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The school music rehearsal facility and gymnasium-auditorium: Design and modification for acoustics and sound isolation

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THE SCHOOL MUSIC REHEARSAL FACILITY AND GYMNASIUM-AUDITORIUM:

DESIGN AND MODIFICATION FOR ACOUSTICS AND SOUND ISOLATION

.by

Murray Hodges

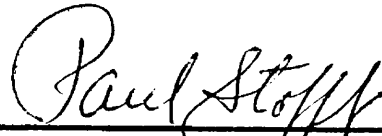B.Ed., University of Alberta, 1972

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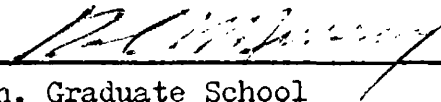
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CHAPTER ONE

INTRODUCTION

Statement of the Problem

When considering the inclusion of music rehearsal facilities in the public school plant, the primary problem is one of isolating these areas from outside noise, and acoustically designing every room to eliminate its own noise, that of unwanted reverberation. Music students are taught not only to hear but to consciously listen to musical sounds, sounds which are organized and controlled; extraneous sounds interfering with them, therefore, will inhibit or even prevent the music student from hearing the elements of music essential for his creation of this art.

Secondarily, because of the music department's high decibel out-puts, the problem is one of excluding its sound from the rest of the school building. Thirdly, whereas rooms devoted to repair, office space, instrument cleaning, and storage are designed so that their unique functions in the music complex operate as efficiently as possible, they should also be built to function as buffer zones in achieving sound isolation. Finally, acoustic deficiencies inherent in traditional gymnasium design generally cause these rooms, frequently the only concert hall available to many musical organizations, to be very unsatisfactory for musical performance. An investigation of desirable gymnasium-auditorium sizes, and ways in which optimum reverberation and

useful reflection patterns can be achieved, is essential to the design of these spaces if acoustical problems are to be alleviated.

Purpose of the Study

The purpose of this study is to provide the school administrator and music educator with the basic acoustical and sound transmission data required for them to assist in the planning of a music rehearsal facility and a gymnasium-auditorium which will accommodate the foreseeable musical objectives of the school. The study presents information pertinent chiefly to the design and construction of new facilities, but is also useful for the modification of existing rooms considered potentially suitable for use by the music department. This information will enable the school personnel involved in the planning to be sufficiently knowledgeable about designing for music that they can intelligently assist the school architect, acoustical engineer, and contractor in achieving the most desirable acoustical and sound isolation results.

Need for the Study

Whereas an increasing number of schools are being equipped with teaching areas designed exclusively for music departments, a large percentage of these designs continue to be evaluated by music educators as less than satisfactory. One recurring reason is that the one who has the most at stake, the one who must live with the results, the music instructor, is frequently the one who has the least to say about what is or is not acoustically desirable. Clarence J. Best's survey indicated that of the 250 music schools involved in his survey, only six percent of the buildings were designed in consultation with the

music department.[1] It is possible, of course, that music directors are

not generally sufficiently competent in their knowledge of acoustics

to convince the architect that they can be of assistance. As Vern Knud-

sen has emphasized however, "the rating of music rooms is a problem . . .

whose complete solution will require [the co-operation of] physicists and

musicians . . . ."[2] Because of a deficiency in the literature available

to music educators and administrators on problems related to acoustics

and sound isolation, this study has been undertaken to provide these

individuals with essential acoustical information relating to the school

music department.

Publications dealing with the use of the gymnasium for musical

performance appear to be virtually non-existent despite the fact that a

great number of school music organizations rely on just such facilities

for major performances. Therefore, suggestions have been offered which

indicate ways in which the gymnasium may be modified to create an

environment suitable to both athletic and music departments.

The Method of Research

The procedure followed for the study was to synthesize available

research conducted by architectural firms, music educators, school

planners, and acoustical engineers with respect to building for school

music. The research was correlated with acoustical experiments conduc-

ted by the author in instances where conclusions could not be determined

from the research alone. Basic to all recommendations in the study is

the consensus of subjective opinion expressed by musicians and other

musically perceptive individuals.

Delimitations

Since this study is directed to school personnel not assumed to be authorities in the field of acoustics, the terminology, language, and complexity of the work will be restricted to what will be easily and usefully understood by them. Secondly, because considerations of equipment, heating, lighting, ventilation, furniture, and the planning for art and drama in conjunction with music are adequately covered in publications listed at the beginning of Chapter Two, this work will be restricted to problems of acoustics and sound isolation. Furthermore, because auditoriums designed specifically for concert use have been studied and discussed very comprehensively by many researchers, the scope of sound problems discussed herein will be further restricted to those of the large rehearsal room the practise room, the studio, and the school gymnasium-auditorium.

Limitations

Owing to the apparent paucity of information available on the acoustics of the gymnasium-auditorium, the discussion of this facility was related to principles for the design of concert auditoriums. This limitation necessitated forming some conclusions about gymnasium-auditoriums which were inferences from recommended optimums for the concert hall, and not suggestions pertaining directly to the gymnasium.

Secondly, in some cases, to reach valid conclusions concerning the acoustical design of school music departments would require a larger sample of music rooms and their rating by musicians, than was available from the literature.

FOOTNOTES

Chapter 1

1. Clarence J. Best, "Building Facilities for Music Education," <u>School Executive</u> 65 (March 1946):59.

2. Vern O. Knudsen, "Acoustics of Music Rooms," <u>Journal of the Acoustical Society of America</u> 2 (1931):434.

CHAPTER TWO

RELATED LITERATURE

A limited number of books have been published which have dealt specifically with architectural and acoustical problems unique to facilities for music education, the best known being the five editions of Music Buildings, Rooms and Equipment, published by the Music Educators National Conference (MENC) in Washington D.C. This particular publication contains a discussion of architecture related not only to acoustical phenomena, but also to heating, lighting, equipment, storage facilities, and the integration of music facilities with those of the other fine arts. A similar publication produced by the American School Band Directors' Association (ASBDA) entitled Instrumental Music Room Designs, Construction and Equipment, is considerably less detailed in its treatment of acoustics and sound isolation, but contains a series of 44 floor plans with related information, of music facilities in several schools across the United States. This series is a highly useful source of ideas which may be collated for use in the basic floor design of a proposed facility.

In many instances, acoustical recommendations have been given only in very general terms such as, "air conditioning ducts must be treated acoustically to retard sound transmission,"[1] or "a good balance can be achieved, but its achievement will definitely dictate certain architectural details in the design of the auditorium."[2] It was felt

that, in most cases, a more detailed treatment of musical acoustics was required to satisfactorily benefit the acoustician, the architect, and the school personnel anticipating involvement in the planning of school music facilities.

Studies exist which, while not treating the music facility specifically, nevertheless do contain useful related information. These works are the books of eminent acoustical scientists, Leo Beranek, Willi Furrer, C. M. Harris, Vern Knudsen, and others, and contain comprehensive discussions of all factors related to architectural acoustics. In addition, periodicals such as American School and University, American School Board Journal, Journal of the Acoustical Society of America, and Kansas Music Review, to name the most useful sources, contain material more specifically pertinent to the school music facility. Basically, the information is a detailed treatment of a limited number of acoustical characteristics of music rooms, usually investigated in terms of the rating of these rooms by musicians. What would appear to be a valuable source for a thorough analysis of acoustics and noise control is the two-volume study, Acoustic Design and Noise Control, by Leo Rettinger. This material was unavailable for inspection and thus no comment can be given. Because the study is current and apparently comprehensive however, it is recommended as worthy of investigation. It was determined that a synthesis of these types of studies in the ASBDA and MENC publications referred to earlier, was incomplete in the analysis of room size, room shaping, optimum reverberation at all frequencies for each room, desirable transmission loss between each type of room, and the nature and placement of absorptive materials.

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The review of the literature would appear to substantiate the assertion by Carl Rosenberg of Bolt Beranek and Newman Inc. that there are evidently no works, published or unpublished, which indicate that there has been any concentrated research into the problem of modifying the gymnasium for concert use.[3] The consensus of opinion appears to be that gymnasium acoustics which are detrimental to musical performance cannot be remedied adequately, and therefore that the athletic facility should never be considered for use as a concert hall,[4] although as noted, this opinion has never been verified by previously published research.

FOOTNOTES

Chapter 2

1. Homer Ulrich et al., <u>Music Buildings, Rooms and Equipment</u>, 5th ed.,
    edited by Charles L. Gary (Washington, D.C.: Music Educators
    National Conference, 1966), p. 71.

2. Ibid., p. 79.

3. See Chapter 5, footnote 2.

4. See Elwyn Carter et al., <u>Music Buildings, Rooms and Equipment</u>, and
    Blundell and Perkins, <u>The School Auditorium—Its Purpose and Design</u>
    for two examples of this opinion. There was no indication of any
    opinion to the contrary in any of the works consulted.

CHAPTER THREE

SOUND ISOLATION

Isolating the Music Department From the School

Whenever sound is generated by a school activity, the potential
for its interfering with education, particularly that of academic
departments, exists throughout the school. Industrial arts, drama,
physical education and possibly home economics departments are such
potential sources of sound irritation and must use carefully designed
rooms. However, as will be subsequently discussed, there is no school
learning activity which has a greater capacity for interfering with a
school's educational processes than that of a music department. The
first decision in planning for school music facilities must consequently
be one which guarantees that the school's classrooms will be protected
from the irritation of unwanted musical sound.

The best guarantee is to plan for a music building completely
separate from the basic school plant, in which case no additional
special precautions regarding sound transmission need be considered.
Inconveniences can result from such an arrangement, however, and the
severity of the inconveniences will ultimately dictate whether or not
such a location is the best possible alternative.

A separate building can, for instance, create large travelling
distances between rehearsal and concert halls, making movement of heavy
or bulky equipment dangerous to the equipment and inconvenient to the

students. Frequently several ensembles will be programmed for the same concert, necessitating efficient movement of groups between the two areas, and large travelling distances create supervision and communication problems when groups are located in two remote areas. Furthermore, if the weather is particularly hot, cold, rainy, or windy, whatever effort expended on warming up and tuning in the rehearsal room will be entirely nullified by the temperature change that wind instruments in particular, will undergo as students move between buildings. Inclement weather will also cause delays in student movement to and from music classes if students are required to walk considerable distances to obtain outdoor clothing.

Clarence J. Best's survey of 258 schools revealed that excessive cost resulting from winter heating, extra janitorial and maintenance work, and higher construction expenses was the principal objection to a separate building.[1] His data revealed a general opinion that only when sound isolation could not be satisfactorily achieved by adapting the music department to established buildings should the separate building be considered. The consensus among the 23.7% of schools reporting using such a facility, however, indicated that when such construction was essential, the benefits appeared to outweigh the disadvantages.

A more popular plan, as can be deduced from the same survey, is to locate the facility in a remote section of the main school building. The site should be as near the concert stage as possible for the already mentioned convenience of movement of students and bulky or heavy equipment, and it is advisable that the location allow for easy ground-level access to a parking lot or driveway for the same reasons. Once these

logistical details have been accounted for, solutions to the more complex problem of containing the department's sound within its walls can be investigated. Although these solutions will ultimately become the responsibility of the architect and acoustical engineer, school personnel, including music teachers, who have some basic knowledge of the principles of sound transmission may be able to offer suggestions which would prevent inadequate acoustical designs.

Music as a Source of Noise

A distinction between intelligible and unintelligible background noise as it affects a school's classrooms must be understood in any discussion of isolating sound. Unintelligible sound is what Watt refers to as sounds of indistinguishable pitch and rapid irregular pulsations,[2] that which would be produced, for instance, by ventilation systems, domestic street sounds, the mumble of conversation, or gymnasium and shop activities.

Willi Furrer's research into tolerable sound levels of background noise for school rooms indicated that noise produced by ventilation systems, for instance, not be permitted to exceed 35 decibels.[3] The decibel (abbreviated db) is the unit by which the intensity or amplitude of sound is measured, the decibel scale ranging, for most purposes of environmental sound measurement, from approximately zero which represents the threshold of audibility, to 120 which represents the level at which sound begins to inflict pain on the human hearing apparatus. The above figures are only approximate and vary with differences in frequency. In the MENC publication, Music Buildings, Rooms and Equipment, the 35 to 50 db range is quoted as an acceptable

level of domestic background noise for areas of concentrated study.

Hearing becomes increasingly intelligible as mechanical or man-made sound replaces natural sounds such as those produced by wind, flowing water or fire, or the domestic sounds described earlier.[5] It becomes progressively more intelligible as rhythm becomes distinguishable and most significantly as rhythm is organized into recognisable music. Paul Fraisse[6] has determined that a pronounced pulse in ongoing stimuli, including music, sets off in the hearer a periodicity to which he spontaneously attends, because this pulsation elicits a motor activity in the hearer which synchronizes with the stimulus. If this pulse is imbedded in perceptible or barely perceptible musical stimuli, a listener who has developed a discriminatory awareness of pulse might "strain to listen." Where this motor response interferes with mental concentration in academic study, therefore, considerable annoying distraction can result.

Whereas moderate amounts of unintelligible background noise may be tolerated in school rooms, owing to their lack of meaning (organization), musical sounds may elicit responses and divert attention, consciously or unconsciously, thus causing distration. All such intelligible sound should therefore be isolated from all areas where it may, by attracting a student's attention, disturb his concentration.

Before the architect can determine in what way the music department's sound shall be eliminated, however, he must know what intensities can be expected to be generated in music rooms by the large performing organizations. A distinction is made here between sound intensity (or sound level), a physical phenomenon measured by a sound level meter,

and loudness, a purely psychoacoustic phenomenon. This chapter's discussion of sound insulative structures will be restricted to their relation to measureable sound levels only, inasmuch as the psychological implications of loudness are factors which have no bearing on sound transmission loss through structural materials.

Rehearsal Room Sound Level

In order to establish an estimate of the amplitude which characterizes the sound of large musical organizations playing at the greatest possible dynamic level, measurements of the maximum sound levels generated by four performing organizations at the University of Montana were taken by the author on a General Radio Company Sound Level Meter, Type 1565A. The results appear in Table 3.1 and were obtained in rooms whose reverberation optimums had been established prior to the taking of the measurements.[7]

University Collegiate Chorale (55 members)	97
University Concert Band (69 members)	104
Missoula Civic Orchestra (70 members)	90
University Jazz Workshop (20 members)	106

Table 3.1.—Maximum sound levels in decibels, produced by University of Montana musical organizations

Two physical characteristics of room acoustics, reverberation and resonance, will actually amplify the sound produced in a room. These phenomena will be discussed in the next chapter, but for purposes of this chapter's observations and recommendations, the first step in

reducing the sound transmitted to areas outside the music department is to control it at the source. This is accomplished with the use of sound absorbing and sound diffusing materials to achieve optimum reverberation and minimal resonance.

L. Richards and B. Krahl revealed that sound levels of 110 db are frequently reached in the band rehearsal room,[8] presumably under more reverberant conditions. Furrer's measurements indicated a full orchestra's maximum decibel capacity will similarly approximate 110 db.[9] A comparison of these figures with those in Table 3.1 may readily illustrate the degree to which sound can be reduced at the source through proper reverberation control.

Additional measurements were taken by the author to compare the projective powers of high, medium and low pitched instrumental groupings through the wall facing the performers. One decibel meter was used in the rehearsal room to help maintain a sound level of 95 decibels and another to record the resultant volume level on the other side of the wall. The results are tabulated in Table 3.2. These results conform to

	Low	Medium	High
University Concert Band	72	70	66

Table 3.2.—Sound level in decibels of three frequencies originating at 95 db, after projection through band room wall

R.N. Lane and E.E. Mikeska's experiments,[10] each of which graphically confirms that high frequencies are more easily contained by wall, ceiling and floor construction than are low frequencies. Furrer states that absorption of sound through any medium decreases by six db per

octave as the frequency decreases.[11] When considering construction

materials which will guarantee high transmission loss, therefore, low

frequency sound isolation becomes the most critical factor. The term

'transmission loss' (abbreviated TL), refers to the degree to which

sound intensity has been reduced as a result of absorption as it passes

through a medium. In none of the research consulted was any correlation

made between the type of low frequency sound source and the degree of

through-the-wall projection. It can be assumed therefore that whether

the sound is generated by a bass drum, a bass voice, or a bass trombone,

the insulative requirements will be identical.

What has been determined to this point is that sound levels

approximating 100 db can be generated in music rehearsal rooms and that

this level must be reduced to inaudibility at all frequencies in neigh-

boring rooms. Inaudibility, for the purposes of the isolation under

discussion, can be considered to be a residual intensity of between five

and ten decibels.[12] The various components of the department's

peripheral structures should therefore ideally ensure a TL of between

90 and 95 db for adequate isolation from the central school plant.

One additional factor useful in the control of background noise,

that of masking, should be analyzed at this point. Whenever background

noise resulting from ventilation for instance, has the effect of reduc-

ing the acuity of hearing and hence elevating the threshold of audibil-

ity, the shift in the threshold level is called masking, quantitatively

measured in decibels. If the acceptable level of normal amounts of

background noise for classrooms is 43 db,[12] Figure 3.1 shows that this

amount of sound will mask 10 to 28 db of musical sound for all but the

lowest frequencies produced by instruments. As significant as this may

seem for insulative pruposes, it has been noted that low frequencies

have the greatest projective powers. Moreover, low pitched instruments

such as the electric bass, bass drum and tympani are those which are

characteristically assigned steadily pulsating rhythmic parts, and hence

are those with the greatest potential for disturbance to areas outside

the music department. Instruments such as these are capable of fre-

quencies as low as 40 cps and can virtually nullify the beneficial

effects of masking. The elimination of 90 to 95 db of musical sound

remains therefore a problem in structural design.
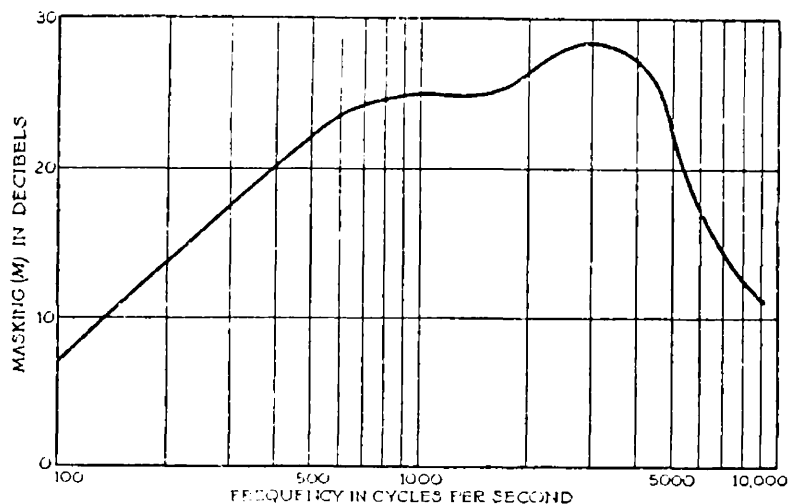
Fig. 3.1.[14]— Masking spectrum due to "average room
noise" having a sound level of 43 db

It is not within the scope of this study to suggest types of

construction material to be used to achieve the desired transmission

loss of sound through walls, floors, ceilings, windows, doors, or

plumbing and heating channels, since the selection of the most economi-

cal and up-to-date products available is best accomplished by the archi-

tect. School personnel need simply to state desired results. Where

this information is desired, the works of V.O. Knudsen and W. Furrer, and the illustrations of Lane and Mikeska give comprehensive comparisons of various types of building construction and their corresponding TL values. Some basic guidelines are presented here nevertheless which illustrate essential procedures in achieving sound isolation and suggest possible economic solutions to a normally expensive problem.

Wall, Floor and Ceiling Design

The TL of a single wall increases as its weight increases, but for economic reasons homogeneous wall design reaches optimum efficiency when an eight inch wall yields a TL of approximately 50 db.[15] TL values greater than this should be achieved through double wall construction with an intervening air space of at least 10 cm. MENC illustrations indicate that the most insulative double wall would reduce sound levels by 61 decibels.[16] Knudsen and Harris noted that the best double wall design found in motion picture studio construction also reduced all frequencies by at least 60 decibels.[17] A wall structure at the University of Texas music department, in measurement revealed a very high average TL of 78 db, a value however, which dropped to 54 db when measured against very low frequencies.[18] It may be reasonable to assume therefore, that double walls can be economically designed to reduce sound by an average of 60 db, but that any insulative efficiency greater than this is likely too costly or bulky.

Doors and windows in walls are paths of least resistance to sound transmission and can greatly reduce the TL value of a wall; the best products offer a 40 db TL in doors and a 39 db TL in triple-pane windows.[19] Windows are unessential components of the desired highly-

insulative walls and should be eliminated. Doors are essential fixtures however, and elicit two additional precautions: the doors should open into hallways instead of adjoining rooms, and should be built in pairs with an intervening air space. The characteristics of such 'sound locks' will be discussed subsequently under "Spatial Isolation."

