NATIONAL BUREAU OF STANDARDS REPORT

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DISCUSSION OF ACOUSTIC ENVIRONMENT GUIDE CRITERIA FOR THE DESIGN AND EVALUATION OF OPERATION BREAKTHROUGH HOUSING SYSTEMS

prepared by

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NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Technical Report to
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1. Introduction

The discussion contained in this report is intended to assist the Operation BREAKTHROUGH housing system producers, DHUD officials, and other interested parties by providing further clarification of the guide criteria for the design and evaluation of the acoustic environment in Prototype Housing for the Department of Housing and Urban Development's "Operation BREAKTHROUGH".

Much of the explanatory material in this report is drawn from the document, "A Guide to Airborne, Impact, and Structure Borne Noise -- Control in Multifamily Dwellings" [1][1/], which was prepared by the National Bureau of Standards several years ago for the Federal Housing Administration, U.S. Department of Housing and Urban Development. The reader is strongly urged to consult this guide for a detailed discussion of the many factors which come into play in the provision of an adequate acoustic environment in multifamily dwellings.

2. Background Information

The accelerated growth and increasing severity of the noise problem in multifamily dwellings has caused considerable concern not only among apartment occupants and owners, but also among investors, real estate interests, and governmental agencies.

The current building trend toward lightweight structures, the increasing concentration of dwellings in urban areas, and the increasing noisiness of our environment have led to a growing number of complaints to the FHA of inadequate sound insulation in multifamily dwellings. People have become aware of the noise problem and are more sophisticated in their appreciation of the benefits which careful attention to noise control can provide; therefore they expect and demand more privacy in their homes and greater freedom from the intrusion of noise from neighboring dwellings.

Although the building industry takes justifiable pride in its achievements, conventional building techniques have produced some of the noisiest buildings in existence.

Major property management firms report that noise transmission is one of the most serious problems facing managers of apartment buildings throughout the country. Managers and owners of apartments readily admit that market resistance is not only increasing as a result of excessive noise transmission, but also that lack of both acoustical privacy and noise control are the greatest drawbacks to apartment living.

[1/] Figures in brackets indicate the literature references at the end of this report.

The basic causes of the noise problem and the major reasons for complaints are due primarily to the following factors:

1. Lightweight building structures: These provide substantially less sound insulation than their more massive counterparts of the past.

2. Poor acoustic design: Site selection and the design and/or layout of interior rooms or spaces without regard to noise sources or to separation of noisy areas from those requiring privacy usually result in or intensify noise problems. This often results from ignorance or neglect of noise control principles.

3. Poor workmanship: Planned sound insulation is often nullified by improper sealing of large cracks, holes, air leaks around wall and floor edges, etc.

4. Mechanization: Increased use of mechanical appliances has raised the background noise level.

5. High rise apartments: This results in a greater concentration of people in a much smaller area resulting in greater interfamily friction unless appropriate counter-measures are taken.

6. Increasing desire for privacy and a high quality of living: Former residents of private dwellings now living in apartments want and expect acoustical privacy similar to that encountered in their former dwellings. Furthermore, the growing national concern with the quality of life has resulted in greatly increased expectations as to the type of environment which a dwelling should provide.

The most prevalent complaints among apartment dwellers involve the transmission of noise originating inside the building. Typical noise sources are television, radio, stereo, occupant activity, plumbing fixtures, electro-mechanical equipment, and household appliances. Exterior noises, particularly from transportation systems and construction work, also lead to considerable annoyance. Luxury, middle, and low income apartments register approximately the same number of complaints because most of the buildings utilize the same type of wall and floor assemblies.

These are the problems that the acoustic environment guide criteria for Operation BREAKTHROUGH are intended to alleviate. By citing lightweight building structures, increased mechanization, and the prevalence of high-rise construction, as causes of the noise problem, there is no intent to deprecate these trends in architecture and construction. Rather the intent is to point out that modern buildings require more specific attention to noise control than did the massive constructions of the past.

