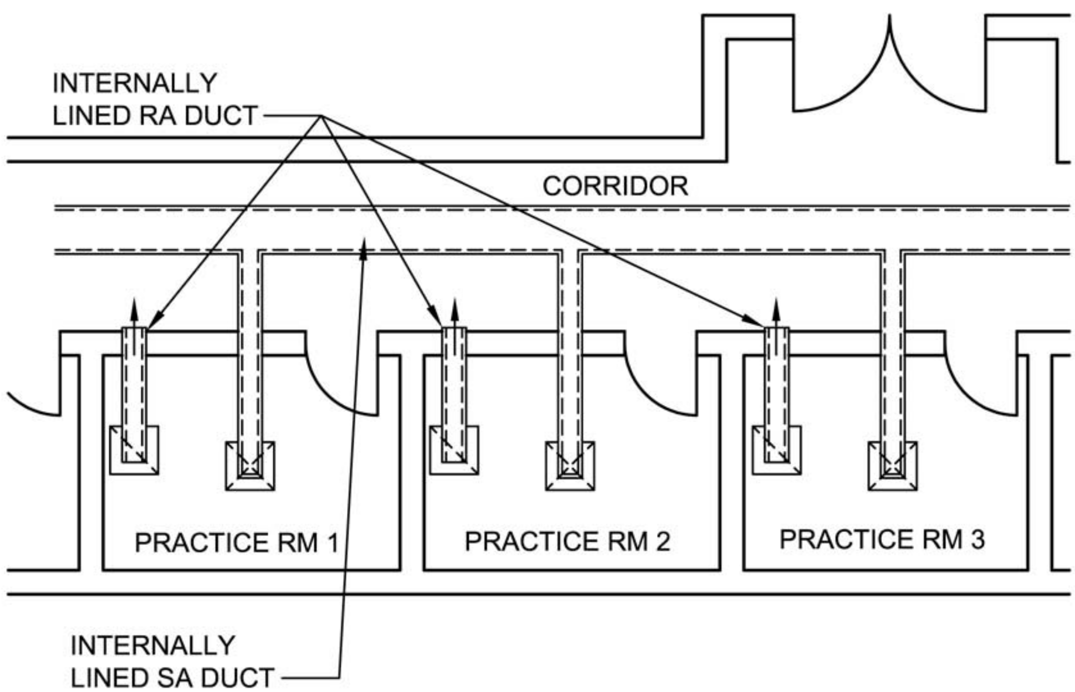

FIGURE 3 Illustration of a row of practice rooms or studios with correct duct design. SA = supply air; RA = return air

Each STC rating carries with it a certain wall or other element thickness. The music executive or the designated representative should review a set of completed schematic design drawings and check the wall thicknesses for accuracy. If wall thicknesses are significantly less than the recommended values, the dimensions must be corrected in order to avoid a loss of net square footage within each room. The recommended wall thickness measurements are as follows:

Between teaching studios:	18 inches
Teaching studio to corridor:	10 inches
Between practice rooms:	12 inches
Practice room to corridor:	6 inches
Between percussion rooms:	24 inches
Percussion room to corridor:	18 inches (with sound locks)

HVAC System Noise

Background noise generated by mechanical systems may be completely undesirable or permissible in varying degrees in music buildings and performing arts centers. In general, noise may be permissible in varying loudness levels in such areas as lobbies, corridors, storage rooms, and other unassigned areas. In the case of teaching studios and practice rooms, some audible but unobtrusive noise is permissible and even desirable to mask any residual sound that may be transmitted through structures.

The term "NC" refers to the loudness of continuous building background noise. Higher numbers refer to more noisy conditions. The meaning of the numbers may be approximated by the following (all assuming no music or other program material being performed or rehearsed):

NC-15:	Not audible
NC-20:	Audible under extremely careful listening
NC-25:	Audible under moderate listening
NC-30:	Audible
NC-35:	Maximum permissible, teaching/practice conditions
NC-40:	Suitable only for lobbies and other public areas

Design guidelines for spaces within music and performing arts buildings are as follows:

Performance spaces:	NC-15 to NC-20
Rehearsal rooms:	NC-20 to NC-25

Teaching studios/practice rooms:	NC-30 to NC-35
Recording studios:	NC-15 to NC-20
Lobbies, corridors:	NC-35 to NC-40

HVAC noise sources are numerous, and the individual source components are summed to create an overall continuous noise "floor." In general, acoustically quiet spaces involve large and sound-absorbing ductwork, lengthy distances between equipment and function rooms, and specially designed duct routing systems.

Audio Systems for Amplification, Reproduction, and Recording

For discussion purposes, there are basically these three types of audio systems. Amplification involves live microphones as sources, either for voice or musical instruments. Reproduction involves CD/DVD players, computers, or other sources that are not live microphones. Recording systems involve live microphones serving performance and/or rehearsal rooms and connected to recording electronics, either localized for individual rooms or centralized to serve multiple rooms.

It is important for the design team and music executive to determine which rooms require such sound systems and for what function. This task should occur as a part of the building programming phase. The acoustical consultant can then provide program-level cost estimates for such systems to be included in the program document, together with narratives that describe the system elements and performance.

The performance elements of primary importance are (1) loudness capability with no distortion; (2) frequency response; (3) spatial variation in loudness over the audience area; and (4) potential gain before feedback.

A Brief Discussion of Acoustical Modeling, Auralization, and Measurement Technologies

Computer Modeling. The computer programs Odeon and Ease are perhaps two of the best examples of this technology. Examples of the deliverables from modeling include line ray tracings, reverberation time predictions, early reflection characteristics, and so on.

Physical Modeling. This approach involves the actual construction of a scale model of a hall, followed by its evaluation with pitches (tone bursts) that are up-scaled in ratio to match the ratio of the model's scale to that of the real hall.

Auralization. Auralization involves the translation of the mathematical or physical model to actual listening. The media over which the listening occurs can be headphones or loudspeakers. Many modeling programs have auralization components. The technology is quite young and will experience many upgrades and improvements during the next decades.

Acoustic Measurement Technologies. These technologies involve executing measurements after construction of a hall is complete. Typical software for this application as of August 2006 includes SIA Smaart Acoustic Tools, Easera, and Praxis. All aim to measure and document such acoustic features as reverberation time, strength of individual acoustic reflections, bass ratios, and a host of others. Most of this technology has come to the industry between the late 1990s and early 2000s.

Conclusion

Music and theater buildings are among the most complex to design and construct. The architect, specialty consultants, and contractor (or construction manager) must be carefully selected. Music faculty representatives should remain interested and involved throughout the design and construction process. It is likely that those involved will find it a rewarding and challenging experience.