Floor and ceiling designs are conceived as a single unit, and become a significant factor in sound isolation principally when rooms are to be built either above or below music rooms. Just as double wall construction effects transmission loss most efficiently, so a type of double ceiling and double floor structure proves to be the most efficient and economical method of containing sound in these mediums.

The best double (suspended) ceiling described by Lane and Mikeska as representing good acoustic isolation, eliminated combined airborne and impact sound by 48 db at the lowest frequencies.[20] This rating must be understood to apply to a combined floor—ceiling unit. Where floors themselves are concerned, the most significant concern related to sound transmission is that of impact noise, that is, the sound received by the floor through direct contact with the sound source. The isolation provided by a floor system against the mechanical impact gen-
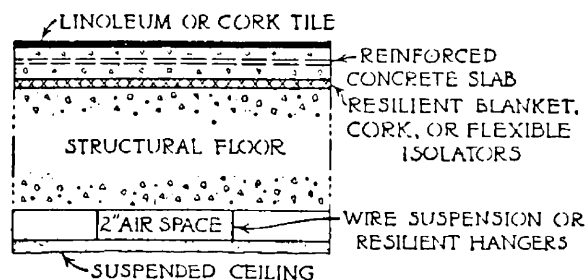
Fig. 3.2.[21]—Section of floor and ceiling showing
floating floor and flexibly suspended ceiling

erated by such instruments as pianos, celli, string basses and percussion instruments can be greatly improved by the use of a floating floor which rests on the structured floor but is separated from it by a resilient support. Floating floors which will reduce impact noise by 20 db are rated by Knudsen and Harris as very good insulators.[22] Figure 3.2 illustrates one method of combining a floating floor and suspended ceiling with the basic structural floor to achieve maximum vertical transmission loss.

According to the investigations of Lane and Mikeska, where this construction achieves a low frequency TL of 48 db, good isolation will be achieved. Since their measurements were based on sound generated in studios and practise rooms, however, it is uncertain whether the increased sound intensity of a large ensemble could be satisfactorily isolated with this TL value. The least expensive and most certain method of alleviating vertical transmission problems is to avoid locating any school rooms either above or below music rooms. Unless school rooms are to be so located the complexity of the above descriptions will represent unnecessarily careful design, but if this type of room arrangement is essential the units above or below the music suite will need to be of the variety whose activity will be able to tolerate moderate amounts of musical sound.

Sound is also conducted horizontally through floors and ceilings, though a general absence of any discussion of this phenomenon in most of the available research indicates that the amount of disturbance to adjacent rooms contributed by this type of transmission may be negligible. If the music department is located in an area where sound

transmission may be a very critical problem, the floors and ceilings of adjacent rooms can be separated by extending sound proof walls between them. This process, illustrated in Figure 3.3, will render these mediums discontinuous and thus result in the same degree of isolation achieved between the rooms' air spaces.
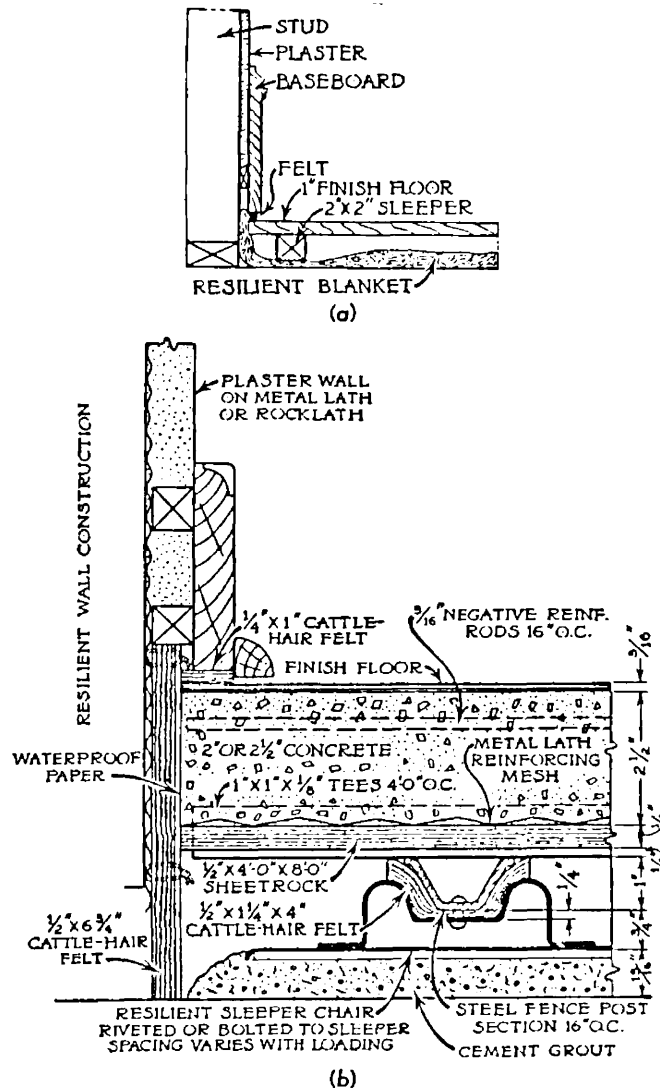
Fig. 3.3[23]—Detail of junction between floating floor and wall for a) wood floor and b) concrete floor

The remaining discussion of sound isolation will centre on horizontal sound transmission. Clearly, careful wall and other

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connective construction is in itself insufficient to prevent disturbance to rooms adjacent to the music complex. It was noted earlier that approximately 100 db can be expected as a sound level in music rehearsal rooms, assuming good reverberation and resonance characteristics in the rooms. It was also suggested that this sound level be reduced to between 5 and 10 db by the time it reaches neighboring school rooms. Since even the best wall construction is not likely to reduce all frequencies by more than 60 db, additional spatial isolation is required to absorb the remaining 30 to 35 decibels.

Spatial Isolation

The desired space can be created in a number of ways, two of which are illustrated in Figures 3.4 and 3.5. In Figure 3.4, rooms which are not used for musical activity can be utilized to provide the required additional spacing. Suppose that Wall A in the figure has an overall TL value of 40 db (door and window influences considered). Sound originating in the rehearsal room at 100 db would set up a steady state sound level[24] of 60 db or less in one of the buffer rooms, assuming additional absorption in the room did not reduce it further. In order for this sound level to be reduced to between 5 and 10 db outside Wall B, this wall's TL value would need to approximate 50 to 55 decibels. The same principle is applicable to a lesser degree when pairs of doors are separated by an intervening air space, provided the seal around the edges is tight. Other equally workable spaces may include the instrument storage area, a washroom or the janitor room. In all cases self closers should be provided for the doors because an open door will render the buffer room useless as a sound lock. If the exposed surfaces of the

small rooms are highly absorptive, additional sound isolation will be
obtained, thus possibly permitting the construction of less sound iso-
lative walls while maintaining the desired overall level of isolation.
Practise rooms and studios should not be used for the purposes described
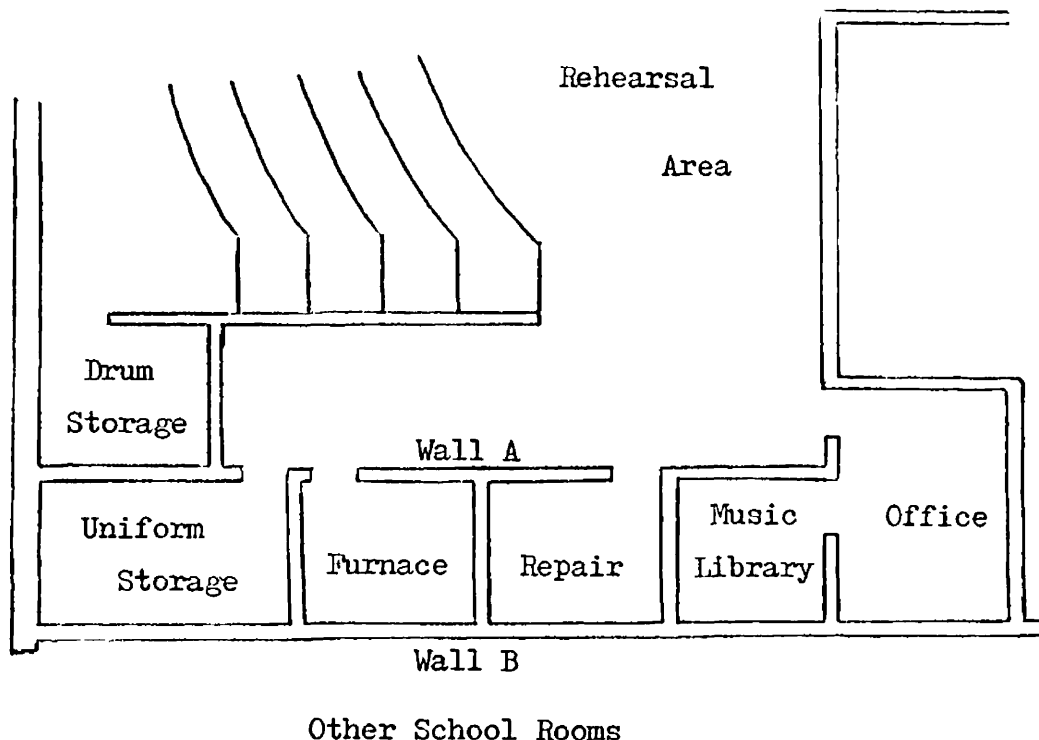
Fig. 3.4.—An example of the use of buffer rooms for spatial
isolation of music rehearsal rooms from other school areas.

above since sound levels will occasionally be generated in these spaces
which will approximate those of large organizations in rehearsal
halls.[25]

The use of corridors in combination with storage areas, practise
rooms and teaching studios (where the latter are not situated next to
classroom areas) is shown in Figure 3.5 as an effective means of putting
distance between major rehearsal rooms and adjacent classrooms. This
floor plan also illustrates tha practicality of locating music next to
activity oriented class areas where, should any sound leakage occur
through such spaces as open doors, the tolerable level of background

noise is higher than that of academic classes involved in concentrated study.
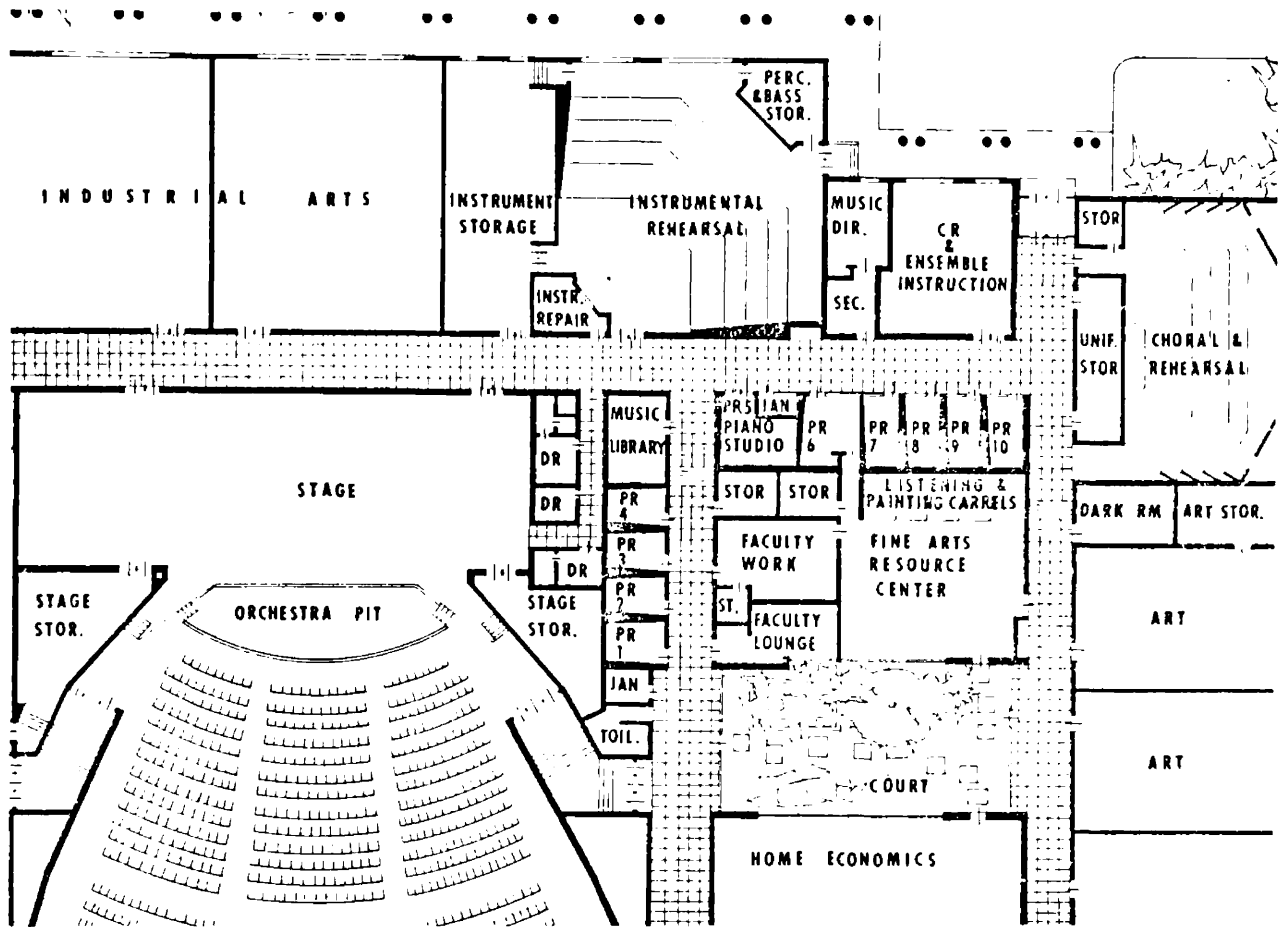
Fig. 3.5.[26]—Northport (New York) Senior High School. An example of the use of corridors and small rooms to isolate major rehearsal areas.

Highly insulative wall structures are costly to build if the music department is to be satisfactorily isolated. When the department can be spatially segregated from all class or library areas, however, increased transmission loss will result from air absorption. If, in addition, connecting corridors are lined with sound absorbents, the cumulative effect on transmission loss may permit a significant reduction in the insulative requirements of the music department's walls, and the corresponding reduction in construction costs could be substan-

tial. Such savings should never be entertained however, without first calculating for effective transmission loss to all school areas immediately adjacent to the music department.

Ventilation Channels

The best guarantee that sound will not be conducted from music rooms to other school rooms through ventilation channels is to provide the music department with an independent air conditioning or other ventilation system. In the likely event that the ventilation system will be shared with other school departments, ducts should be lined with acoustical absorbents; the attenuation of sound passing through unlined ducts is very little unless the ducts are very long.[27] Attenuation refers to the amount of transmission loss in decibels per foot along the length of a duct.

Additional factors affecting the efficiency of ducts, lined or unlined, include the frequency of the source sound and the cross-sectional size of the duct opening. The fact that losses are least when ventilation channel openings are large and frequencies low is graphically illustrated by Furrer.[28] An analysis of Sabine's graphs illustrating attenuation as a function of frequency reveals that the lowest frequencies produced by musical instruments (40 cps) would allow for an attenuation of scarcely one decibel per foot in a 9" by 12" lined duct.[29] If the duct contains several elbows, this transmission loss can be increased by about one to two decibels per elbow.[30] The length required, even in lined ductwork, to reduce 100 decibels of low frequency sound to inaudibility in adjoining rooms may therefore render the mutual use of a ventilation system impractical. If sufficient attenua-

tion between music and other departments is not achievable by lining

the ductwork, additional methods for increasing transmission loss can be

used, and are discussed in the second section of this chapter.

Summary

The first step in designing school music facilities is to plan

their location and design in such a way that no sound disturbance will

be created in adjacent spaces, particularly classrooms. This will have

the reciprocal effect of insulating the music department against unwan-

ted outside noise. No mention has been made of isolating sound which

enters music rooms but it is logical to assume that with the exception

of noise from low flying aircraft, very little domestic noise would be

capable of penetrating room structures designed to absorb the escaping

intensity of musical sound.

Reducing sound transmission to outside areas begins by control-

ling sound intensity at the source. Sound absorptive and diffusing

materials control reverberation and resonance, two phenomena of room

acoustics which will actually amplify the source sound. Once these

optimums have been established, walls, doors, buffer spaces, ventilating

shafts and any additional construction which connects the music depart-

ment with the main school building, should be designed with a combined

TL value which will reduce approximately 100 db of musical sound to a

level below the 5 to 10 db threshold of audibility, after it has passed

through these mediums. Rooms should not be located above or below music

rooms because of the insufficient TL achievable in ceiling and floor

combinations. Since TL is least for the lowest frequencies, it is

always necessary to take into account the lower pitch levels when

calculating sound projection.

Walls, doors, and floor-ceiling units should be constructed with a double thickness separated by at least a 10 cm air space. but windows should not be built into the perimeter walls of a music department. Ideally, the department should contain its own ventilation system but where this is not possible, all ductwork extending to other rooms in the school will need to be lined with acoustical absorbents. If this process yields insufficient attenuation, the ductwork will need to be treated in additional ways as described later for rooms within the music department.

Sound Isolation Within the Music Department

It has been noted that sound emanating from music rooms must be reduced to inaudibility before it reaches the nearest classrooms. However, the sound generated in one music room is acceptable to a certain degree as background noise in another music room for two reasons: (a) the learning processes which occur in music rooms are activity-oriented and are not characterized by prolonged, relatively silent, concentrated study as is learning in academic classrooms, and (b) the sound generated in one music room will, much of the time, cover up or mask a considerable amount of sound received from neighboring music rooms.

The spaces which house musical activity include practise rooms, ensemble rooms, studios, and band, choral, and orchestral rehearsal areas. This section of the chapter will discuss what is an acceptable background noise level in each of these units (practise rooms and ensemble rooms will be considered synonymous), and how this level is

achievable when music activity occurs simultaneously in several rooms. Because a definition of what is acceptable as background noise in a music room is largely a matter of subjective interpretation, measurable acoustical observations will be related to the opinions and preferences expressed by musicians in previous research.

In research conducted by Lane and Mikeska at the University of Texas and the University of Houston, the TL values of various walls were compared to subjective evaluation, by musicians, of the quietness of the rooms which were soundproofed. Because there was no mention of the level of sounds generated in the rooms by musical instruments or voices, there was no indication of what background sound levels were considered by musicians to be acceptable. Therefore the author measured sound levels in music rooms at two Montana institutions to determine the level of residual sound which musicians could be expected to evaluate as acceptable. These findings were then related to the study by Lane and Mikeska. The investigations relate to three types of music rooms: rehearsal rooms, practise rooms, and studios.

Sound Levels Generated in Music Rooms

In any musical performance, a range of sound levels will be measured. Earlier, in Table 3.1, measurements of maximum sound levels produced by large ensembles in rooms treated for optimum reverberation were shown in some cases to be in excess of 100 db. It was important at that time to determine maximums in order to calculate for the elimination of all musical sound in spaces outside the music department. It is reasonable to assume however, that within the department, where a certain amount of sound penetration through walls is permissable, only

the predominating dynamic level requires satisfactory isolation. The occasional uncomfortable audibility next door of the relatively rare maximum outputs illustrated in Table 3.1 is not likely to be disturbing, particularly when these sounds will frequently be masked in the receiving room. Table 3.3 illustrates the range of rehearsal room sound levels that can be expected from various performing groups in acoustically treated units, as measured on a General Radio Company Sound Level Meter Type 1565A. Also indicated is the predominant sound level characteristic of music being performed at the 'forte' level by each organization. The greatest intensities recorded were those characteristic of the two bands (95 db) and it is this figure which will be used in subsequent calculations as characteristic of rehearsal rooms.

	Range	Predominant 'Forte' Intensity
Missoula Civic Symphony	70 - 90	85
University Concert Band	70 - 100	95
University Collegiate Chorale	70 - 95	85
University Jazz Workshop	80 - 104	95

Table 3.3.—Sound levels produced by four performing groups at the University of Montana in rehearsal rooms treated for optimum reverberation

Because the practise rooms at the University of Montana were frequently judged by musicians as over-reverberant or too live, measurements of individual instruments and voices were also recorded in the more modern practise rooms of a Montana high school in order to obtain a more reliable estimate of average practise room sound levels. Table

3.4 records the decibel range which characterized high, medium and low

frequencies in each instrument family, and the predominant intensity for

	University of Montana		Sentinel High School (Missoula)	
	Range	Predominant db Level	Range	Predominant db Level
Violin	65 - 87	80	65 - 85	77
Cello	70 - 90	85	70 - 85	75
String Bass	75 - 90	80	60 - 80	75
Flute	70 - 95	85	70 - 95	85
Clarinet	70 - 95	85	70 - 95	85
Alto Sax	80 - 95	90	80 - 95	85
Bassoon	80 - 90	85	70 - 85	78
Baritone Sax	85 - 95	90	80 - 90	85
Trumpet	80 - 100	90	75 - 100	90
French Horn	70 - 100	85	80 - 100	90
Trombone	80 - 100	90	80 - 95	90
Tuba	80 - 95	85	80 - 90	80
Female Voice	70 - 100	90	80 - 100	90
Male Voice	75 - 95	85	80 - 95	85
Piano	70 - 90	85	75 - 85	80
Snare Drum	70 - 100	90	70 - 100	90

Table 3.4.—Sound levels in practise rooms at two
Montana institutions. Average practise room size was
approximately 8' x 9' x 8' high.

each instrument. In practise rooms and studios the magnitude of sound

level fluctuation from the mode was not as great as experienced with large groups in the rehearsal rooms. It was therefore considered more appropriate to identify the predominant sound intensity rather than the predominating maximum in the small rooms. As with rehearsal rooms, the greatest average intensity (brasses and saxophones—90 db) will be the figure which in later calculations will represent practise room sound level.