Many buildings constructed before World War II were built with 8 to 12 inch thick concrete floor slabs and utilized massive partitions as room separators. Thus considerable attenuation of noise between dwelling units was provided. Furthermore, these buildings did not have to cope with the sounds from an abundance of mechanical appliances and equipment, and the amplified sounds from radio, television, and high-fidelity audio equipment.

With the current trends toward lightweight construction and an increasing number of noise sources, it is clearly evident that architects, engineers, and builders must pay specific, and often detailed, attention to the development and incorporation of noise control techniques which are compatible with modern building designs and construction methods. Otherwise, the acoustic environment will be seriously inferior to that which many buildings provided several decades ago. In an era characterized by a burgeoning demand for improved environmental quality, such a deficit almost certainly would lead to serious dissatisfaction and vigorous complaints from the tenantry.

3. Basic Characteristics of Noise Transmission

A brief synopsis of basic physical principles and concepts relevant to noise control is given in Appendix A; a list of acoustic terms and their definitions is given in Appendix B. Following is a list of some of the more important facts to remember when dealing with noise transmission in buildings:

1. A sound wave in open air travels radially in all directions at a speed of approximately 1100 feet per second, with a wave front that is usually spherical in shape.

2. The sound pressure level of a sound wave in open air falls off inversely as the square of the distance from a point source, i.e., there is a drop of about 6 dB with each doubling of the distance from the source.[2/]

[2/] dB is the abbreviation for decibel, the unit of sound pressure level (see Appendices A and B).

3. In hard-surfaced unfurnished rooms, ordinary sound may build up to annoying levels and may be distorted by excessive reverberation due to the multiple reflections of the sound waves. For this reason, noise from conversation and foot traffic in reverberant hallways is much louder than in open areas outside of the building.

4. Airborne sound penetrates more readily through light porous materials and lightweight structures than through heavy, massive masonry materials or structures.

5. The direction of propagation of a sound wave may be changed by reflection from wall or other building surfaces. This explains why noise is often transmitted great distances in long winding corridors or duct systems.

6. Sound travels easily through small cracks and openings such as those normally found under doors and around windows.

7. Mechanical energy from an impacting body or a vibrating source, which is imparted directly to a solid structure, travels at a higher speed, with less attenuation and generally over a much longer distance than an airborne sound wave of the same initial energy. For example, in materials such as wood, metal or stone, the speed of sound may be as high as 12,000 to 20,000 feet per second.

8. The attenuation of sound with distance in solid materials is surprisingly low. In wood, for example, the rate of attenuation may be as low as 1 dB per 100 feet and for certain metals as low as 1 dB per 3,000 feet. The attenuation of sound in building structures is usually much higher because of discontinuities in construction, divergent transmission paths, and the mechanical coupling of building materials with different densities, weights, stiffnesses or other physical properties.

9. Generally speaking, for any given type of construction, the heavier or more massive the wall or floor structure, the better its sound insulation.

10. As a rule of thumb, most wall and floor structures are much better sound insulators at the higher frequencies than at the lower frequencies.

Generally speaking, building noise may be classified according to its origin, as either airborne, structure borne or a combination of both. Airborne noise is exemplified by the drone of the aircraft, the voices of children, or the music from a stereo or radio. In short, it is the noise produced by a source which radiates directly into the air. If a wall is in the path of an airborne sound wave, the fluctuating sound pressure against one side of it causes it to vibrate, and the sound is transmitted to the other side from which it is reradiated as airborne sound waves. Structure borne noise occurs when wall, floor or other building elements are set into vibrating motion by direct mechanical contact with vibrating sources such as mechanical equipment or domestic appliances. Quite frequently, these vibrations are short in duration, as those caused by slamming doors and falling objects.

The desired acoustical isolation between dwelling units can often be controlled effectively by proper selection of the sound insulating wall and floor structures. The sound insulating effectiveness of a wall or floor assembly is dependent upon the following factors.

1. Mass
2. Stiffness
3. Discontinuity in construction
4. Proper installation, particularly in regard to edge and boundary conditions
5. Elimination of noise leaks, especially around perimeter edges, joints, and penetrations of walls and floors
6. Control of flanking noise[3/]
7. Sound absorbent material in the voids or cavities in structures of discontinuous or double-shell construction.

4. Goals of Acoustic Environment Guide Criteria for Operation BREAKTHROUGH

The guide criteria developed for the design and evaluation of the acoustic environment of Prototype Housing in Operation BREAKTHROUGH are intended to permit attainment of three distinct, but related goals:

--Provision of a sufficiently quiet environment in which to live comfortably

--Provision of acoustical privacy between dwelling units

--Provision of acoustical privacy within a dwelling unit.

[3/] For a definition of flanking noise, see Appendix B.

Criteria which are suitable to all situations and environments would be virtually impossible to establish and very difficult to apply. Therefore, the intent was to establish criteria which would satisfy a majority of the occupants most of the time, and yet would be relatively easy to administer.

The distinction and interrelationship between the provision of a quiet environment and the provision of acoustical privacy may not be immediately evident. The following example, plus the later discussion of the specific criteria, should make this distinction clear.

Consider a particular apartment building in an urban environment. The exterior envelope of the building does not attenuate adequately the noises of traffic, aircraft, and nearby construction activity. The tenants complain vigorously so the developer, correctly identifying the windows as the primary sound transmission path, uses carefully gasketed double-pane construction for the next apartment building at this site. The new building is constructed and found to be quite effective in attenuating exterior noise sources. However, because of the reduced noise level in the apartments, tenants now complain that they can clearly hear conversations, radio, and television in adjacent dwelling units. With the lower background noise level, resulting from improved window construction, the inter-dwelling walls do not provide adequate privacy between dwelling units. This example is somewhat of an over-simplification but does illustrate the distinction between quiet and privacy and the need to consider the entire acoustical performance of a building system, not merely one attribute thereof.

5. Summary of Acoustic Environment Guide Criteria for Operation BREAKTHROUGH

All of the acoustic environment guide criteria interact to permit attainment of the three goals listed in the previous section. However, for the purposes of discussion and summarization it is convenient to group the criteria under headings corresponding to the three goals.

Prior to summarizing the criteria, it is convenient to define briefly three quantities which are referred to frequently in the criteria; these are discussed more fully in the following chapters and in the appendices:

<u>Noise Criteria (NC) curves</u> -- These curves are used to prescribe the maximum permissible noise-level characteristic for rooms. The lower the number, the quieter a room is required to be.

<u>Sound Transmission Class (STC)</u> -- This is a single-figure rating which provides an estimate of the airborne sound insulating performance of building walls and floor-ceiling combinations; the better the acoustical isolation provided by a partition, the higher is the STC-rating. In the guide criteria, the STC-rating is used only for laboratory measurements.

<u>Noise Isolation Class (NIC)</u> -- This is a single- figure rating which provides an estimate of the acoustical isolation between different rooms and spaces in a building; the higher the acoustical isolation between rooms, the higher is the NIC-rating. The NIC-rating includes flanking transmission paths (i.e., sound transmission through ductwork, ceiling plenums, etc.) as well as transmission through partitions and thus is used only for field measurements.

<u>Impact Insulation Class (IIC)</u> -- This is a single-figure rating which provides an estimate of the impact sound insulating performance of a floor-ceiling assembly; the better the acoustical isolation provided, the higher is the IIC-rating. By impact sound is meant the sound produced by the impinging or striking of one object with another, e.g., sound caused by footsteps striking a floor-ceiling assembly. In the guide criteria, the IIC-rating is used for both laboratory and field measurements.