Studios, like practise rooms, are used primarily for individual playing or singing. They are, however, considerably larger than practise rooms and usually contain a number of sound absorbing materials such as small libraries, chairs, a desk, curtains, and occasional carpeting. The combined effect of increasing room size and adding sound

	Range	Predominant db Level
Violin	70 - 85	80
Cello	70 - 85	80
Flute	70 - 90	80
Clarinet	70 - 90	80
Alto Sax	75 - 90	85
Bassoon	75 - 85	80
Trumpet	80 - 95	85
Trombone	80 - 90	87
Piano	70 - 85	80
Female Voice	70 - 90	80

Table 3.5—Sound levels in studios at the
University of Montana. Average room size
measured 12' x 10' x 8' high.

absorbing surfaces, as will be shown in the next chapter, is to reduce the sound level of a room, given identical sound sources. A comparison of Figures 3.4 and 3.5 illustrates this principle by revealing a difference of an average of 5 decibels between practise room and studio sound intensity at the University of Montana. These studios were considered by all musicians interviewed, to be very satisfactory in terms of liveness and loudness. Their sound level statistics may therefore be assumed reliable. The 85 db figure will be the one used as representative of studio sound level.

Desirable Transmission Loss in Walls
Separating Music Rooms

Walls separating practise rooms

A measurement of what constitutes desirable transmission loss has been noted to be essentially an observation based on subjective analysis by musicians. Reference is again made at this point then, to Lane and Mikeska's comparisons of objective and subjective observations of music rooms at two Texas universities.

Musicians observed practise rooms to have excellent isolation whose walls were measured to have an average TL of 61 db. Satisfactory isolation was observed when the average TL was reduced to 55 db, and a rating of anywhere from adequate to wholly inadequate isolation was given to rooms whose walls averaged a TL of 39 db. The concluding recommendation proposed that "a minimum acoustic isolation of 55 db should be maintained between all . . . practise rooms."[32]

If sound levels in practise rooms can be expected to reach a maximum mode of 90 db (as illustrated earlier), walls with an average

TL of 61 db would permit background sound levels of up to approximately 30 db in adjoining rooms; the minimum TL of 55 db recommended by Lane and Mikeska would allow noise levels of about 35 db in these spaces. Musicians could therefore be expected to rate as well isolated, practise rooms in which background noise did not exceed 30 db and as satisfactory rooms whose background levels did not exceed 35 db. It must be noted that the above TL values represent an average for all frequencies, and that the 90 db source room level will on occasion be exceeded by as much as 10 db. It can therefore be expected that on occasion, low frequency sound and very loud brass passages will produce background levels in adjacent rooms which will exceed the 30 db and 35 db levels established as excellent and satisfactory respectively. The Lane and Mikeska observations would indicate however, that these occasional excessive intrusions are not disturbing when the prevailing background noise levels are as calculated above.

Walls separating studios

In the same study the measured TL values of walls separating studios were compared with the musicians' evaluations of the quietness of these rooms. The average measured TL of 78 db in the walls of the University of Texas studios afforded virtually complete isolation between adjoining rooms, the faculty reporting being able to teach or work at their desks without being able to hear even faintly the music instruction in the adjacent studio. The lower average TL of 59 db which characterized studio walls at the University of Houston also yielded what was rated as excellent insulation between studios. The design goal recommended in the study was that studio partitions average 60 db as a

minimum TL value.

From table 3.5 the 85 db figure was noted to be the most frequently occurring intensity in studios where the loudest instruments were being used. Background noise from a studio whose partitions average a TL of 78 db could then be expected to be about 7 db, or virtually inaudible. The recommended 60 db minimum would mean a noise level of about 25 db would be created in the next room. It is apparent therefore that musicians consider studio background noise inaudible at the 7 db level and satisfactorily isolated when not exceeding 25 db.

Again it is important to note that the above TL values are only an average for all frequencies. At 150 cps the wall averaging a TL of 78 db, for instance, absorbed only 54 db, meaning that sound originating at 85 db at this frequency would create a background disturbance of almost 30 db. It was shown in Table 3.5, furthermore, that studio intensities will on occasion reach 95 db and thus create higher noise intensities in other rooms.

From the foregoing discussion it is readily apparent that there is a noise level difference of at least 10 db between what is satisfactory in studios and what is acceptable in practise rooms. It can be presumed that the reason for this is that a teaching studio is used for both performance and instruction and as a result, must be considered a classroom at least part of the time. Within a practise room however, the musician is almost always producing his own musical sound and thus almost always masks intruding sounds. The effects of masking in practise rooms can be very significant under some conditions but virtually nullified under others.

Experiments indicate that low pitched tones produce a significant masking effect upon high pitched tones but that the reverse is not true unless the two pitches are similar in frequency.[33] This would suggest, for instance, that the masking achieved by a flute on a neighboring tuba would be negligible, assuming roughly equal sound levels. The effectiveness of the tuba's sound in masking that of the flute, however, is such that between 20 db and 70 db of masking can be expected.[34] These generalizations apply principally to frequencies between 50 and 2000 cps, the predominant frequency range of most musical performance. The benefits of masking will be put to most efficient use, therefore, through a judicious allocation of practise rooms and studios, such that instruments of similar pitch and sound volume are located next to each other.

Walls separating rehearsal spaces

Band, choral and orchestral rehearsal rooms function similarly to studios in that both performance and instruction takes place within them; it may be assumed therefore, that tolerable background noise for these two areas will similarly correspond. This assumption is reinforced by research conducted by Robin M. Towne and Associates of Seattle Washington. Acousticians with this firm have determined that the minimum TL values of structures separating large rehearsal rooms should lie in the 75 to 80 db range.[35] This range would reduce a potential average maximum of 100 db in the sending area (see Table 3.1) to between 20 and 25 db in the receiving room, a level which corresponds to the satisfactory level established for studios.

Table 3.6 is a summary of what has been observed and concluded

with respect to sound levels originating in music rooms, desirable transmission loss between three types of rooms and the resultant acceptable background noise level in each.

	Characteristic Sound Level	Background Noise Level	
		Excellent	Satisfactory
Practise Rooms	90 db	30 db	35 db
Studios	85 db	10 db	25 db
Rehearsal Rooms	95 db	10 db	25 db

Table 3.6.—Summary of average characteristic sound levels and desirable background noise level maximums in music rooms

Other Factors Affecting Transmission Loss

Room location

An analysis of Table 3.6 reveals that the location of rooms in the music suite becomes an important factor in achieving sufficient transmission loss between rooms. This might not be so if walls averaging a TL of 78 db were available as required, but the majority of authorities consulted for this study seldom recommended structures with a TL greater than 60 db as being economically feasible.[36] It becomes apparent then that if the 60 db TL rating cannot be economically exceeded, satisfactory transmission loss can be achieved only when practise rooms are located next to practise rooms and studios next to studios. All other juxtapositions may require additional intervening buffer spaces to augment the sound insulative qualities of the music department. A buffer space must be a room used for relatively silent activity other than study. Such a room may be the music library, the instrument or uniform storage room, a furnace room, the music office,

the repair facility, a washroom, or a corridor.

A second alternative is to schedule for room usage in such a manner that some music rooms are left temporarily vacant and thus serve as buffer spaces. A vacant practise room or studio next to a large rehearsal room could provide such necessary separation. If on the other hand, there is small liklihood of practise rooms or studios being used while large groups are in rehearsal, there will be no background noise concerns when these smaller units are located next to the larger ones. In order for two or more large rehearsal rooms to function efficiently however, they will need to be in more or less constant simultaneous use, and any separation of these areas will necessitate the inclusion of intervening sound locks.

Table 3.7 indicates the total transmission loss that should be effected between music rooms showing what would yield both excellent and satisfactory results. This table is essentailly an interpretation of data from Table 3.6.

TL Between → ↓	Practise Room		Studio		Rehearsal Room	
	Exc	Satisf	Exc	Satisf	Exc	Satisf
Practise Room	60	55	80	65	80	65
Studio	80	65	75	60	75	60
Rehearsal Room	80	65	75	60	90	75

Table 3.7.—TL (in db) required between music rooms
for both excellent and satisfactory sound isolation

Doors and windows

It was shown earlier that because the TL value of doors and

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windows can never be as great as those of a well constructed wall, these fixtures can substantially lower the overall TL of a sound proofed wall. The degree to which the TL is lowered is dependent on the TL value of the window or door and the percentage of the wall area occupied by them.

Ideally, sound producing rooms should not contain doors and windows in the wall partitions which separate them. The alternative, illustrated in Figure 3.2, is to face these fixtures into a corridor connecting all rooms. The corridors in turn need to be lined with sound absorbent material and separated from all adjoining rooms by doors equipped with self-closers. "No amount of treatment of corridors can be as effective as a closed door."[37]
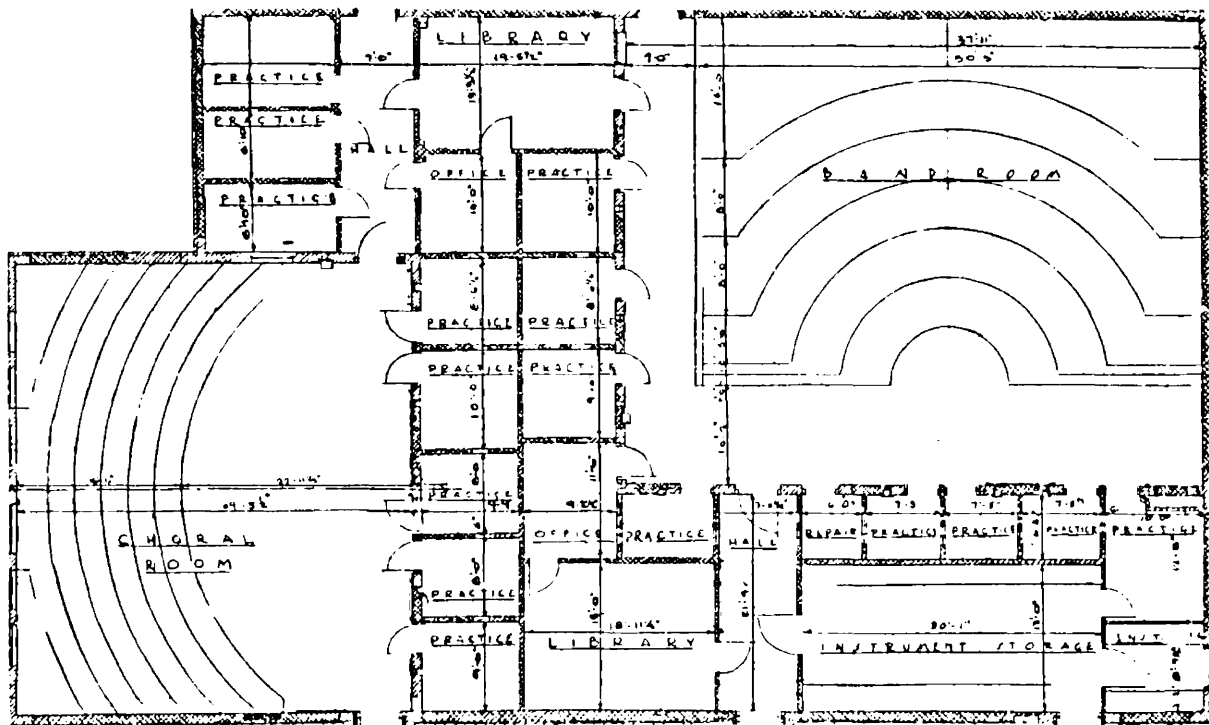
Fig. 3.6.—Parma Senior High School, Parma, Ohio.[38]
Occasionally it is necessary to open practise rooms
into rehearsal areas.

Figure 3.6 illustrates a situation where the most practical

design may actually be to open the practise rooms into a rehearsal room.

Where this is essential, placing windows within doors instead of locat-

ing them separately in the wall will reduce the amount of wall surface

so displaced and conserve more of the wall's TL capacity.

A well designed sound proof door may have a TL as high as 40 db

at high frequencies but will insulate as little as 27 db of low fre-

quency sound.[39] Using a double door entrance with a minimum of one foot

intervening air space will increase the minimum TL to about 60 db.[40]

The efficiency of a sound proof door is additionally affected to a sig-

nificant degree by its air-tightness, the seal around the edges affect-

ing sound transmission by as much as 15 to 20 per cent.[41]

Windows usually form the weakest acoustic point in a wall and

should be kept to as small a size as possible. Structurally isolated

double panes with an intervening air space of about one half inch will

yield an average TL of 36 db when these panes are tilted from each other

no less than one inch in twelve and when the panes are of slightly

differing thicknesses. This design will, by diffusing the sound, have

the effect of minimizing resonance both in the panes and in the dividing

air space.[42] The use of thick, triple panes and large intervening air

spaces will improve attenuation by as much as ten additional decibels

but the space and bulk of the supportive structure required would render

this design impractical for music room use.

Ventilation systems

Sound transmission through ventilating ducts has a critical

effect on the isolative qualities of a music department's building

structures. The practicality of segregating the music department's heating and ventilation system from that of the remainder of the school has been discussed. But the close proximity of music rooms to each other makes sound transmission between rooms through these ducts an even greater problem than would have been experienced between the music complex and the more distant central school plant.

Generally speaking, the ductwork insulation between two rooms should be equivalent to at least the sound insulation of the partition wall. This is achievable in a number of ways, but whatever the design, it is essential to treat the inner surface of ducts with an efficient absorbent. The difference in attenuation between an efficiently lined duct and an unlined duct can be as much as 58 db per ten feet.[43] But ... because this efficiency can be greatly reduced where low frequency vibrations exist, additional precautions are necessary.

Where rooms such as music rooms, requiring maximum sound isolation, are involved, each room is ideally supplied with a separate run of duct from the furnace or air conditioning unit.[44] Where this is not
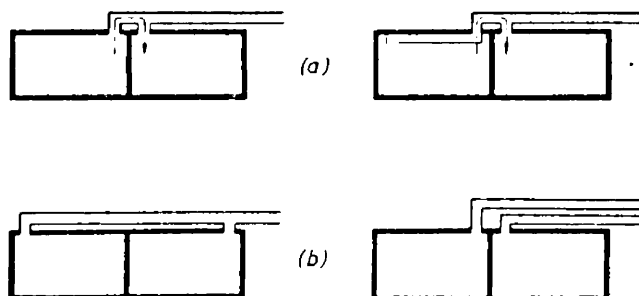
Fig. 3.7.[45]—Arrangement of ventilating ducts to minimize direct sound transmission between rooms.
(a) incorrect, (b) correct

practical or possible and two rooms must share a common duct, the long-
est possible distance should be placed between the ventilating apertures
of the two rooms. This may mean that a single run will connect rooms no
closer together than every other unit. Figure 3.7 illustrates desirable
and undesirable ventilation designs in ductwork connecting adjacent
rooms.

When the connecting duct between two rooms must be so short that
the absorbing material does not provide sufficient attenuation, the duct
may be split into several smaller ducts, or baffles may be installed in
a zigzag fashion to offer obstacles to sound waves.[46] These considera-
tions become even more critical in music rooms because both supply and
return air channels must be used due to the otherwise airtight properties
of these spaces. Doubling the number of connective ventilation ducts
doubles the risk of sound transmission between rooms.

Floors and ceilings

If the floor and ceiling of each music room is separated from
that of each neighboring room by extended sound proof walls, horizontal
sound transmission through these mediums can be satisfactorily elimina-
ted. The sound proofing of floors and ceilings themselves, however,
becomes important principally when music rooms are located next to each
other in a vertical arrangement. Where this becomes necessary, the
transmission loss between music rooms should correspond to the TL
requirements of the walls separating similar types of rooms, with
special attention being devoted to isolating impact sound. Additional
characteristics of effective floor-ceiling sound proofing have been
discussed in an earlier section of this chapter and will not be repeated

here. Where possible, however, the vertical juxtaposition of rooms should be avoided due to the difficulty of satisfactorily insulating floors and ceilings, particularly against impact transmission.

Summary

Because education in music rooms is characterized by sound-producing activity as contrasted with the silent, concentrated study which takes place in classrooms, the resultant masking permits higher levels of background musical sound in music rooms than is tolerable in the classroom. Tables 3.6 and 3.7 summarize what has been discussed as acceptable noise levels for different music rooms and how this determines the transmission loss which must characterize each room's structures.

Sound transmission must first be controlled at the source. Calculations for sound-absorptive materials in floors, ceilings and walls should guarantee optimum reverberation and minumum room resonance before desired TL characteristics of wall structures are determined. The relation of reverberation and resonance to ideal room sound levels will be treated in the next chapter.

Maximum efficiency and economy are achieved when sound proof walls, ceilings, doors and windows are structurally isolated double units with intervening air spaces. Because of the relatively low attenuation characteristic of even good floor-ceiling designs, any vertical arrangement of music rooms should be avoided. Where possible, doors and windows should face only into sound-absorbing corridors in order that the TL values of partitions separating rooms housing musical activity be maintained at the highest possible maximum. Doors and windows should seal perfectly enough to render all music rooms air-tight except for the

openings of ventilating apertures. Ductwork insulation between rooms should be equivalent in TL to that of the wall separating the units, a condition achievable only when ducts are lined with a sound-absorbing material. Ideally, each room should be supplied with a separate run of duct from the ventilating equipment but where this is not possible, the length of duct joining two rooms should be as long as possible. Short connecting shafts will require additional baffling and splitting within the channels.

FOOTNOTES

Chapter 3

1. Clarence J. Best, "Building Facilities for Music Education," School Executive 65 (March 1946):58.

2. Henry J. Watt, The Psychology of Sound, (Cambridge: Cambridge University Press, 1917), pp. 34-39.

3. Willi Furrer, Room and Building Acoustics and Noise Abatement, trans. Evelyn R. Robinson and Peter Lord (London: Butterworth and Co. Ltd., 1964), p. 48.

4. Homer Ulrich et al., Music Buildings, Rooms, Equipment, 5th ed., edited by Charles L. Gary (Washington, D.C.: Music Educators National Conference, 1966), p. 64.

5. Furrer, Acoustics and Noise Abatement, p. 40.

6. Paul Fraisse, Les Structures Rhythmiques: Etude Psychologique, Studia Psychologica, collection dirigée par A. Michotte et J. Nuttin, (Louvain, France: Publications Universitaires de Louvain, 1956), pp. 100-103.

7. Towne, Richards and Chaudiere and Associates, acoustical engineers of Seattle Washington, modified the band room to achieve an RT of 1 sec. at 125 cps, .6 secs at 500 cps, and .75 secs. at 4000 cps. This reverberation pattern conforms to what they have determined to be preferred by most instrumental directors and is discussed in Chapter Four. The choral room is slightly more reverberant, an acoustical characteristic usually preferred for vocal rehearsal.

8. R. Richards and R. B. Krahl, "Sound Control in Difficult Areas," American School Board Journal 147 (November 1963):34.

9. Furrer, Acoustics and Noise Abatement, p. 34.

10. R. N. Lane and E. E. Mikeska, "Problems of Field Measurement of Transmission Loss as Illustrated by Data on Lightweight Partitions Used in Music Buildings," The Journal of the Acoustical Society of America 33 (November 1961):1531-35. See graphs on pp. 1531-34.

11. Furrer, Acoustics and Noise Abatement, p. 163.

12. Ibid., pp. 21, 29. The statistics of Figure 17 (p. 21) and Table 13 (p. 29), when used together will, for our purposes, yield an audibility threshold of 5 to 10 db.

13. Elwyn Carter et al., Music Buildings, Rooms, Equipment, 4th ed., (Washington D.C.: Music Educators National Conference, 1955), p. 35.

14. After V. O. Knudsen and C. M. Harris, Acoustical Designing in Architecture, (New York: John Wiley and Sons, Inc., 1950), Fig. 2.7, p. 30.

15. Carter, Music Buildings, pp. 38, 39.

16. Ibid., p. 39.

17. Knudsen and Harris, Acoustical Designing, p. 234.

18. Lane and Mikeska, Problems of Field Measurement of Transmission Loss, p. 1531. See Fig. 2 and discussion.

19. Knudsen and Harris, Acoustical Designing, pp. 236, 442.

20. Lane and Mikeska, Problems of Field Measurement of Transmission Loss, pp. 1533, 34. See Fig. 8.

21. After Knudsen and Harris, Acoustical Designing, Fig. 12.4, p. 263.

22. Ibid., p. 257.

23. Ibid., Fig. 12.5, p. 264.

24. See discussion of 'steady state sound level' in Chapter Four.

25. See discussion of practise rooms under "Sound Levels Generated in Music Rooms" elsewhere in this chapter.

26. Ulrich, Music Buildings, p. 35.

27. Knudsen and Harris, Acoustical Designing, p. 282.

28. Furrer, Acoustics and Noise Abatement, Fig. 159, p. 173.

29. Hale J. Sabine, "The Absorption of Noise in Ventilating Ducts," Journal of the Acoustical Society of America 12 (July 1940):55.

30. Knudsen and Harris, Acoustical Designing, p. 282.

31. R. N. Lane and E. E. Mikeska, "Study of Acoustical Requirements for Teaching Studios and Practice Rooms in Music School Buildings," Journal of the Acoustical Society of America 27 (November 1955): 1087-91.

32. Ibid., p. 1091.

33. Knudsen and Harris, _Acoustical Designing_, p. 30.

34. R. L. Suri, _Acoustics Design and Practice_, (Bombay, India: Asia Publishing House, 1966), pp. 38-40. See graphs and discussion.

35. Richards and Krahl, _Sound Control in Difficult Areas_, p. 34.

36. See: V. O. Knudsen, _Architectural Acoustics_; V. O. Knudsen and C. M. Harris, _Acoustical Designing in Architecture_; R. L. Suri, _Acoustics Design and Practice_. Consult appendices containing sound absorption tables.

37. Ulrich, _Music Buildings_, p. 67.

38. After Carter, _Music Buildings_, p. 86.

39. Knudsen and Harris, _Acoustical Designing_, p. 442.

40. Furrer, _Acoustics and Noise Abatement_, p. 173. See Table 58.

41. Suri, _Acoustics Design and Practice_, p. 28.

42. Knudsen and Harris, _Acoustical Designing_, pp. 235, 36, 442.

43. Harold Burris-Meyer and Lewis S. Goodfriend, _Acoustics for the Architect_, (New York: Reinhold Publishing Corp. 1957), p. 30. See large table.

44. Ibid., p. 31.

45. After Furrer, _Acoustics and Noise Abatement_, p. 178.

46. Suri, _Acoustics Design and Practice_, p. 309, 10.

46

CHAPTER FOUR

ACOUSTICS OF ROOMS WITHIN THE MUSIC DEPARTMENT

Introduction

The function of the music department simply is to teach music;

therefore, once rooms within the department have been satisfactorily

isolated from each other, room acoustics must be the first design con-

sideration. "Air conditioning, decor, high lighting levels—in fact, all

other design elements are secondary."[1] In teaching situations involving

balance, intonation, articulation, and dynamic and tone colour control,

teachers and students may frequently find it difficult to determine

whether inaccuracies are due to inadequate performance or a poor acous-

tical environment. Proper acoustic conditions should therefore be

considered a prerequisite for the realization of a satisfactory educa-

tional experience in music.

The acoustical design of music rooms is clearly not a problem

that can be solved by the engineer alone, the problem being more than

purely physical. "Its complete solution will require the co-operation

of physicists and musicians, and it may be necessary to seek the help

of psychologists and estheticians."[2] Musical taste is profoundly

influenced by historical tradition, and any definition of good fidelity,

balance, definition, reverberation, or loudness must be a judgement made

by those who have developed a sensitivity to the dictates of musical

tradition. For this reason, the subjective consensus of musicians in

acoustical problem solving will be basic to all discussion in this chapter.

In the MENC publication, Music Buildings, Rooms, Equipment (1955), the acoustic environment of a given space is defined as: "(a) the intensity and character of all sounds existing in that space, and (b) the way in which sounds are prolonged and spread within the space."[3] The array of acoustical phenomena treated in this chapter includes reverberation, absorption, diffusion, definition, noise reduction, and the necessity for approximating concert hall acoustics in the rehearsal room. The concert auditorium itself will not be discussed until Chapter Five except as the rehearsal room is compared with it. Two general types of rooms will be analyzed in relation to their acoustical ideals and problems: (a) large rooms, or rehearsal spaces for band, chorus, and orchestra, and (b) small rooms, a designation referring to practise rooms, studios and ensemble rooms.

Room Size and Dimension

Discussion in this section will be concerned with the area of the floor space as a function of optimum square footage per person, total room volume as a function of optimum cubic footage per person, dimensional proportions of the floor plan (or room shape), and optimum ceiling height.

Large Rooms

There is considerable difference in the square footage per person requirements of instrumental rehearsal rooms and those of vocal rooms due to the space requirements for instrument and music stand in

instrumental ensembles, and the absence of these items in choral

rehearsal rooms. The trend in recent years has been to recommend

greater space per person than was felt essential in the pre-World War II

era. In 1966, research conducted by the Music Educators National Con-

ference and by Nelson Patrick and Charles Boner revealed a prevailing

preference among instrumental directors for an allotment of approxi-

mately 20 sq ft per student.[4] The MENC publication further recommended

that in choral rooms, 6 sq ft per person be sufficient if students are

required to stand during rehearsal, and 10 sq ft per pupil be con-

sidered adequate where chairs are used, but that 15 to 18 sq ft per

student may be desirable under certain conditions, and is in fact, not

an uncommon practise.[5] It may be reasonable to assume therefore, that

an average of 10 sq ft per person is an adequate allotment for choral

rehearsal space.

Because the quantity of air inhaled and exhaled during vocal and

wind instrument performance far exceeds that of normal breathing in

classrooms, the volume of air per student in rehearsal rooms should be

correspondingly greater. In addition, acoustical requirements for large

performing organizations demand larger-than-normal room space. This

problem will be treated later in the chapter.

In the research just quoted, there again was agreement between

the MENC committee and Patrick and Boner, that an allotment of 400 cu ft

of air space per performer be a desirable optimum objective for instru-

mental groups.[6] The MENC recommendation for choral rooms was a minimum

of 125 cu ft per seat.[7]

A comparison of floor plans for large rehearsal rooms revealed

a strong preference for a rectangular floor dimensional proportion of

approximately 3:2. There was considerable proportional variation, however, ranging from a perfect square to rectangular proportions of approximately 2:1, with a variety of room shapes including semi-circular, pentagonal, and hexagonal designs. Generally speaking, however, traditional seating and standing patterns for large musical groups dictate that rehearsal rooms be wider than they are deep, but the actual dimensions of the room will essentially be determined by the size of the groups expected to be rehearsing in it, and by whether the ensemble is vocal or instrumental. A rehearsal room's shape is significant only as it affects room acoustics with regard to sound diffusion, the elimination of flutter echo and sound foci, and the minimizing of room resonance, these acoustic phenomena being positively modified when no two room surfaces are parallel with each other. This will be fully discussed in subsequent sections dealing with reverberation and resonance.

The ceiling height of an instrumental rehearsal room should average between 14 and 18 ft for acoustic purposes. "Anything less than a 14 ft ceiling in an instrumental rehearsal room should be questioned."[8] Differences in height will occur if the ceiling is angled slightly from the horizontal in order to prevent parallelism with the floor, or if the floor is split into several levels by the use of risers. For purposes of general discussion, an average ceiling height of 16 ft might therefore be reasonably recommended for instrumental rehearsal rooms. The only conclusion stated by the MENC research panel regarding ceiling height in choir rooms was that "choral room ceilings do not need to be as high as those in instrumental rehearsal halls, but

should be higher than those of an ordinary classroom."[9]

The foregoing data reflects current practises or preferences prevailing among instrumental and choral music directors, and is summarized in Table 4.1.

	Seating Area per Person	Total Volume per Person	Dimensional Proportions	Ceiling Height
Instrumental Rooms	20 sq ft	400 cu ft	3:2	16 ft
Choral Rooms	10 sq ft	150 cu ft	3:2	*14 ft

Table 4.1.—Data illustrating optimums in rehearsal room size and dimensional proportion

*The 14 ft ceiling height for choral rooms was determined by averaging classroom ceiling height (10 ft) with that of instrumental rehearsal rooms (maximum 18 ft).

In Richards and Krahl's publication, Sound Control in Difficult Areas, acousticians with the firm stated that although an exact optimum rehearsal room volume cannot be determined, the total room volume should not be less than 35,000 cu ft for instrumental rooms.[10] This is the volume they have determined ideal for an organization of 70 players. If the optimum cubic footage recommended in Table 4.1 is multiplied by 70, the minimum room volume would approximate 28,000 cu ft. A generalization might be made, therefore, which would suggest a minimum room volume of approximately 30,000 cu ft for instrumental rehearsal rooms. If the 3:2 floor dimensional proportion and optimum ceiling height of 16 ft were applied to this cubic footage, the resultant room dimensions would approximate 54 ft by 35 ft by 16 ft. If groups larger than 70 students are anticipated, the room size should then be increased from the above minimum by 400 cu ft per person and floor dimensions altered

proportionately.

Richards and Krahl's recommendation for minimum volume in choral rehearsal rooms was 30,000 cu ft. If this figure is divided by the per-person cubic footage recommenced by the MENC committee, the room could house a choir of 200 members. Although this will usually represent an unrealistically large size for a choir, it should be noted that frequently choral rooms double as recital halls because of the unobstructed theatre style of seating, and where this doubling is desired, a room of 30,000 cu ft may prove ideal for performances requiring small audiences. If the room is to be used for rehearsal only, a 20,000 cu ft space should prove adequate for choirs not exceeding 100 members. These volumes and a ceiling height of 12 ft would suggest floor dimensions approximating 40 ft by 60 ft for the larger unit, and 32 ft by 48 ft for the smaller, if the 3:2 proportion is maintained.

Small Rooms

Practise rooms are generally constructed in two sizes, one to accommodate individual practise, the other for use by small groups. Unlike large rehearsal rooms, the size of practise rooms is not determined by acoustical considerations because "the small individual practise rooms lack the interior volume for optimum acoustics."[11] Factors governing their size include the number of individuals to be housed, and space requirements for equipment such as pianos, music stands and chairs. As already mentioned, these requirements usually result in the necessity for two types of small music rooms, one referred to as simply the practise room, the other as the ensemble room.

An analysis of university practise rooms by Lane and Mikeska

revealed a general dissatisfaction among musicians with practise rooms averaging 60 sq ft of floor space or less.[12] In fact, the most satisfactory minimum floor space approximated 90 sq ft in this survey, an area which conforms closely to the 8 ft by 10 ft floor dimension recommended by the MENC committee.[13] This same committee suggested that the dimensions of ensemble rooms designed to house two pianos, or up to five instrumentalists, should measure no less than 10 ft by 12 ft. This size is equal to a minimum of about 24 sq ft per player and approximates the square footage recommended earlier for the seating area in instrumental rehearsal rooms. Before deciding on ensemble room size, the number of players comprising the largest ensemble expected to use the room should be determined, and that figure multiplied by 24 to calculate for the necessary floor area of that ensemble room. Ceiling height in practise rooms surveyed by Lane and Mikeska varied between 8 and 9 ft, but was not a factor mentioned in the study as influencing the quality of the rooms.

Studios are generally considerably larger than either practise or ensemble rooms because of the additional space required for a desk, a small library, a piano, and storage of musical or electronic equipment. The sizes of university studios analyzed by Lane and Mikeska ranged from 11 ft by 13 ft by 9 ft to 25 ft by 21 ft by 10 ft, with an average floor space of 182 sq ft. The concluding summary suggested an optimum studio floor dimension of 12 ft by 20 ft (240 sq ft), but again ceiling height, varying between 8 ft and 10 ft, was not a factor mentioned as affecting the musicians' rating of the rooms.[14]

It must be noted that the dimensions given above are only

approximate and must not be taken to imply rectangular room shaping.
Because of the size of small music rooms, problems with reverberation,
room resonance points, and flutter-echo will be exaggerated if room
surfaces are parallel. A deviation from the parallel of one foot in
fifteen will, in conjunction with acoustic treatments of the surfaces,
provide the necessary diffusion of sound required to minimize the above
acoustic problems.[15]

A concluding summary appears in Table 4.2 which tabulates the
sizes and dimensions advocated as optimum for small music rooms.

	Dimensions	Square Footage	Ceiling Height	Room Volume
Practise Rooms	8' x 10'	80	8'—9'	640 ft^3
Ensemble Rooms	10' x 12' min.	120	8'—9'	960 ft^3
Studios	12' x 20'	240	8'—10'	2160 ft^3

Table 4.2.—Approximate optimums for small music room sizes

Reverberation

Quantitatively, reverberation is expressed in terms of rever-
beration time which, by definition, is the time required for a given
level of sound to decrease by 60 decibels after the source of sound has
ceased."[16] The phenomenon arises from the multiple reflection of
sound waves from all room surfaces. Each time a sound wave meets a
surface, a portion of its intensity is absorbed, causing each succeeding
reflection to diminish in intensity until inaudibility is reached.

Reverberation has a direct effect on musical quality, and deter-
mines whether a performance is experienced as intimate, warm, full,

balanced, brilliant, clear, detailed, or blended. A long reverberation time (RT) will destroy the intimacy essential for performances requiring attention to intricate detail but will actually enhance the fullness of tone that, say, an organ performance requires. An enclosure is said to be acoustically warm if bass tone reverberation is long in relation to that of mid range frequencies. Reverberation affects balance when reverberation times fluctuate with differences in frequency. Most noticeable, however is the advantageous effect of reverberation on blend and fullness as contrasted with its detrimental effect on definition and clarity.[17]

Leo Beranek, a prominent authority on music and acoustics,[18] stated that from interviews he had conducted with musicians and from the experience of the recording industry, it seemed clear that listeners today prefer particular reverberation times for the performance of music of particular eras, this preference corresponding to the reverberation times characteristic of concert salons or halls built during those eras. Those built during the Baroque and Classical eras, for instance, had reverberation times ranging between 1.4 and 1.8 seconds; the RT of those built since the early nineteenth-century averaged 2.0 seconds or longer.[19] Seeing it is impractical to alter a room's reverberation characteristics with each change in performance style, however, what is a satisfactory reverberation quality for a music room? Sabine states that "no one can say arbitrarily, but the consensus of experienced opinion gives us a workable standard . . . ."[20] It is reasonable to assume that rehearsal areas should not differ too greatly from the concert hall in acoustical characteristics, though some deviation is essential. Too

great an adjustment by school musicians when transferring from rehearsal to concert hall will not only create performance insecurity but will almost certainly result in improper balance and interpretation.

Reverberation in School Music Rooms

Rehearsal rooms

Optimum reverberation is primarily a function of room volume.[21] Where school rehearsal rooms are concerned, two additional variables will modify the primary calculation based on room volume: (a) the use of the room, whether for choral or instrumental purposes, and (b) the frequency of the sound. At the core of all such calculation, moreover, are the preferences determined by the experiences of many musicians and experienced listeners.

A general optimum based on room volume alone (RT should increase with an increase in room volume) is obtainable from the graphs published by prominent acoustical engineering firms. Those produced by Sabine, Knudsen and Harris, and Furrer[22] are in very close agreement, and when applied to a space the size of an instrumental rehearsal room (earlier established as an optimum 30,000 cu ft) reveal a desirable RT of 1.3 seconds. The smaller choral rehearsal room (20,000 cu ft) would, from these graphs, ideally possess a slightly reduced RT of 1.25 seconds.

The opinions expressed by school and university music directors reveal, however, a preference for a considerably lower RT in rehearsal areas. Table 4.3 compares the recommendations of seven individuals or groups who specifically studied preferred reverberation times for school rehearsal rooms. The unusually high RT recommended by Burris-Meyer and Goodfriend for choral rooms was not substantiated by any other sources

consulted and appears to be overly reverberant for rehearsal areas. The experience of Richards and Krahl, gathered through the design and evaluation of more than one hundred band rooms, led to the discovery that most band directors preferred rooms with an RT of .8 seconds or less when fully occupied. A measurement taken when unoccupied would have yielded a slightly higher RT due to a decrease in the number of sound absorbing surfaces.

	Instrumental	Choral	Choral/Instrumental Not Designated
Patrick and Boner	1.0	1.1	
Hale Sabine			.8 to 1.1
Clarence Best			.8 to 1.3
Burris-Meyer and Goodfriend	1.1	1.7 to 1.9	
MENC (Carter et al)			1.2
Nickerson	.9	1.0	
Richards and Krahl	.8	1.1	

Table 4.3.—Preferred RT in seconds as obtained by seven researchers for school music rehearsal rooms

The range of preferred reverberation times illustrated in Table 4.3 indicates that optimum RT for a rehearsal room will not be the same for every director. It can be deduced from the table, however, that a design objective of approximately one second reverberation time for both instrumental and choral rooms is likely to prove satisfactory to most musicians. Provision should nevertheless be made for the alteration of the rooms' absorption characteristics in order that slight changes in

reverberation time can be effected, if necessary, after the rooms have been evaluated during actual rehearsal. This is suggested because of evidence in the table to indicate that an RT of one second may prove generally too reverberant for instrumental and too dead for choral purposes; furthermore, increased absorption by the addition of several persons to the room will undoubtedly significantly affect the initial reverberation characteristics of a rehearsal room. The final measurement of the rooms' RT shoulu be done when fully occupied.

A general statement of the reverberation time of a music room is usually given as an average for frequencies ranging between 128 and 4096 cycles per second (cps), specifically, that which is measured at 512 cps.[23] An analysis of nine famous concert halls by Leo Beranek revealed a very consistent pattern of deviation from this average. Reverberation times increased by an average .2 seconds for lowest frequencies and decreased by an average .3 seconds for highest frequencies.[24] This trend corresponds to the recommendations of Knudsen and MacNair.[25] The reason for this trend is further illustrated by Knudsen.

In order for music to be aurally balanced, it appears desirable from the listener's standpoint that the reverberation characteristics of a room permit all frequencies to become inaudible at the same instant. Upon analysis of the relative intensities of different frequencies in a musical performance, Knudsen revealed that low pitched intensities averaged 30 db less than mid-frequency intensities. If all frequencies were to become inaudible at the same instant, therefore, low frequencies would require a slightly longer reverberation time. The study also noted that slightly reduced intensities existed for

frequencies above 2000 cps, indicating that, contrary to the acoustical characteristics of concert halls investigated by Beranek, some prolongation of sound for high frequencies may be desirable.

Patrick and Boner's investigation of six band rehearsal rooms considered by the band directors as acoustically adequate, revealed an increase in low frequency reverberation over that of middle and high frequencies approximating an average of one half second. In every case, bass instruments were considered too 'boomy' and treble instruments too inaudible. This suggests both that a one half second difference in RT between middle and low frequencies results in musical imbalance, and that high frequencies may also need reinforcement. A reasonable guide in determining optimum reverberation times for low, middle, and high frequencies may then approximate that recommended by Carter and Associates for the MENC.[26] Suggested by them is a 25% increase in RT for low frequencies (125 cps) and a maximum 10% deviation for frequencies in the 4000 cps range. If the RT of a rehearsal room at 512 cps is established at one second as previously recommended, the RT at 125 cps would ideally be 1.25 seconds, and at 4000 cps, 1.1 seconds, assuming that high frequencies were to be prolonged as suggested above. The graph outlining RT variations as a function of frequency will not, however, form a continuous curve, but will generally be flat, with the indicated slight increases occurring at the ends of the graph. Methods of achieving this balance in reverberation time will be analyzed in subsequent discussion of absorption.

Small music rooms

Satisfactory reverberation times for practise rooms, studios,

and ensemble rooms will not differ significantly from each other because of the similarity in the sizes of these spaces. Table 4.4 shows a comparison of preferred reverberation times for small rooms as investigated by eight researchers.

	Practise Rooms	Studios
Lane and Mikeska	.4—.5 sec (.6—.7 sec at 100 cps)	.55—.65 sec (up to .8 at 100 cps)
Blankenship, Lane, and Fitzgerald	.4—.5 sec	.6 sec
Richards and Krahl	.5 sec	
Nickerson	.4 sec	

Table 4.4.—Preferred RT in small music rooms,
from investigations by eight researchers

There is virtually complete agreement among the researchers as to what musicians consider to be satisfactory reverberation for small rooms. It will be noted that optimum RT for small music rooms is approximately half that of rehearsal rooms, but that the amount of increase at low frequencies as advocated by Lane and Mikeska is almost identical to that of the larger units.

The Control of Reverberation

The single most important factor in reverberation control is sound absorption by a room's walls, ceiling, floor, furnishings, and occupants. It is true that sound diffusion achieved by irregular room shapes, absorption by the air, and even a room's relative humidity are additional variables which affect reverberation, but where rehearsal units and smaller music rooms are concerned, their combined effect on

sound decay is negligible. The present concern is therefore with sound absorption by room surfaces as it relates to optimum reverberation at various frequencies, the maintenance of useful room reflections through discreet positioning of sound absorbent materials, and the most effective location of these materials for optimum reverberation control.