The following is a summarization of the acoustic environment requirements and criteria. The detailed criteria, including test methods and commentary, are reproduced in Appendix E.

5.1. Provision of Quiet Environment

The key requirement and criterion to permit attainment of this goal is listed under Built Element L -- Enclosed Spaces.

- ■ Requirement L.5.1
  Noise levels in residential interior spaces should be controlled.
- ■ Criterion L.5.1.1*
  Daytime Noise Criterion Contour (0700-2200) of NC-40 and Nighttime Noise Criterion Contour (2200-0700) of NC-30.

The intent is to achieve a nighttime noise level of less than NC-30 in residential interior spaces. Due to the increased activity, an NC-40 environment is acceptable in the daytime. Since noise level in a space fluctuates rapidly with time, a question arises as to what is meant by an NC-30 or NC-40 environment. It would be totally impractical to require that the noise level in an enclosed space never exceed the NC-30 or NC-40 curve. Some loud noises occur at infrequent intervals and thus do not represent serious sources of annoyance. Tentatively, the interpretation of this criterion is that an NC-30 or NC-40 environment will be considered as being attained if the noise level exceeds the NC-30 or NC-40 curve less than 15 minutes out of any typical 24-hour day.

The following requirements and criteria are intended to supplement L.5.1:

- ■ Criterion L.5.1.2
  The reverberation time of corridors, hallways, and stairwells should be less than 0.8 second above 500 Hz and less than 1.5 seconds below 500 Hz.

- ■ Requirement A.5.1
  There should be control of generation and transmission of vibration that results in airborne sound radiation.
- ■ Criterion A.5.1.1
  Structure borne noise radiation should not exceed noise criterion established for the space as given in L.5. (See Criterion A.1.5.1 for control of vibration)

- ■ Requirements E.5.1 and F.5.1
  Protection should be provided from noise generated by and radiated from the multiplicity of sources outside of the home.
- ■ Criteria E.5.1.1 and F.5.1.1
  The exterior envelope should attenuate sound of exterior origin at a given site to permit attainment of the specified NC environment; see L.5.1.

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*Shows proposed future change.

5.2. Privacy Between Dwelling Units

The following requirements and criteria are intended to provide acoustical privacy between dwelling units. Criteria for both laboratory and field measurements are included. These requirements and criteria do not apply to single-family dwelling units.

- ■ Requirement B.5.1 (Inter-Dwelling Walls and Doors)
  Provision should be made for acoustical privacy between dwelling units.
- ■ Criterion B.5.1.1 (Laboratory)

Partition Function Between Dwellings			STC
Apt. A		Apt. B	
Bedroom	to	Bedroom	52
Living room	to	Bedroom	54
Kitchen	to	Bedroom	55
Bathroom	to	Bedroom	56
Corridor	to	Bedroom	52
Living room	to	Living room	52
Kitchen	to	Living room	52
Bathroom	to	Living room	54
Corridor	to	Living room	52
Kitchen	to	Kitchen	50
Bathroom	to	Kitchen	52
Corridor	to	Kitchen	52
Bathroom	to	Bathroom	50
Corridor	to	Bathroom	48

- ■ Criterion B.5.1.2 (Field)
  Noise Isolation Class, to be determined by field test of prototypes, of 4 less than STC values of Criterion B.5.1.1. For example: The partition between bedrooms of adjacent apartments should meet or exceed NIC-48 after installation

■ Requirement D.5.1 (Inter-Dwelling Floor-Ceiling Assemblies)
Provision should be made for acoustical privacy between dwelling units.