Absorption and frequency

A material's capacity for absorbing sound is given by its absorption coefficients at different frequencies. If a surface were capable of absorbing 100% of the sound it received, the absorption coefficient of the material would be 1.0; if only 60% of the sound received was absorbed and the remainder reflected, the material's absorption coefficient would be stated as .6. The total sound absorption by a given surface is stated in sabins, a sabin being equivalent to one square foot of surface whose material has an absorption coefficient of 1.0.[27] Since absorption varies with the angle of the incident sound, the absorption coefficient is a figure averaged over all angles of incidence.

It was stated earlier that, for purposes of musical balance, it is desirable that low frequencies (128 cps or lower) and high frequencies (4000 cps and higher) be permitted to have slightly longer reverberation times than mid frequency sounds measured at 512 cps. Of the two, low frequency sound control is the most critical factor to consider when selecting and locating absorbent materials.

The major difficulty associated with achieving optimum low frequency reverberation is not one of raising its RT above that of mid frequencies, but one of preventing its RT from becoming excessively

high. Furrer indicates that the reverberation which is subjectively perceived as most unpleasant is that which occurs at low frequencies.[28] This observation was reinforced by Patrick and Boner's investigation of six music rooms (discussed earlier), considered satisfactory by their occupants. Despite general adequacy, there was consistent dissatisfaction with excessive low frequency reverberation, resulting in "boomy bass and percussion, indistinct tympani roll, and lack of tone separation."[29] One reason for this problem is readily apparent from an analysis of absorption coefficients for various materials; with the great majority of materials, sound absorption is least efficient at low frequencies. Low frequency sound absorption is economically achievable however, in two basic ways.

The first is to use materials which have their highest absorption coefficients at low frequencies. This is true of wooden structures such as those found in the walls of several of the world's major concert halls and the floors of many well designed rehearsal rooms. Knudsen shows that low frequency absorption is greatest when wood is used in the form of a light, flexible panel which will vibrate sympathetically with low frequencies and thereby absorb them. He indicates that this is also true of fiberboards such as Masonite, and acoustical tile such as Acousti-Celotex.[30]

Secondly, low frequency absorption is increased considerably when an air space is provided between the absorbing panel and the rigid wall. If the panel is fastened to wood strips which in turn are affixed to the rigid wall, the panel can vibrate freely and thereby increase its absorptive qualities. Furrer states that "in the fre-

quency range of 100 to 300 cps the absorption . . . is more than doubled by this simple and economic method."[31]

Materials for the absorption of high frequencies are numerous and rely chiefly on their porosity for effective absorption. Many materials have a number of small, deeply penetrating intercommunicating pores into which a portion of the sound may pass and become converted into heat by frictional resistance within the pores. Knudsen states that "as much as 95% of the energy of an incident sound wave may be absorbed in this manner."[32]

Both high and low frequency absorption are important for reverberation control in music rooms. By using porous materials and panels in proper proportions, a balanced reception of all musical frequencies can be assured. As was pointed out earlier, this balance will be only roughly approximated when measured in an empty room, and provision for alteration should be made if the final absorption characteristics of a music room cannot be determined prior to actual rehearsal.

Table 4.5 is an interpolation of data from a graph published by the MENC[33] relating reverberation time, room volume and absorption units, into data obtained from recommendations in this chapter as to optimum music room size and corresponding optimum reverberation times. It must be noted that because reverberation time varies with frequency and room usage, the figures for required absorption are an average for all frequencies; in the final analysis, however, optimum absorption must correspond with optimum reverberation time at low, middle, and high frequencies.

	Room Volume	Average RT (empty)	Absorption Required
Rehearsal Rooms	30,000 cu ft	1.0 sec	1300 sabins
Studios	2,160 cu ft	0.6 sec	160 sabins
Ensemble Rooms	960 cu ft	0.5 sec	85 sabins
Practise Rooms	640 cu ft	0.5 sec	65 sabins

Table 4.5.—Music room sound absorption as a
function of room volume and optimum RT

Location of absorptive material

Acoustical material "will absorb the greatest amount of acoustic energy when placed at the point of maximum pressure."[34] R. L. Suri has determined, and his findings are confirmed by others, that sound pressure is greatest at or near room corners and next highest along the edges between two walls.[35] Hence, maximum efficiency due to location will be realized when absorbents are placed in these positions. Corners are then perhaps the best location for low frequency absorbents.

Sound absorption must also be built into walls and the ceiling because of the magnitude of sound reflection from these surfaces. Richards and Krahl's investigations reveal that materials with high absorption at low frequencies are also very efficient when placed in the ceiling at the rear of a rehearsal room and in the back wall of the room.[36] Nickerson suggests that the placement of acoustical tile is most effective when the front wall is the principal absorbing surface.[37] Lane and Mikeska's investigations of preferred acoustics in practise rooms and studios indicated that in small music rooms, reverberation is best controlled at all frequencies when one wall surface is panelled

with wood, the ceiling is covered with acoustic tiling, and a panel measuring approximately 3 ft by 7 ft which will absorb primarily middle and high frequencies, is affixed to one of the plaster walls.[38]

An important principle in the placement of porous or panel absorbents is that sound absorption is significantly increased when the material forms a non-uniform patchwork on the reflecting surface. A table produced by Knudsen revealed as much as 60 to 70 percent increased absorption in walls when panel sizes were reduced to about one-sixth to one-tenth their original size and considerable space was left between panels.[39] This random patterning of absorbent materials permits, in addition, the retention of some useful reflection of sound which is essential for sound diffusion, a phenomenon discussed next in the chapter.

Useful and Detrimental Sound Reflection

Diffusion

Sound is said to be perfectly diffuse when its pressure is equally distributed throughout a room.[40] Besides ensuring a uniform distribution of sound intensity, good sound diffusion creates uniformity in the rate of growth and decay of sounds throughout a room. This section of the chapter will outline, first of all, several musical and acoustical phenomena related to sound diffusion or the absence of it. Then because the correction of problems caused by some of these phenomena have a common base, the chapter will conclude with appropriate structural solutions to these problems.

The immediate implication of the definition of diffusion for musical response is that all persons within a room, whether performer or

listener, will with good diffusion, be able to hear a performance in the same way that everyone else hears it. This ability is vital wherever several people are performing simultaneously, particularly if the organization is large, because balance, blend, rhythmic precision, and accuracy of intonation are elements of musical performance whose perfection requires careful listening to all parts of the ensemble. This careful listening is in turn dependent on every performer being able to hear every sound as every other performer hears it.

A phenomenon frequently encountered in music rehearsal rooms is that, whereas front row personnel are able to hear distinctly both their own sound and that of the group (because of its projection toward them), those in the back rows either cannot hear the sounds generated in front of them or hear them too faintly to be able to perform (aurally at least) in balance and cohesion with them.[41] It frequently becomes difficult therefore to teach school choir, band, and orchestra members to listen for and thereby produce a unified musical sound, and the teaching must resort to frequent directions from the podium for correction of the imbalance and disunity which cannot be detected by the players or singers.

Achieving the desired diffusion may require considerable experimentation with reflective materials during actual rehearsal, but general guidelines can be outlined which will help to secure very satisfactory results in most designs. These will be discussed following an analysis of other problems of room acoustics which are correctable by the same processes used for improving sound diffusion.

Echo

The echo phenomenon is one which becomes a problem in spaces the size of auditoriums but does not really exist, in the acoustical use of the word, in rooms the size of those under discussion in this chapter. The echo problem and its remedies will be analyzed in Chapter Five.

Flutter

When multiple sound reflections occur between two hard, smooth, highly reflective parallel surfaces, usually walls, the aural effect is a flutter. Flutter is a form of echo but is heard as an annoying buzz after a tersely articulated note or speech consonant, and resembles the fire of automatic weapons if the room is large enough. These disturbing reflections not only create annoying sound effects psychologically, but are also detrimental to clarity and definition in the hearing of musical sounds.

Room Resonance

Every enclosure will, at certain frequencies, vibrate sympathetically with sound generated within or near it and thereby amplify the sound at those frequencies.[42] This phenomenon can be dramatically demonstrated in a shower stall enclosed on all sides. If a person standing in the stall were to hum a glissando throughout his vocal range, he would discover that certain pitches would become suddenly louder without any additional effort on his part. These frequencies would be the resonant points of that enclosure. Small music rooms are particularly vulnerable to the effects of resonance due to the audibility of many of their resonant points. Band, choir and orchestra rooms

are large enough that their resonant frequencies would lie in a sub-audible range.[43]

The effect of resonance points on the reception of musical performance is clearly that of creating imbalance between frequencies. A fluctuation of as much as 20 db[44], particularly at low frequencies, can be experienced when resonance points (sometimes referred to as standing waves) are permitted to exist.

Kent suggests that standing waves will be a problem whenever room surfaces are parallel, and will be most pronounced when the ratio between two room dimensions is a whole number or nearly a whole number. A perfect cube would be the poorest possible choice of dimensions, but a room with a dimensional ratio of 1:2:2 would remain almost as poor acoustically.[45] The room design which most efficiently eliminates standing waves is one where no two surfaces are parallel.

Sound Foci and Dead Spots

Both of these phenomena will be experienced at the focal point of two reflected sound waves. Dead spots occur when two waves focus in such a way that the rarefaction of one wave coincides with the compression of the other, resulting in a neutralization of the sound's intensity. The ear then hears the sound as greatly diminished in intensity. Sound foci result from a similar focusing of sound waves but with the simultaneous arrival of two compressions or two rarefactions. The two reflections now reinforce each other, thereby creating sound amplification. A person situated in such a focal point in a rehearsal room is likely to experience distracting fluctuations in sound intensity and thus be inhibited in his ability to hear or perform with an ensemble in

a balanced or blended fashion. Focal points can be anticipated in any room with a concave wall or ceiling shape unless the curvature is so slight that the focal point actually exists outside the room.

Achieving Diffusion

Acoustic problems elicited by sound foci, dead spots, flutter, and standing waves originate from uneven concentrations of sound intensity within a room. An imbalanced or unclear perception of sound by musicians performing together within the room can frequently be attributed to the non-uniform hearing conditions these phenomena create. The engineer's problem then becomes one of transforming these uneven patterns of sound concentration into a diffuse distribution of sound.

The first step in the design of a new structure is to ensure that no two surfaces within a room are parallel, a deviation from the parallel of one foot in fifteen being one suggested floor plan.[46] The avoidance of parallel surfaces will automatically eliminate the possibility of flutter and standing waves occurring and will contribute substantially to general sound diffusion by increasing the number of directions that sound can be reflected. If the ceiling of a rehearsal room is to be slanted to avoid parallelism with the floor, a downward slope toward the front of the room will increase the amount of sound reflected to the back of the room and in this way allow those in the rear areas of the room to hear sounds from the front rows more audibly.

Additional provision for diffuse sound reflection patterns should also be made; for rooms with parallel surfaces this provision is essential. An effective method is to splay the walls or ceiling by applying reflective panels (illustrated in Figure 4.1) which give the

surfaces an irregular shape. The purpose is to increase still further the number of directions in which the sound can be reflected, particularly if this increased reflection will improve audibility in the rear sections of a rehearsal room. A type of splaying mentioned in a previous section of the chapter involves the random positioning of small absorbent panels over walls or in the ceiling, a device which will break up a uniform reflective pattern into uneven diffusion. Additional diffusion is achievable in a rehearsal room when the number of reflecting surfaces is increased by a judicious positioning of storage cabinets or other room furnishings against one or more walls. Many instrumental music directors prefer this type of instrument storage to that of a separate room for this reason.
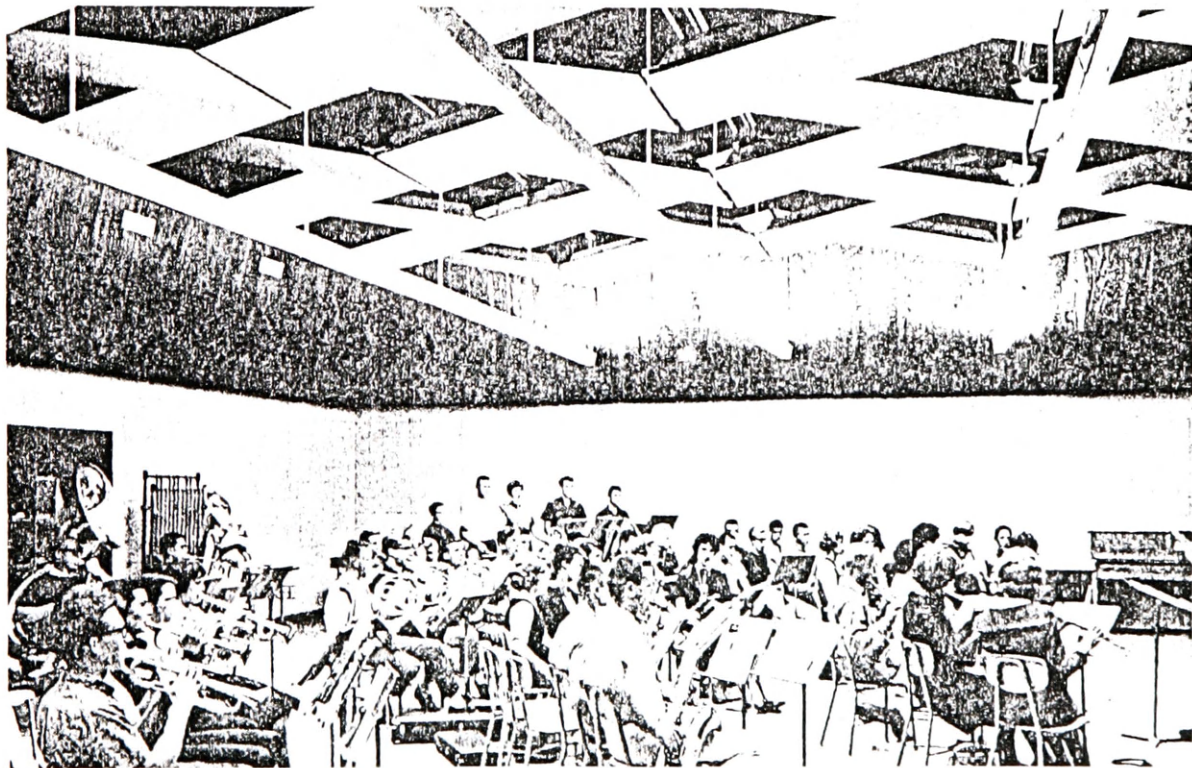

Fig. 4.1.—An example of splayed ceiling panels[47]

The advantages of splaying room surfaces are essentially identical, from a musical standpoint, to those realized by non-parallel room surface construction; a uniform distribution of sound throughout the room is achieved, and the possibility of the occurrence of flutter and standing waves eliminated. In practise rooms, studios or ensemble rooms, where all reflecting surfaces are in close proximity, where a large percentage of the room space is occupied by furnishings and personnel, and where reverberation times are low, it is unlikely that the diffusion achievable through the use of non-parallel room surfaces could be significantly improved by the application of additional reflecting splays.

The elimination of sound foci and dead spots is principally a matter of eliminating concave curvatures in wall and ceiling structures. Sounds reflecting from the perimeter of a curvature will tend to converge on a single focal point creating either amplification or diminution of sound intensity as discussed earlier. Concave room surfaces will usually be found in ceilings or rear walls, either for purposes of structural strength or architectural suitability to the general building design. Where these curvatures cannot be eliminated, their focal tendencies can be minimized by considerable splaying of the surfaces.

It has already been noted that sound absorption is greatest when absorbent material is located in corners and edges where two walls meet. The MENC committee under Homer Ulrich indicated that, in small music rooms, these locations are also the most effective for absorptive treatment which controls resonances, particularly those at low frequencies.[48]

The expense of building music facilities is one which will exceed that of most other types of school construction of comparable size. Good acoustical planning at the outset will, however, prove inexpensive in comparison to the cost of acoustically correcting a poorly designed facility. It is important therefore, to plan for a room's location, vertical and horizontal shaping, and optimum volume before the relatively expensive processes of providing absorption, diffusion and isolation are begun.

Noise Reduction

In Chapter Three, a basic assumption underlying all statements of both maximum and predominant sound levels within music rooms was that the rooms possessed optimum reverberation and diffusion characteristics and that these characteristics in turn reduced the sound levels that could normally be expected in the rooms. The effect of improved room acoustics on the reduction of a room's sound intensities is discussed in terms of two characteristics of sound in enclosed spaces: steady-state sound level, and room resonance, the latter having been treated in an earlier section of the chapter.

When a steady sound is emitted in an open space where there are no reflecting surfaces, the sound's intensity varies with its distance from the source. When the same sound is brought into a room, reflected waves become superimposed on incident waves and thus create amplification. This process repeats itself as the number of reflected waves multiplies, until a steady state is achieved whereby the energy present in the room is absorbed by boundary surfaces at the same rate at which it is generated.[49]

The intensity of this steady-state sound will be reduced by an increase in sound absorbing material within the room. Because sound build up is dependent on energy reinforcement by reflected waves, a reduction in a reflected wave's energy by increased absorption will reduce the amount of amplification created by that wave. Steady-state sound intensity will also be reduced by an increase in sound diffusion for similar reasons: the more a sound wave is reflected within a given period of time, the greater the absorption of its energy during that period.

From his formulas relating absorption to reduced intensity, Rigden calculated that by increasing the absorption in a small studio-sized room (1728 cu ft) by about 13 sabins through the application of acoustic tile on the ceiling of a very reverberant concrete enclosure, a 9 db decrease in reverberant noise was achieved.[50] Nickerson has determined that between 7 and 10 db of noise reduction can be expected in a band room and adjacent classrooms by the application of absorptive materials to achieve optimum acoustical conditions, if the rooms are initially quite reverberant.[51] He indicated that doubling a room's absorption will reduce intensities by 3 db but that trebling the absorption would further decrease sound levels by only one decibel.

It must be emphasized that what is being advocated to reduce steady-state intensity levels is not the achievement of the greatest amount of absorption possible. This would simply result in a very lifeless acoustical atmosphere. The amount of absorption in a room must essentially be determined by its optimum reverberation time, and it is the creation of this optimum RT which will in turn decrease sound

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levels as indicated above.

<div align="center">Summaries</div>

<div align="center">Room Measurements</div>

The size of a rehearsal room should be determined by the amount of floor and air space required for each individual in the largest group expected to occupy that space. The differing requirements for choral and instrumental music rooms are summarized in Table 4.1 and will not be restated here. It is additionally important, however, that these requirements be calculated upward from a minimum of 30,000 cu ft for instrumental music rooms and 20,000 cu ft for choral music rooms, in order that desirable acoustic conditions for group rehearsal not be jeopardized by insufficient room volume. Practise room and studio sizes need not be governed by acoustic considerations, however, inasmuch as their cubage will always be insufficient for optimum room acoustics. Details relating to optimum sizes for small music rooms are summarized in Table 4.2.

<div align="center">Reverberation</div>

The reverberation time of a music room ideally should vary with the degree of definition characteristic of the style of music being performed. Because the constant adjustment of a room's reverberation time is logistically impractical however, a consensus of experienced opinion has provided acousticians with workable standards which are essentially satisfactory compromises. Optimum reverberation has therefore become primarily a function of room volume and secondarily one of frequency.

The results of surveys conducted to determine reverberation time optimums for music rooms have indicated that there is general satisfaction with rehearsal room acoustics when, in an empty room, mid frequency reverberation time is about one second, and there is a 25% increase at low frequencies (125 cps), and a 10% increase at high frequencies (4000 cps). Satisfactory reverberation times for small music rooms have been determined through similar research, to be approximately half that of the rehearsal rooms. These are summarized more specifically in Table 4.4.

The achievement of this reverberation spectrum is accomplished through a balanced absorption of sound at the three frequency levels mentioned. Low frequency sound will usually be over-reverberant unless considerable amounts of low frequency absorbents, such as wood panelling, are used, but high frequencies are easily absorbed by most commercial materials, and care must be taken to avoid over-absorption of these sounds.

Reflected Sound

In music rooms, reflected sound is acoustically advantageous only when it is diffused throughout the enclosure. When sound is reflected in this manner, every performer is able to hear his own sound in relation to that of every other performer; hence, ensemble blend, balance, rhythmic precision, and intonation can be positively reinforced. When sound is reflected between parallel surfaces, flutter and standing waves are elicited; when concave room curvatures have focal points within the room, sound foci and dead spots will inevitably result. Any of these phenomena can be the cause of an imbalanced or unclear recep-

tion of music by performers within an ensemble, and must be eliminated
through the avoidance of parallel or concave surfaces when designing the
basic room shape, and the use of irregular room shapes, splays, and
randomly spaced absorbents. As diffusion is thus achieved, reflections
detrimental to good acoustics are eliminated.

Noise Reduction

The achievement of optimum reverberation times through sound
absorption and multiple reflection may create a reduction of up to 10 db
in a music room's general sound level. Such a reduction was noted in
Chapter Three to be the first step in isolating a room's sound from
adjacent areas.

Chapter 4

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Nelson Patrick and Charles Boner, "Acoustics of School-Band Rehearsal Rooms," Journal of the Acoustical Society of America 41 (January 1967):217, 19.

5. Ulrich, Music Buildings, pp. 28, 29.

6. Ibid., p. 27.
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9. Ibid., p. 28.

10. Richards and Krahl, Sound Control in Difficult Areas, p. 35.

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    Willi Furrer, Room and Building Acoustics and Noise Abatement, trans. Evelyn R. Robinson and Peter Lord (London: Butterworth and Co. Ltd., 1964), p. 82.

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    Walter A. MacNair, "Optimum Reverberation Times for Auditoriums," Journal of the Acoustical Society of America 1 (January 1930): 242-4.

26. Carter, Music Buildings, p. 41.

27. Knudsen and Harris, Acoustical Designing, p. 87. See discussion in entire first paragraph.

28. Furrer, Acoustics and Noise Abatement, p. 62.

29. Patrick and Boner, Acoustics of Band Rooms, p. 218.

30. See V. O. Knudsen, Architectural Acoustics, pp. 212, 15; V. O. Knudsen and C. M. Harris, Acoustical Designing, pp. 85, 86. Compare Knudsen's discussion of low frequency absorption with the absorption coefficients of materials listed in the tables.

31. Furrer, Acoustics and Noise Abatement, p. 62.

32. Knudsen and Harris, Acoustical Designing, p. 85.

33. Carter, Music Buildings, p. 33.

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35. Ibid.

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39. Vern O. Knudsen, Architectural Acoustics, (New York: John Wiley and Sons, Inc., 1932), p. 196.

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44. Carter, Music Buildings, p. 44.

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48. Ibid., p. 66.

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CHAPTER FIVE

ACOUSTICAL DESIGNING IN THE GYMNASIUM-AUDITORIUM

Of the literature available on the acoustics of music rooms, the greatest bulk deals with the design of concert auditoriums. Twentieth-century research in auditorium design has resulted in the establishment of very reliable methods of achieving optimum acoustic conditions in all but the very largest of concert halls.[1] Where acoustical researchers have had opportunity to comment on the design of multi-purpose rooms such as gymnasiums or cafetoriums for the performance of concert music however, the viewpoint has consistently stated that any such dual usage of these areas will always be undesirable from a musical standpoint. With the prevalence of such a viewpoint, the research into acoustical designing for the gymnasium-auditorium is understandably scarce, if not perhaps non-existent. In a letter to the author from Carl Rosenberg of Bolt, Beranek and Newman, Inc., the statement was made that, to the company's knowledge no studies or papers had been published which dealt specifically with this type of acoustical design.[2] The author's own research has similarly failed to obtain any such publications.

Because of the wealth of information available on auditorium design, this phase of music room acoustics will not be discussed in this chapter. It appears evident moreover, that the practise of building an auditorium for the school is far from universal, presumably because of the expense involved relative to the usage the facility would receive.

As an alternative, a high percentage of school designs include a stage as part of the gymnasium structure, and thus provide at least the seating space for the performers and the audience. Because this arrangement is frequently the only concert auditorium available to school musical organizations, a chapter of this study is devoted to an investigation of ways in which the principles of good concert hall design can be incorporated into the design of the stage-gymnasium. The author does not wish to suggest that the acoustic conditions of an auditorium can be exactly duplicated in the gymnasium-auditorium combination, but only to present what he believes to be an original concept in gymnasium design, one which will allow its acoustics to conform reasonably closely to those of the auditorium. The recommendations should lead to greatly improved, if not occasionally optimum, acoustic conditions for musical performance in the school gymnasium.

Acoustic Liabilities and Assets Inherent in Traditional Gymnasium Design

The most undesirable acoustic condition found in gymnasiums is that of excessive reverberation. It is conceivable that audiences for athletic events require the psychological support of a live gymnasium to reinforce enthusiasm, and that "a gymnasium that is treated acoustically . . . for music would have a depressing effect on athletic activities."[3] However, recent research into the psychological effects of reverberation in sports areas was conducted by Kenneth Penman and associates, which indicates that the reverse may be true. In their research, the reverberation time for all areas except the very large fieldhouse, fell between 2.0 seconds and 6.6 seconds at 500 cps, and was

judged by the researchers to be over-reverberant and consequently overly noisy in all cases. The concluding statement expressed a hope that more favourable (less reverberant, noisy) conditions be sought for these areas in the future.[4] If a 2.0 second reverberation time conld be considered over-reverberant for athletics, a reduction of that time to what will be shown to be suitable for music would suggest that optimum reverberation for both activities may be more similar than has been traditionally thought.

Other undesirable musical conditions are elicited by the presence of a highly reflective floor, the area where most absorption should occur, and hard, parallel walls which create echoes and standing waves. A fourth significant disadvantage is the result of the necessity for a level playing floor. Irvin Blundell and Lawrence Perkins state that "any room seating 150 or more people demands either a sloping floor or an excessively high stage platform. A brief exercise in simple geometry, comparing sight lines in a bowl-shaped seating arrangement with lines from a flat floor quickly demonstrates one reason why the auditorium-gymnasium combination is impractical."[5] Knudsen and Harris recommend a slope, or rake, no less than 8 degrees if good hearing and seeing conditions are to result.[6] This last problem is undoubtedly unsolvable, but the first three adverse conditions mentioned may be remediable without exorbitant expense.

The gymnasium also possesses assets which will facilitate its conversion to a concert auditorium. Leo Beranek's investigation of fifty-four auditoriums revealed that "narrow rectangular halls are rated highest by musicians and critics,"[7] a shape generally characteristic of

gymnasium design. The normal gymnasium floor plan described by Furrer measures 72' x 36' for the small rooms and 90' x 54' for large ones,[8] an approximate 2:1 dimensional ratio which has been recommended by Knudsen as satisfactory for most auditoriums.[9] The author's own investigations of gymnasium dimensional ratios in the United States is shown, in a subsequent section, to correspond closely with Furrer's statistics where playing area only is concerned. If side bleachers are added, however, the ratio approximates 4:3, and may frequently correspond to that of a square unless bleacher space is also used to lengthen the room.

It was pointed out earlier that it is only when concert halls are very large that significant differences of opinion emerge as to what constitutes ideal or even satisfactory acoustical designing. A medium sized gymnasium would be able to comfortably seat between 400 and 600 listeners on the floor and could thus be considered a medium sized concert hall, a size which can generally be expected to yield predictable acoustic conditions.[10]

It must be stressed, however, that in order for adequate concert acoustics to be realized in a gymnasium, music must establish the acoustic standard. Whether or not this results in depressing athletic activity, acoustics are a far more integral part of musical performance than of sports activity and should be recognized as such if this type of dual purpose space is desired. To provide well designed rehearsal facilities without provision for an adequate concert environment would appear to be inconsistent planning, and would negate much of the purpose of music education. If the gymnasium is to be that environment, the recommendations in this chapter will reveal in what ways it can be

adequately modified for music without detriment to its functions for athletics.

Gymnasium Volume and Dimensions

A general analysis of gymnasium sizes and shapes must preface any discussion of musical acoustics in these spaces, inasmuch as volume and dimension are the two most basic factors in determining what is acoustically optimum in any enclosure.[11] The statistics in Table 5.1 have been obtained from the Athletic Institute and American Association for Health, Physical Education and Recreation, and represent these authorities' recommendations for the space essential for basketball, the indoor sport requiring the greatest playing area within a gymnasium.

	Play Area (Incl. Safety Space)	Bleacher Area (5 rows* ea. side)	Ceiling Height	Room Volume
Elementary School	54 x 90	8 x 180	18	113,400
Junior High Instructional	54 x 90	8 x 180	20	126,000
Junior High Interscholastic	62 x 100	8 x 200	22	171,600
Senior High Instructional	57 x 90	8 x 180	22	144,540
Senior High Interscholastic	62 x 100	8 x 200	22	171,600
Auxilliary Gymnasium	75 x 90	-	22	148,500

Table 5.1.[12]—Floor and air space in gymnasiums as recommended by the Athletic Institute and American Association for Health, Physical Education and Recreation. All measurements are in feet and cubic feet.
* Five rows would allow seating for 575 persons in the small gymnasiums and 650 in the longer ones (10 persons for every 14' row length).

Although playing area dimensions are generally standard, the safety zone and bleacher spaces may vary considerably from school to school, depending on their expected use by the school. For purposes of general discussion, however, these statistics will supply information which is sufficiently reliable to be used as a point of departure in the present analysis of gymnasium-auditorium acoustics.

Gymnasium Volume

In consultation with many educators, Blundell and Perkins have determined that high school auditoriums should seat between 1000 and 1200 persons, junior high auditoriums between 700 and 900, and elementary auditoriums between 350 and 500.[13] In order to compare these recommendations with the potential seating capacities of the gymnasiums listed in Table 5.1, Table 5.2 illustrates what their seating capacities would be, based on volume-per-seat recommendations from three of the sources consulted. If seating were to be determined on a square foot basis, with bleachers closed to a 3 foot depth (whereby one person comfortably occupies 6.5 sq ft, aisles included),[14] the seating capacities would exceed those shown in Table 5.2 except for some calculated in terms of the Burris-Meyer and Goodfriend formula. The largest gymnasium would hold, on a square footage basis, approximately 1100 people. The floor space of the gymnasiums could therefore comfortably accommodate the seating capacities determined as optimum by most of the volume-per-seat formulas.

It would appear therefore, that desirable auditorium seating capacities, as determined by Blundell and Perkins, could be accommodated in the gymnasiums shown, but would be suitable only for junior and

senior high school audiences. Even if 200 cu ft were allowed for each seat, all of the gymnasiums would be too large to function as elementary school auditoriums.

	Knudsen and Harris (180 ft^3)[15]	Burris-Meyer and Goodfriend (120 ft^3)[16]	Paul Sabine[17] (200 ft^{3}max)
Elementary School	630	945	567
Junior High Instructional	700	1050	630
Junior High Interscholastic	950	1430	858
Senior High Instructional	800	1200	720
Senior High Interscholastic	950	1430	858
Auxilliary Gymnasium	825	1240	740

Table 5.2.—Seating capacities of gymnasiums described in Table 5.1, after volume-per-seat formulas given by three groups of acoustical engineers

In his publication, Architectural Acoustics, Knudsen stresses that where auditoriums are larger than 200,000 cu ft, unsatisfactory acoustics inevitably result. More specifically, he states that the upper limit of high school auditorium size be 150,000 cu ft, that junior high school halls not exceed 100,000 cu ft, and that elementary school auditoriums be kept under 75,000 cu ft.[18] If the room volumes given in Table 5.1 are averaged and compared with Knudsen's recommendations, the size of the junior high instructional gymnasium (approximately 125,000 cu ft) could be considered a suitable size when correlating gymnasium size with desirable auditorium size. It is this gymnasium which will

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be cited in all subsequent acoustic calculations.

Gymnasium Dimensions and Shape

A measurement of the length of an auditorium includes the depth of 'coupled spaces' (adjoining enclosures) such as the shell on the stage, where these face down the length of the room. Both Beranek[19] and the two most recent MENC editions of Music Buildings, Rooms and Equipment[20] suggest a concert shell depth approximating 30 to 36 feet. If this depth is added to the length of each of the gymnasiums listed in Table 5.1, and 16 ft is added to the width to accommodate bleacher space, a length-to-width ratio of approximately 1.5:1 is achieved. This corresponds very closely to the ideal dimensional range recommended by Knudsen and Harris (2:1 to 1.2:1),[21] the ratio suggested by Furrer (5:3),[22] and the ratio illustrated by Johnson (2:1), as most suitable for musical purposes. Although these same acousticians agree that strict adherence to this shaping is not essential, they indicate that historically, long narrow halls with floor ratios approximating those stated, appear to have elicited the most favourable responses from audiences.

In Table 5.1, an analysis of ceiling height in relation to room width reveals a ratio of between 1:3.5 and 1:4. These proportions are a significant deviation from the 2:3 ratio suggested by Furrer[23] and the 1:2 to 2:3 range recommended by Knudsen and Harris.[24] It appears therefore that the realization of satisfactory acoustic conditions in gymnasiums may require increasing the minimum ceiling height to approximately 23 feet for the smaller spaces and 26 feet for the larger ones. A three foot increase in ceiling height in the junior high instructional gymnasium would, however, increase its volume from 120,000 cu ft,

suggested earlier as a suitable average school auditorium size, to 144,000 cu ft, a volume which approaches the upper limits set by Knudsen for high school auditoriums. The additional cubage would permit the extra seating of 100 persons, to a total of 800, a quantity which could still be accommodated in the gymnasium described, with a floor space allotment of 6.5 sq ft per person.

It is evident that the basic shapes and volumes of school gymnasiums can conform very closely to those essential to good school auditorium design. With this basic design satisfactorily established, the problems involved in acoustically treating the room are substantially reduced.

Reverberation

Optimum Reverberation Time

The effect of reverberation on the intimacy, fullness, balance, blend, definition, brilliance, warmth, or clarity of a musical performance was explained in detail in Chapter Four. Clearly, all of these characteristics will not be ideally achievable in any hall unless the reverberation time of certain frequencies can in some way be mechanically manipulated. Over half a century of acoustical experience in auditorium design however, has led to general agreement among acousticians as to what constitutes satisfactory reverberation in small and medium sized halls, and can provide us with workable standards for the modification of gymnasiums.

It was pointed out earlier that music must set the acoustical standard whenever a gymnasium is to serve both athletic and musical purposes. It was also observed in the previous chapter that optimum

reverberation time for music rooms varies with both room volume and the frequency of the source sound. Optimum reverberation time for the junior high instructional gymnasium (144,000 cu ft with the 23 ft ceiling) will be discussed in terms of these two phenomena.

An analysis of Knudsen and Harris' graph in Figure 5.1 shows optimum reverberation at mid frequencies for school auditoriums to be a compromise between what is recommended for speech and what is average for music. If the recommendations of this graph are used as a guide, the RT for a 144,900 cubic foot school auditorium would ideally approximate 1.3 seconds at 512 cps. This figure corresponds exactly to that determined by Burris-Meyer and Goodfriend as maximum for school auditoriums.[25] This reverberation time is an average for all frequencies, however, and should vary slightly for high and low pitch levels as explained in Chapter Four.
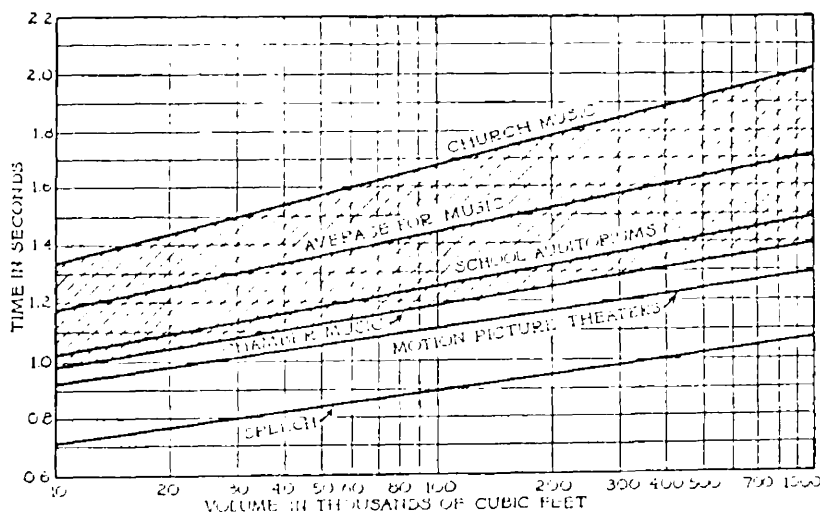

Fig. 5.1.[26]—Optimum reverberation time at 512 cps for different types of rooms as a function of room volume

The deviations given in Chapter Four, as recommended by Carter

and associates, suggested an RT increase of 25% for frequencies approximating 125 cps, and a maximum increase of 10% for frequencies in the 4000 cps range. This calculation would result in an RT of 1.6 seconds for low frequencies, and 1.4 seconds for high pitch levels in the gymnasium being considered. A line representing reverberation time as a function of frequency would not form a gradual curve, but would generally be a straight line with a slight increase at the ends of the graph, as illustrated in Figure 5.2 for low frequencies.
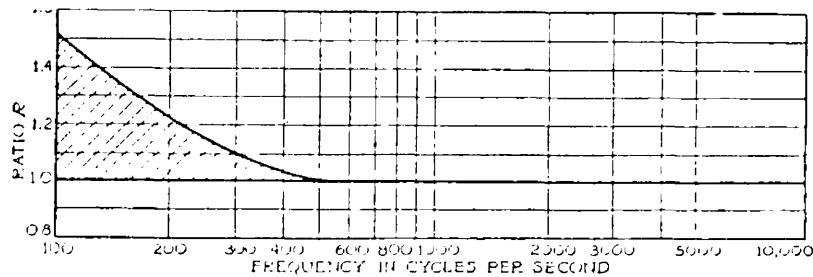

Fig. 5.2.[27]—Chart for computing optimum reverberation time as a function of frequency

Because the audience absorbs a high percentage of the sound in an auditorium, the reverberation times given above should be calculated in terms of the anticipated audience size being present. Calculations based on an empty room would result in very 'dead' acoustic conditions with the audience present.

Absorptive Materials and Their Location

Because sound generated and reflected within a concert hall should stop after it reaches the hearer, most of the room's sound should be absorbed by the floor, the seats and the listeners.[28] Fortunately, the audience contributes the most significant part of the

sound absorption in a hall;[29] in fact "in an auditorium seating less than 1000 which has approximatiely 120 cubic feet volume per seat, the audience and the seats supply practically all the needed absorption."[30] It is evident from this that fluctuations in audience size will create corresponding differences in the absorption, and hence, reverberation characteristics of a room. Because it is desirable to keep reverberation time constant under all conditions of audience size, it has become general practise to build auditoriums with highly absorbent upholstered seats, so that whether or not they are occupied, sound absorption in the floor area remains relatively constant. The necessity for readily removable folding or stacking chairs in a gymnasium rules out the use of upholstery however, and other methods of securing a reverberation time that is independent of audience size must be investigated.

A partial solution is to use easily stored chairs with padded backs. If these chairs face the concert stage in a staggered fashion, maximum absorption of sound waves emanating directly from the stage will be achieved. The exposure achievable through staggering the rows is particularly essential in an audience area where the floor cannot be sloped and each row of chairs is almost completely concealed from the stage by the row in front of it.

A more effective solution is to increase sound absorption in the floor by laying down carpeting which can be rolled up and stored, though due to the amount of carpeting involved, storage and handling problems may be considerable. Sectionizing the carpet into sizes which could be easily handled and stored on custom designed trucks cound permit installation and romoval which would not be excessively time consuming. Where

carpeting the entire floor in such a manner would prove to be logistically prohibitive, the carpeting of aisles and other similarly exposed floor spaces would be a useful alternative, though a somewhat less effective one for purposes of reducing the fluctuation in absorption which would result from variances in audience size.

If additional absorption is desired, the upper rear wall should be the next location considered for the application of absorbent materials.[31] Absorption in this area will serve the dual purpose of reducing reverberation and preventing the reflection of sound back to the stage in the form of an echo. The only remaining area which should be treated for sound absorption is the upper part of the rear side walls. The front part of side walls, and the entire ceiling should remain essentially reflective in order that sound originating on the stage be reflected to reinforce the sound reaching the rear parts of the auditorium where reinforcement is needed most.[32] As was explained in the previous chapter, the placement of wall absorbents in an irregular patchwork is the most efficient method of acheiving sound absorption in these surfaces.

The absorbents used on the upper rear and side walls are generally porous materials whose absorption coefficients increase with an increase in frequency. Unless low frequencies are efficiently absorbed by a material whose coefficient is highest at low pitches, they will become over-reverberant, creating the same low-pitched unpleasantness noted as frequently distracting in rehearsal rooms. The most efficient low frequency absorbent has been shown to be wood panelling randomly braced against the structural wall but separated from it by an air space; in

auditoriums, this panelling is called a 'wainscot' and covers the bottom four or five feet of the side and back walls. Knudsen and Harris indicate that in order for the panelling to vibrate freely in sympathy with low frequency sound waves, the material should be thin and flexible.[33] Beranek's investigations of low frequency response in concert halls, however, indicated that auditoriums with thin panel wainscots were deficient in the audibility of bass tones, but halls with thick wood panelling elicited good to excellent bass response.[34] This observation suggests that thin wood panelling may actually be over-absorptive at low frequencies.

It is conceivable therefore, that bleachers closed against the side walls of a gymnasium could form the required wainscot made of heavy wood panelling. This possibility cannot be fully substantiated from previous research but it does appear from Beranek's investigations that a substantial wood surface anywhere in an auditorium has the effect of optimizing bass response within the room. If bass reverberation cannot be reduced in this manner, commercial absorbents are available whose absorption coefficients are highest for low frequencies.[35]

The designing of a gymnasium in such a way that the largest percentage of its absorption occurs in the floor, the chairs, and the audience, may contribute to a reverberation problem when the room is no longer a concert hall. With the principal source of absorption removed for sports events, reverberation times may become excessive even for athletic use. A suggested solution to this problem would be to provide adjustable draperies on the upper portions of as many walls as would be required to provide comfortable acoustic conditions. These draperies

could be extended for athletic functions but would be drawn back for concert purposes to prevent over-absorption of the reverberant sound essential to liveness in musical performance. Curtains at the stage proscenium may also be closed to provide additional absorption.