■ Criterion D.5.1.1 (Laboratory)

Partition Function Between Dwellings			STC	IIC
Apt. A		Apt. B		
Bedroom	above	Bedroom	52	52
Living room	above	Bedroom	54	57
Kitchen	above	Bedroom	55	62
Family room	above	Bedroom	56	62
Corridor	above	Bedroom	52	62
Bedroom	above	Living room	54	52
Living room	above	Living room	52	52
Kitchen	above	Living room	52	57
Family room	above	Living room	54	60
Corridor	above	Living room	52	57
Bedroom	above	Kitchen	55	50
Living room	above	Kitchen	52	52
Kitchen	above	Kitchen	50	52
Bathroom	above	Kitchen	52	52
Family room	above	Kitchen	52	58
Corridor	above	Kitchen	48	52
Bedroom	above	Family room	56	48
Living room	above	Family room	54	50
Kitchen	above	Family room	52	52
Bathroom	above	Bathroom	50	50
Corridor	above	Corridor	48	48

■ Criterion D.5.1.2 (Field)
Noise Isolation Class and Impact Insulation Class, to be determined by field test of prototypes, of 4 less than the STC and IIC values, respectively, of Criterion D.5.1.1. For example: The floor-ceiling assembly between the bedroom of one apartment and the bedroom of the subjacent apartment should meet or exceed NIC-48 and IIC-48 after installation.

The FHA document, "A Guide to Airborne, Impact and Structure Borne Noise -- Control in Multifamily Dwellings",[1] contains the following fundamental or key FHA-recommended criteria for airborne and impact sound insulation of wall and floor assemblies which separate dwelling units of equivalent function:

	Key Criteria of Airborne and Impact Sound Insulation Between Dwelling Units		
	Grade I	Grade II	Grade III
Wall Partitions	STC $\geq$ 55	STC $\geq$ 52	STC $\geq$ 48
Floor-Ceiling Assemblies	STC $\geq$ 55 IIC $\geq$ 55	STC $\geq$ 52 IIC $\geq$ 52	STC $\geq$ 48 IIC $\geq$ 48

The following discussion of these three grades is quoted from this FHA document:

"Descriptive definitions of three grades of acoustic environment are given in order to ascribe criteria suitable to the wide range of urban developments, geographic locations, economic conditions and other factors involved in the areas of concern of the FHA. Constructions which meet the criteria will provide good sound insulation and satisfy most of the occupants in the buildings which fit the conditions of each grade. Emphasis should be placed upon Grade II, as described below, for this category will be applicable to the largest percentage of multifamily dwelling construction and thus should be considered as the fundamental guide.

"Grade I is applicable primarily in suburban and peripheral suburban residential areas, which might be considered as the "quiet" locations and as such the nighttime exterior noise levels might be about 35-40 dB(A) or lower, as measured using the "A" weighting network of a sound level meter which meets the current standards. The recommended permissible interior noise environment is characterized by noise criteria of NC20-25. In addition, the insulation criteria of this grade are applicable in certain special cases such as dwelling units above the eighth floor in high-rise buildings and the better class or "luxury" buildings, regardless of location.

"Grade II is the most important category and is applicable primarily in residential urban and suburban areas considered to have the "average" noise environment. The nighttime exterior noise levels might be about 40-45 dB(A); and the permissible interior noise environment should not exceed NC25-30 characteristics.

"Grade III criteria should be considered as minimal recommendations and are applicable in some urban areas which generally are considered as "noisy" locations. The nighttime exterior noise levels might be about 55 dB(A) or higher. It is recommended that the interior noise environment should not exceed the NC-35 characteristic."

The FHA document went on to give comprehensive tables showing the criterion values related to partition function (i.e., type of rooms separated by a wall partition or floor-ceiling assembly) as applied in the separation of dwelling units. "The purpose of this detail is to illustrate the importance of the acoustical separation between sensitive and non-sensitive areas. Where the partition between dwelling units is common to several functional spaces, the partition must meet the highest criterion value."

Consistent with the above-quoted discussion, for privacy between dwelling units the Grade II criteria were selected for Operation BREAKTHROUGH and these are the STC- and IIC-values given in Criteria B.5.1.1 and D.5.1.1 for laboratory performance of inter-dwelling walls and doors and inter-dwelling floor-ceiling assemblies, respectively. The criteria for NIC-values were set 4 below the laboratory ratings in order to allow for flanking paths and defects in workmanship.