The general fragility of commercial sound absorbents may necessitate added precautions for their protection during athletic activity. It is unlikely that any such panel could sustain a direct hit from a basketball for instance, much less repeated direct hits. Unless very durable absorbents are available, therefore, it may be necessary for musicians to use the adjustable draperies in the upper portions of rear walls for absorption during concert performances. An analysis of Knudsen's tabulated results on coefficients, however, indicates that this solution could result in over absorption at high frequencies.[36] The relatively uniform absorbing surface so created would also reduce the sound diffusion that would have been achievable through a random positioning of the commercial panels. It is suggested, therefore, that durable absorbents be purchased if possible, or that a wire mesh be installed around the panels if this can be achieved without incurring excessive expense or creating an unsightly appearance.

Reflection and Diffusion

The pioneer research of W.C. Sabine in the field of room acoustics laid considerable emphasis on the role of reverberation in determining the quality of acoustics in enclosed spaces. The subsequent eagerness of building material manufacturers to assist architects in the acoustical treatment of rooms with sound absorptive materials, led to "a tendency to regard the control of reverberation time as the

dominant and almost determining element in room acoustics, and . . . to give too little regard to other important aspects of design, such as shape and size."[37] Blend and balance are the two musical phenomena most significantly enhanced or destroyed by a room's shape, and hence its reflection patterns.[38] This is particularly true of the stage or 'sending' area. Reflection patterns in the receiving area also govern the clarity with which musical detail is heard, by the degree to which they reduce echo, flutter, sound foci, or dead spots. A careful shaping of the concert shell and a modification of the traditionally rectangular gymnasium will therefore need to be undertaken to ensure a well defined, balanced, and blended reception of music by all listeners.

Stage Location and Design

In addition to the need to locate the stage close to the music instruction area for purposes of ease of transportation and communication, the stage should be situated at one end of the gymnasium, facing down the length of the room. Johnson indicates that "a wide hall is unsatisfactory for . . . music because the long delayed acoustic reflections from widely spaced side walls arrive too late to integrate with the direct sound," and specifies a width of 65 to 75 feet as sufficient for optimum reflection characteristics.[39] Moreover, as was noted previously, long, narrow halls have throughout history generally elicited the most favourable responses from audiences.

The total size of the stage area must be determined from the standpoint of expected use by drama as well as music personnel. Because the scope of this study encompasses only what is acoustically desirable for musical performance however, all reference to stage size will be

made in terms of the area occupied by musicans only. The total floor
space required by performing musical groups should be calculated to
accommodate the largest organization expected to be using the facility.
This group will usually be the band or orchestra inasmuch as choral
ensembles do not require chairs, stands or instruments, and can be
placed on the stage more compactly. In Chapter Four it was shown that
a floor area of about 20 sq ft per performer was the allotment generally
preferred by instrumental directors for rehearsal rooms. Since musi-
cians can be arranged somewhat more compsctly on the concert stage, this
amount of space may include an additional forestage area.

It will be assumed that a band or orchestra not exceeding 100
members is to be accommodated on the stage, though larger organizations
are not uncommon. A 100 member instrumental group could then be expec-
ted to comfortably occupy approximately 2000 sq ft of stage floor space.
(Commercially manufactured riser sets have been advertised, incidentally,
which will seat instrumental groups of this size in as little as 1500
sq ft, including a 10 foot forestage area).[40] This floor space then
forms the base of an enclosure which will be used to project sound from
the stage to the audience.

This enclosure is commonly referred to as a concert shell and
completely surrounds the performing groups except at the stage opening,
or proscenium. A stage designed for multi-purpose use—drama, public
speaking, music—will not contain a permanent concert shell but should
be built so that a demountable shell can be readily incorporated into
its structure. If the stage is not to be used for dramatic presenta-
tions, the construction of a permanent shell will greatly reduce the

time required to prepare the stage for a musical performance, and will permit the use of heavier panelling in the shell. Whether permanent or demountable, a shell must be considered an essential component in concert auditorium design. Part of the shell should reflect each musician's sound to every other performer in order that performers may balance their individual sounds with that of the ensemble, and part of the shell should reflect this sound to the seating area in a way which ensures a balanced reception by the listeners.
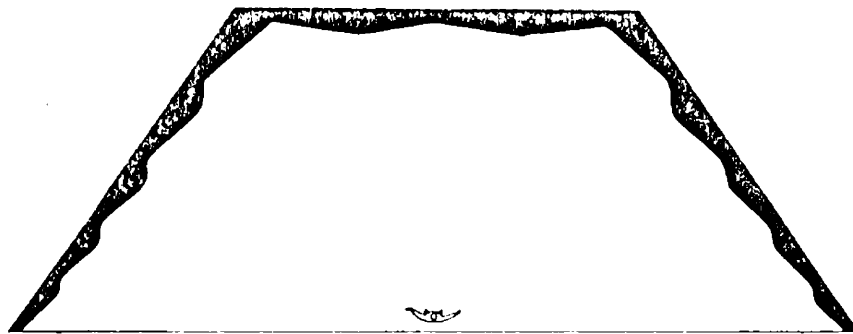

Fig. 5.3.—Floor plan for a concert shell, showing splayed side and back walls

The 2000 sq ft floor area should be shaped as a trapezoid with sides diverging toward the proscenium as illustrated in Figure 5.3. The proscenium opening should not exceed approximately 65 feet in width, though the shell opening will probably not require a width greater than about 50 feet. The shell depth should range between 30 and 40 feet. The angle of the side walls is then determined by the square footage desired in the enclosed floor space. The generally recommended 30 foot proscenium height[41] obviously cannot be realized in a gymnasium with a 23 to 26 foot ceiling. The alternative is to build the proscenium to a

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height which is only slightly lower than the gymnasium ceiling, and allow the ceiling over the shell to slope downwards to the back of the shell as shown in Figure 5.4. The shell ceiling should then be extended to the gymnasium ceiling in the form of a canopy, illustrated in Figure 5.5 as part of an auditorium. This design would help integrate the stage and audience areas into a one room auditorium, a design which greatly enhances communication between the sending and receiving ends of the hall.
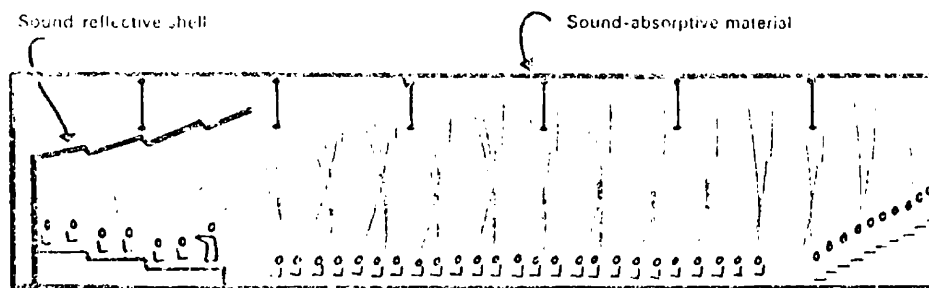
GYMNASIUM ARRANGED FOR A CONCERT

Fig. 5.4.[42]—Cross section of a gymnasium showing a splayed stage ceiling design for integrating receiving and sending areas

The side wall, back wall, and ceiling irregularities illustrated in Figures 5.3 and 5.4 are essential for the reflection of sound to all musicians within the performing area, and uniformly to all points in the receiving area. Wall panels may be joined together but ceiling units will need to be separated somewhat to allow space for suspended lighting fixtures.

A balanced reception of sound by all persons in the auditorium cannot be achieved simply by diffusing the sound with irregular shell
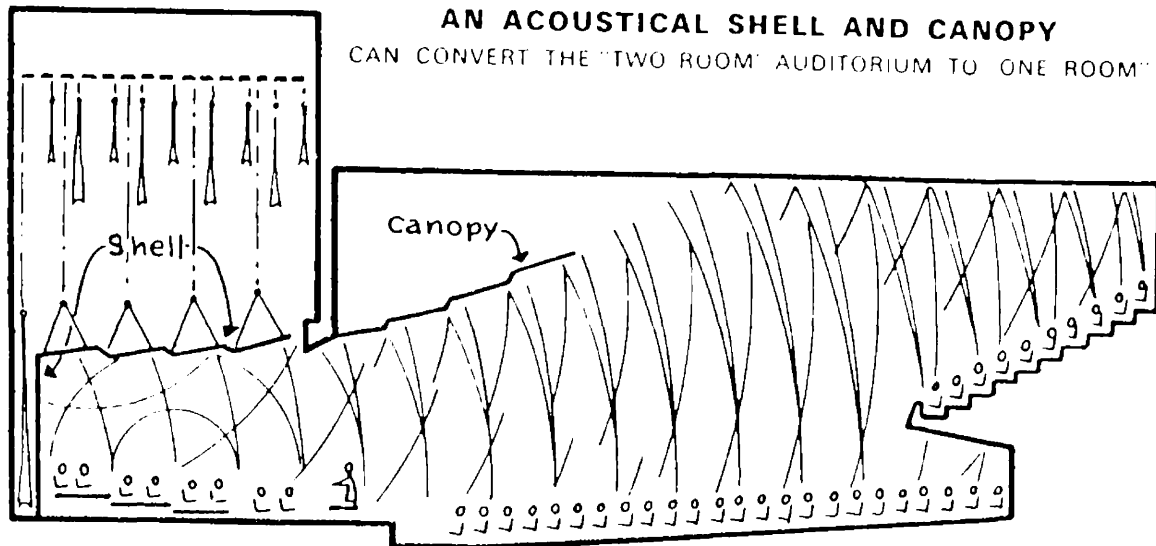
AN ACOUSTICAL SHELL AND CANOPY
CAN CONVERT THE "TWO ROOM" AUDITORIUM TO "ONE ROOM"

Shell

Canopy

Fig. 5.5[43]—Cross section of an auditorium, illustrating the use of
a shell ceiling and a canopy for integrating the auditorium and its
'coupled' shell space into a single room

surfaces. Balance also involves the reception of all frequencies in a

proper proportion and is best realized when the surfaces of the shell

are made of very heavy wood panelling. Thin panelling, as has been

noted, absorbs low frequencies efficiently, but will reflect high fre-

quency sound and thus create an unpleasantly brilliant sound texture

due to an over-emphasis of upper partials. Although heavy wood panel-

ling is both uneconomical and unwieldy where demountable shells are

concerned, commercially built wall and ceiling units are available

which combine plywood with medium density plastic for satisfactory

projection of high and low frequencies.[44] These units are also mounted

on wheels and built to nest into a compact storage space.

Because of the necessity for an unsloped floor in the gymnasium,

sight lines will be unsatisfactory unless the stage floor is excessively

high. Visual communication should be adequate, however, if the stage

floor is $3\frac{1}{2}$ to 4 feet above the playing floor, and will be further

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enhanced if the performers stand or are seated on risers. Raising the platform will, in addition, create storage space under the stage for audience chairs stored on trucks.

Modifying Gymnasium Shape and Surfaces

A considerable portion of Chapter Four was devoted to explanations of the relation between parallel room surfaces and the presence of echo, flutter, and standing waves produced by reflections between these parallel surfaces. In order to eliminate these negative acoustical conditions in the gymnasium, the traditional rectangular shaping of the room and paralleling of all opposing surfaces will require modification.

The ceiling

Because of the necessity for the gymnasium floor to remain horizontal, the ceiling should be inclined upwards toward the back of the room, until approximately the mid point where it should begin a slight downward slope which is somewhat increased in the last few feet of ceiling, particularly if the floor area is to remain an uncarpeted, highly reflective surface. Inclining the ceiling in this way will not only prevent the occurrence of disturbing reflections between the floor and ceiling, but will reflect sound toward the rear of the auditorium as illustrated in Figure 5.6.

The ceiling may also be used to diffuse sound if adequate means for scattering sound about the room are not provided in the wall and floor areas. Where possible, the ceiling should be utilized for advantageous reflections such that the farther a listener is from the source, the greater the amount of sound reflected to him. "A rough rule is that

two-thirds to three fourths of the ceiling reflecting area should

reflect sound to the half of the audience farthest from the sound

source."[45] Reflections from the ceiling to forward sections of the

auditorium would not only create unnecessary reinforcement in this area

but could elicit echoes, particularly when these reflections originate

in rear sections of the ceiling. An echo is created when the difference

between the path length of a direct sound and that of a reflected sound

exceeds 65 feet, though annoyances can result when the difference is as
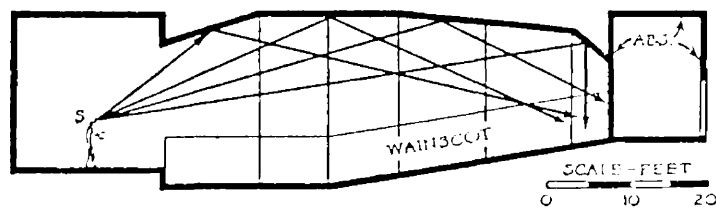
little as 50 feet.

Fig. 5.6.[46]—The ceiling should be construc-
ted to reflect sound to the rear half of the
auditorium

The ceiling described above should take the form of panels sus-

pended from the structural roof in conformity with the configuration

outlined. This design would conceal the roof's steel beams and thus

eliminate both their unsightly appearance and their potential for

creating unwanted reflections toward the stage. If diffusion is to be

achieved through reflections in the ceiling, the panels should be

installed in a splayed pattern, but should not be dropped any farther

than necessary, both to protect them from misdirected sports equipment

and to conserve as much of the room's volume as possible.

Side walls

It was noted that an extension of the shell ceiling into the auditorium by means of a canopy would contribute to the integration of shell and gymnasium into a one-room unit and thereby enhance communication between performer and listener. A similar, highly reflective lateral extension of the shell's side walls through the use of angled walls in the forward part of the gymnasium (see Figure 5.7) will similarly unify the two spaces. A floor and ceiling plan of this type is general practise for auditoriums of all sizes and should be adaptable to a gymnasium without interference either to the playing area or to equipment such as basketball hoop and backboard structures, though this latter would require careful integration with the canopy. Halls which widen abruptly at the proscenium do not project sound waves through a wide angle and thus cause people in front sections of the auditorium to be deprived of important reflections.[47]

The remainder of the side walls should serve three functions: to direct sound waves to reinforce sound reaching the back of the auditorium, to reflect sound downward into all parts of the audience, and to diffuse sound through randomly scattered reflection patterns. The basic floor plan should include side walls diverging toward the rear of the hall, particularly for purposes of diffusing reflections from the closed bleacher surfaces, inasmuch as these surfaces cannot be splayed. Splaying refers to the application of irregular reflecting surfaces to a basically flat surface in order to increase the number of angles at which sound is reflected. If the divergence is too great, spectator discomfort during athletic events will result from awkward viewing
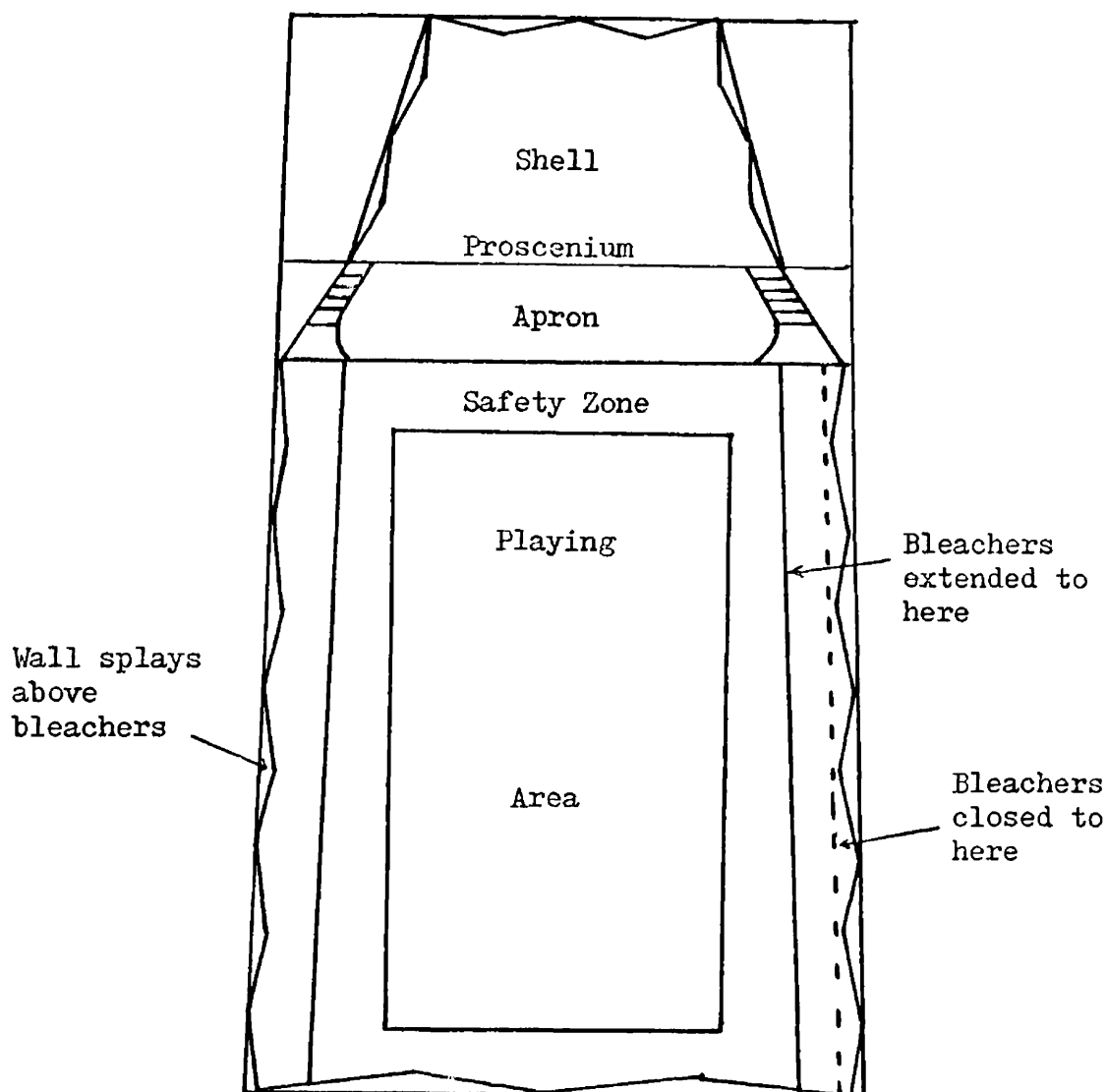
Fig. 5.7.—Suggested floor plan of the stage-gymnasium showing overall proportions, wall splays, method of extending shell walls into auditorium

angles; if too little, flutter echo and standing waves may occur between

side walls. A total deviation of about 6% from the parallel (3% for

each wall)[48] appears to be a divergence which would prove satisfactory

to both concert and athletic audiences.

If random spacing of absorbent materials in the upper side walls

is combined with a type of splaying illustrated in Figure 5.7, suf-

ficiently adequate acoustic conditions should result. If the splayed

surface, a false wall attached to the structural wall, is also inclined inward however, the inclination will have the additional advantage of directing useful reflections upon the audience.

The rear wall

The most critical acoustical problem arising from the presence of a vertical rear wall is the production of echoes in forward sections of the auditorium through long delayed reflections originating at the back wall. These reflections can be prevented only partially by the installation of sound absorbent materials in the wall, the ultimate solution requiring a type of splaying which will reflect sound to an area no farther forward than the last 30 feet of the gymnasium. This can be accomplished by the installation of splays which will reflect sound in both downward and lateral directions, but which will also absorb a large percentage of the incident sound.

The rear wall of a gymnasium is a considerably larger reflecting surface than that of a concert hall of comparable proportions, owing principally to the presence of one or more sound absorbing balconies in the latter. The upper portions of the rear wall of a gymnasium may need either to be totally absorbent, or to require splays which will reflect sound almost directly downward. The latter option may require splay projections of such magnitude as would render them vulnerable to damage during athletic activity. A third option would be to extend the rear floor area of the gymnasium and install upholstered, or at least highly sound absorbent, seating in a pattern similar to that illustrated in Figure 5.4, and thereby reduce the amount of vertical reflecting sur-face while providing additional audience seating space.

Auditorium Noise Control

The primary requisite for noise control in the vicinity of the auditorium is the establishment of good listening conditions for the audience, rather than the control of sound escaping to other parts of the school. During school hours, the gymnasium-auditorium will generally be occupied by the athletic department, and the control of sound transmission from this space should be determined in accordance with standards governing the isolation of sounds created by athletic activity. When musical performances are held in the gymnasium, it is probable that a large proportion, if not all, of the school population will be present, in which case the projection of musical sound into school halls and nearby classrooms will not be a major concern. If frequent musical activity or rehearsal is expected to occur here while other classes are in session, however, it may be necessary to consider isolating the gymnasium in a manner similar to that described for music rooms in Chapter Three.

Acoustical conditions for concert performance will be optimum only when noise levels in the auditorium are very low. If the gymnasium is designed to reinforce through reflection, all dynamic levels of music in all sections of the audience, it would be inconsistent to permit any portion of this carefully reinforced sound to become masked by back-ground noise. There is general agreement among acousticians that satis-factory conditions will exist if noise from all sources except the audience does not exceed 35 db; if the highest standards of acoustics are required this level should be reduced to 30 db.[49] A more precise measurement of maximum acceptable noise is shown in Figure 5.8 and

involves deviations from the above stated average based on the frequency of the source sound.
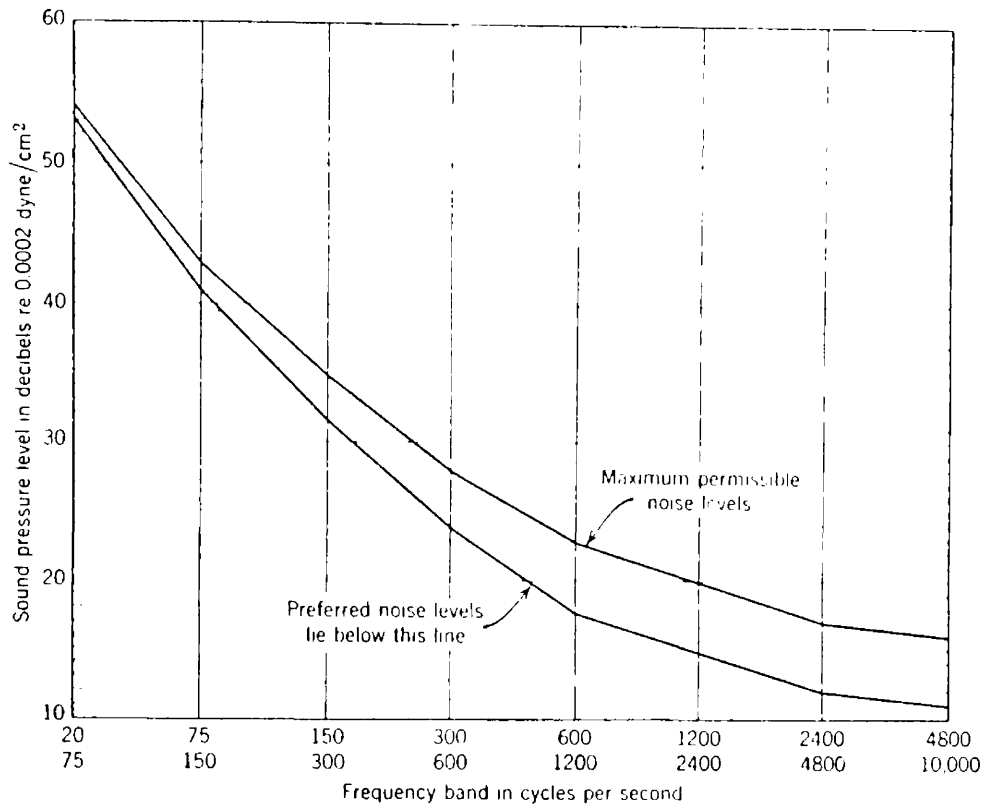

Fig. 5.8.[50]—The range of acceptable noise levels in concert halls, as measured in a hall without audience

The least expensive way to eliminate incursions from outside the auditorium is to locate the facility in a quiet environment, remote from other school activity, traffic noise, or industrial disturbances. Knudsen and Harris indicate that the sound level of the environment in the vicinity of the auditorium should not exceed 70 db.[51] Unavoidable detrimental locations such as those close to the flight path of a nearby airport for instance, may result in occasional disturbing noise levels which cannot be economically isolated. In such cases a TL of 60 db must be achievable in the room's peripheral structures[52] as described in

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Chapter Three.

The most disturbing source of noise originating within the auditorium is that which can be produced by the ventilation system. Air cannot be removed more than 300 feet per minute without creating noise, and must be moved much more slowly where a considerable number of obstructions are present.[53] In addition, ventilation grilles will need to be large and all channels lined with an efficient absorbent, if sufficient attenuation is to be achieved within the mechanical apparatus. Where further precautions are required, detailed explanations have been given in prevoius discussions relating to the music department.

Noise created by movement in the audience will likely raise the total noise level of an auditorium to approximately 40 db.[54] Though much of this sound will not be controllable, the use of chairs of sturdy construction, the application of removable carpeting on the floor, and the avoidance of the use of bleachers during concerts will reduce audience related noise appreciably.

<u>Summary</u>

Although gymnasiums are almost universally considered to be inherently unsuitable for musical performance, despite modification, the fact remains that this is the only concert hall available to a great number of school music organizations. For this reason, the various ways in which the gymnasium may be transformed into a suitable auditorium was investigated.

The general length-to-width ratio of a gymnasium's playing area approximates 2:1, a ratio which progressively approaches that of a

perfect square as lateral bleacher space is increased. If a space the
size of a junior high instructional gymnasium (play area = 54' x 90')
is increased by the addition of five rows of bleachers along the sides
of the play area for the full length of the room, and by the extension
of one end of the gymnasium to include a stage with a 30 foot depth,
the resultant dimensions (70' x 120') would approximate the 1.5:1 ratio
shown in the research to be most suitable for musical purposes. A
ceiling height of 23 feet would then create a room volume of 144,900
cu ft (stage area excluded), a cubage which approaches the upper limits
recommended for high school auditoriums. If 180 cu ft per person were
allowed, approximately 800 persons could be accommodated in this space,
a quantity which could also be comfortably seated if a recommended 6.5
sq ft of floor space were allotted per person, aisles included. The
bleacher space indicated above would seat a maximum of 570 spectators
for athletic events.

The optimum average reverberation time for a 144,900 cubic foot
concert hall is about 1.3 seconds, the RT increasing to a desirable 1.6
seconds for low freqencies and perhaps 1.4 seconds for high pitch levels.
Because the audience forms the greatest area of absorption, these
measurements should be based on acoustic conditions which exist with
an audience present.

In order to achieve a reverberation time which does not fluc-
tuate greatly with differences in audience size, removable sections of
carpeting and chairs with padded backs should be used. It is suggested
that low frequency absorption by bleacher surfaces be investigated to
determine whether these seats may form a satisfactory wainscot; if

additional low frequency absorption is needed, commercial materials are available which are most efficient at these pitch levels. The only remaining areas designated for absorption should be the upper portions of the back wall and rear side walls. All absorbents will need to be durable enough to withstand possible damage during athletic activity.

A concert shell should be incorporated into the stage design, which has a width no greater than 65 feet and a maximum depth of 40 feet, the total space requirements being determined by an allotment of 20 sq ft per performer. The ceiling should slope upwards to the top of the proscenium and extend to the gymnasium ceiling in the form of a canopy. Gymnasium side walls should diverge toward the back wall at a 3 degree angle, and the area above the bleachers should have an inward inclination of approximately 5/8 inch per foot. All surfaces in the shell, the suspended gymnasium ceiling, and forward parts of the side walls should be splayed and highly reflective in such a way as to achieve maximum sound diffusion, and masimum sound reinforcement in rear sections of the audience seating area. Reflecting panels on the back wall must ensure that reflected waves from this surface reach only the audience area contained in the last 30 feet of the auditorium.

The total amount of background noise in the gymnasium-auditorium should not exceed 35 db and should ideally be reduced to 30 db. Outside domestic noises are controllable by locating the concert hall in a quiet environment, or by using highly insulative room structures if environmental noise exceeds 70 db. Mechanical noise from the ventilation system can be kept within satisfactory limits by designing ducts with large apertures and by lining all channels with an absorbent material.

Audience noise is only partially controllable, but this limited control

can be maximized by the use of removable floor carpeting and chairs

which are noiseless during normal audiance usage.

Chapter 5

1. A. F. B. Nickson and R. W. Muncey, "The Acoustic Conditions Accepted by Listeners in an Auditorium," _Acustica_ 9 (1969):319.

2. Carl J. Rosenberg, Manager, Architectural Technologies Department, Bolt, Beranek and Newman Inc.; see personal letter in Appendix A.

3. Homer Ulrich et al., _Music Buildings, Rooms, Equipment_, 5th ed., edited by Charles L. Gary (Washington D.C.: Music Educators National Conference, 1966), p. 39.

4. Kenneth Penman et al., "Reverberation and Noise Levels in Sports Areas," _Journal of the Acoustical Society of America_ 62 (October 1977):1046-48.

5. W. I. Blundell and L. B. Perkins, "The School Auditorium—Its Purpose and Design," _American School and University_ 25 (1953):274.

6. Vern O. Knudsen and C. M. Harris, _Acoustical Designing in Architecture_, (New York: John Wiley and Sons, 1950), p. 185.

7. Leo L. Beranek, _Music, Acoustics & Architecture_, (New York: John Wiley and Sons, Inc., 1962), p. 450.

8. Willi Furrer, _Room and Building Acoustics and Noise Abatement_, trans. Evelyn R. Robinson and Peter Lord (London: Butterworth and Co. Ltd., 1964), p. 109.

9. Knudsen and Harris, _Acoustical Designing_, p. 182.

10. Nickson and Muncey, _Acoustic Conditions_, p. 319.

11. The relation between room volume and reverberation, and the effect of room shape on the clarity with which music is heard, are discussed in Chapter Four. Good room acoustics are described there as being primarily a function of room volume and shape.

12. T. P. Banks et al., _Planning Areas and Facilities for Health, Physical Education and Recreation_, (Washington D.C.: The Athletic Institute and American Association for Health, Physical Education and Recreation, 1966), pp. 84-99.

13. Blundell and Perkins, _The School Auditorium_, p. 273.

14. Russell Johnson, "Acoustical Design of Multi-purpose College Auditoriums," _American School and University_ 34 (1962):H6.

15. Knudsen and Harris, Acoustical Designing, p. 306. This figure was calculated by dividing the room volume of 50,000 cu ft by the recommended seating capacity of 300.

16. Harold Burris-Meyer and Lewis Goodfriend, Acoustics for the Architect, (New York: Reinhold Publishing Corp., 1957), p. 63.

17. Paul Sabine, Theory and Use of Architectural Acoustical Materials, (New York: Acoustical Materials Association, 1950), p. 13.

18. Vern O. Knudsen, Architectural Acoustics, (New York: John Wiley and Sons, Inc., 1932), pp. 433, 34.

19. Beranek, Music, Acoustics and Architecture, p. 497.

20. Elwyn Carter et al., Music Buildings, Rooms, Equipment, 4th ed., (Washington D.C.: Music Educators National Conference, 1955), p. 22. The recommendation by Homer Ulrich et al. in the 5th edition of this publication appears to be an unrevised statement from the 4th edition.

21. Knudsen and Harris, Acoustical Designing, p. 182.

22. Furrer, Acoustics and Noise Abatement, p. 72.

23. Ibid.

24. Knudsen and Harris, Acoustical Designing, p. 185.

25. Burris-Meyer and Goodfriend, Acoustics for the Architect, p. 113.

26. After Knudsen and Harris, Acoustical Designing, p. 194.

27. Ibid., p. 195.

28. Burris-Meyer and Goodfriend, Acoustics for the Architect. pp. 48, 51, 113, 121.

29. Beranek, Music Acoustics & Architecture, p. 486.

30. Burris-Meyer and Goodfriend, Acoustics for the Architect, p. 63.

31. Ibid., p. 48.

32. Knudsen and Harris, Acoustical Designing, pp. 174, 186, 307.

33. Ibid., p. 197.

34. Beranek, Music, Acoustics & Architecture, p. 438.

35. See "Summary of Absorption Coefficients" by Knudsen, Architectural Acoustics, pp. 198-224.

36. Ibid. Compare absorption coefficients for draperies (p. 212) with those of other materials in the tabulation.

37. Knudsen and Harris, Acoustical Designing, p. 181.

38. Christopher Jaffe, "Sound Improvement Via the Acoustical Shell," The Instrumentalist 20 (February 1966):40.

39. Johnson, Multi-purpose Auditoriums, p. H9.

40. This area was calculated using dimensions given in Bulletin SM9-177 from the Wenger Corporation, Owatonna, Minnesota.

41. Ulrich, Music Buildings, p. 71.

42. After "Performing Area Acoustics," a bulletin published by Wenger Corporation, Owatonna, Minnesota.

43. After Ulrich, Music Buildings, p. 71.

44. These units are advertised in Bulletin SM-6-672 published by Wenter Corporation, Owatonna, Minnesota.

45. Burris-Meyer and Goodfriend, Acoustics for the Architect, p. 85.

46. After Knudsen and Harris, Acoustical Designing, p. 309.

47. Beranek, Music, Acoustics & Architecture, p. 468.

48. Knudsen and Harris, Acoustical Designing, p. 187. This deviation was derived from a similar recommendation of 5/8 inch per foot for inwardly-slanting walls, the purpose for the slant being identical to that for horizontal wall divergence.

49. See Furrer, Acoustics and Noise Abatement, p. 47; Knudsen and Harris, Acoustical Designing, p. 175, 308; and Ulrich, Music Buildings, p. 35, for recommended auditorium noise levels. The suggestions from each source vary from each other only slightly.

50. After Beranek, Music, Acoustics & Architecture, p. 456.

51. Knudsen and Harris, Acoustical Designing, p. 329.

52. Ibid., p. 310.

53. Ulrich, Music Buildings, p. 77.

54. Knudsen and Harris, Acoustical Designing, p. 175.

CHAPTER SIX

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

Academic class areas require complete isolation from sounds generated in music rooms due to the psychological 'intelligibility' which characterizes rhythm and pitch in musical sounds. The least audibility of these sounds will cause the hearer to attend to the sound and thus to be distracted from his focus of concentration. Music rooms do not require the same degree of isolation from each other inasmuch as music education involves physical activity whose sound will mask out a portion of the sounds intruding from adjacent rooms. The level of acceptable background noise will vary with the type of music room, depending on whether the room is to be used solely for performance or if instruction is to be included (see Tables 3.6 and 3.7).

Sound transmission should be controlled first by achieving optimum absorption of the source sound within the room where it is produced. The second requirement is the construction of walls, ceilings, doors, and windows as structurally isolated double units with intervening air spaces. Finally, the arrangement and acoustical treatment of ventilation ductwork should guarantee the same degree of isolation between rooms as is achieved by the partitions separating them.

The size of a rehearsal room is determined by the volume-per-person requirements of choral rooms and instrumental rooms, though these

spaces should be no smaller than 20,000 cu ft and 30,000 cu ft respectively. Small music room sizes are governed by the amount of equipment or the number of people expected to occupy the space (see Table 4.2).

The optimum reverberation time (RT) of a music room is calculated as a function of both room volume and sound frequency. The RT is stated as an optimum for mid frequencies with a 25% increase recommended for low frequencies and a 10% increase suggested for high pitch levels. Reverberation is controllable by a balanced absorption of sound at each of these frequency levels.

Reflected sound is acoustically advantageous when it is diffused, thus creating an equal distribution of sound throughout the enclosure. Acoustically detrimental reflections such as sound foci, dead spots, flutter, and standing waves, are created by the presence of parallel room surfaces and concave structural curvatures, and can be eliminated both by avoiding these designs and by the use of irregular room shapes, splays, and randomly spaced sound absorbents. Echoes are elicited in auditoriums when the path length of a reflected sound is 65 ft longer than that of directly received sound, and can be avoided through careful room shaping.

Because the gymnasium is frequently the only concert hall available to school music organizations, a modification of its basic shape, size, and sound absorbing characteristics should be undertaken to ensure listening conditions which will be satisfactory for musical performances. An approximate length-to-width ratio (stage and bleacher space included) of 1.5:1 has been revealed in the research to be an auditorium dimensional pattern which historically has elicited the most favourable

auditory responses from experienced concert listeners. The total gymnasium volume (stage excluded) should probably vary between 100,000 and 150,000 cu ft, the optimum reverberation time varying proportionately for all frequencies.

The area of greatest sound absorption in an auditorium should be the floor, with its seats and audience. In order to minimize the fluctuation in reverberation which would occur with variances in the audience size, it is suggested that readily removable, portable carpeting be used to cover at least the aisles and other exposed floor areas, but preferably the entire audience floor space. Other areas to be considered for sound absorption include the upper rear wall, back portions of the upper side walls, and the exposed bleacher surfaces for low frequency absorption.

All surfaces within the shell, in the front part of the auditorium, and in the ceiling should remain highly reflective, both to reinforce direct sounds reaching rear sections of the auditorium, and to diffuse sound within the shell and in the audience seating area. The walls and ceiling of the concert shell should diverge toward the receiving area, and this divergence should continue in each of the auditorium side walls as well as in the forward part of the ceiling in the form of a 'canopy'. Upper side walls should have an inward, splayed slant, and the auditorium ceiling should be a series of panels suspended from the structural roof, in a manner that will both diffuse sound and reflect it rearward. The rear wall should be highly absorbent over most of the surface but may also be used to reflect sound to the back 30 feet of the auditorium.

Background noise caused by environmental disturbances or by the mechanical apparatus of a ventilation system should not exceed 35 db, though noise from movement in the audience will raise this sound level to perhaps 40 db. The use of floor carpeting, acoustically lined ducts, and highly insulative wall and ceiling structures may need to be considered if the necessary reduction of noise is to be achieved.

Conclusions

The architecture which constitutes a facility for the teaching and performance of music cannot be considered complete or even satisfactory where the design does not contribute to adequate sound isolation between rooms and to optimum listening conditions within rooms. It is important to understand that optimum acoustic conditions can be realized if care is taken to study the literature and research available on architectural acoustics where it relates to school music facilities, if the school administration and music directors are requested to assist with the planning, and if the services of an acoustical engineer are engaged in a way which gives them a priority at least equal to the services of the architect.

The information and recommendations contained in this study are based on successful experiences in designing for music education, and on half a century of refinement in the science of acoustics. The content of the study indicates that adequate acoustical results have been achieved within school music departments, and forms a base upon which preliminary planning can be established.

Recommendations

Due to the extent to which gymnasiums are used as concert auditoriums, it is suggested that additional research be conducted which will reveal ways in which acoustical conditions satisfactory for the performance of music, can be economically realized in gymnasiums without jeopardizing the environment required for athletic activity. In particular, it will be most important to: (a) devise a method for achieving absorption in the floor area which will not fluctuate significantly with differences in audience size and which will not be cumbersome to utilize, (b) develop or identify sound absorbents which can withstand possible damage from sports activity, and (c) determine the extent to which bleacher surfaces absorb low frequency sound, and if insufficient, develop bleacher equipment which can double as a low frequency absorbing wainscot.

Secondly, it is suggested that future research similar to that contained in this study, be undertaken with a larger sample of music rooms than was available in the research consulted, and with a more extensive investigation of the rating of these rooms by musicians. The psychoacoustic effects of background noises in particular, need to be more conclusively determined.

A final recommendation relates to the way in which this and other related studies may be used. It must be emphasized that the acoustician can be of greatest assistance only when he receives knowledgeable input from school personnel, particularly music directors, as to desirable room sizes, reverberation times, transmission loss, and sound reflection patterns. In this study, information is presented

which is basic to the acoustical design of school music rooms, yet

which is flexible enough to be adaptable to many types of plans. Where

a rationale, background, or philosophy is desired to substantiate each

recommendation, the central discussions of each major chapter can be

consulted. Where only the acoustical data and recommendations need to

be consulted, these are available in each of the summaries, or tables

and illustrations referred to in the summaries.

Bolt Beranek and Newman Inc.

31 January 1978

Mr. Murray Hodges
1040 Yreka Court
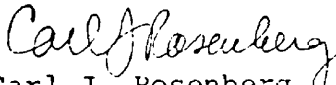Missoula, Montana 59801

Dear Mr. Hodges:

In response to your letter of 17 January 1978, I can appreciate
the difficulty you may be having in pulling together research
on school gymnasiums used as auditoriums. BBN has not conducted
particular research in this area, although we do deal directly
with this problem and the others you mentioned quite often. In
general, whenever a building owner or architect proposes a multi-
purpose space as a way to save money, we caution him that this
will invariably create a compromise solution in terms of acoustics
which is less than ideal for any one purpose.

The most useful reading matter I could recommend would be the
general architectural acoustics texts noted on the attached
bibliography. I know of no studies or papers which focus on
just the applications you have in mind; the closest article that
comes to mind is "Reverberation and Noise Levels in Sports Areas"
by Penman et al, in the October 1977 issue of the Journal of the
Acoustical Society of America. I have copied and enclosed that
excerpt for you.

If, during the course of your research, you find specific questions
which arise, we will be glad to try to answer them for you.

Sincerely yours,

BOLT BERANEK AND NEWMAN INC.

Carl J. Rosenberg
Manager, Architectural Technologies Department

CJR:mf

Encl: Bibliography
       Article

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