5.3. Privacy Within Dwelling Units

The following requirements and criteria are intended to provide acoustical privacy within dwelling units. Criteria for both laboratory and field measurements are included. These requirements and criteria apply to both multiple-family and single-family dwelling units.

- Requirement C.5.1 (Intra-Dwelling Walls and Doors)
  There should be acoustical privacy within the dwelling unit to create and allow for development of personal and family relationships.
- Criterion C.5.1.1 (Laboratory)*

Partition Function Between Rooms	Minimum Desirable STC	Minimum Acceptable STC
Bedroom to Bedroom	40	36
Living room to Bedroom	42	36
Bathroom to Bedroom	45	36
Kitchen to Bedroom	45	36
Bathroom to Living room	45	36
Bathroom to Bathroom	45	36

- Criterion C.5.1.2 (Field)
  Noise Isolation Class, to be determined by field test of prototypes, of 8 less than STC values of Criterion C.5.1.1.

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*It is anticipated that the incentive for improvement in acoustical quality will advance the state-of-the-art to the extent that this criterion can be upgraded in the near future.

- ■ Requirement D.5.2 (Intra-Dwelling Floor-Ceiling Assemblies)
  In the case of a multi-level dwelling unit, there should be acoustical privacy between different levels of the dwelling unit to create and allow for development of personal and family relationships.
- ■ Criterion D.5.2.1 (Laboratory)
  Sound Transmission Class, STC-40 and Impact Insulation Class, IIC-40 to be determined by laboratory test of floor-ceiling assembly.
- ■ Criterion D.5.2.2 (Field)
  Noise Isolation Class, NIC-35, and Impact Insulation Class, IIC-35 to be determined by field test of prototypes.

The FHA-document, "A Guide to Airborne, Impact, and Structure Borne Noise -- Control in Multifamily Dwellings"[1] lists suggested criteria for airborne sound insulation of partitions separating rooms within a given dwelling unit. Because of the suggested nature of these criteria, the Grade III Criteria (STC-40 to 45) rather than the Grade II Criteria (STC-44 to 48) were selected for evaluation of the acoustical performance of intra-dwelling walls in Operation BREAKTHROUGH. In view of the unlikeliness of utilizing more than one floor-ceiling construction within a given dwelling unit, only single values were selected for evaluating the airborne and impact noise isolation of floor-ceiling assemblies.

More allowance between laboratory and field performance in the case of intra-dwelling room dividers was given (than in the case of inter-dwelling room dividers) because of the more serious flanking paths that are likely to be present (e.g., air ducts, undercut doors).

Some questions have arisen as to the intent of the criteria for intra-dwelling sound isolation, particularly with regard to doors. Criterion C.5.1.1 refers to laboratory measurement of the sound transmission loss through the <u>partition</u> between the rooms in question. The Commentary (see Appendix E) on C.5.1.1 states that the "laboratory test specimen should include weak links (e.g., doors) in transmission chain." However, consideration of the adjacent room combinations listed under Criterion C.5.1.1 reveals that the layout of most dwelling units is such that there rarely would be a door in the common wall between these adjacent rooms. Most interior doorways in apartments and homes open onto a hallway -- a space which is intentionally omitted from Criterion C.5.1.1. Thus, for laboratory tests, it would be unusual to have to include a door in the test specimen. The most obvious exception to this statement is the door between a master bedroom and the master bathroom. Since the master bathroom is typically used chiefly by the husband and wife, acoustical privacy is of somewhat less concern. Therefore, the master bedroom/master bathroom partition is specifically exempted from compliance with both Criteria C.5.1.1 and C.5.1.2.

As regards field performance, bedrooms and bathrooms would each have doors, usually opening onto a hallway. For sound transmission between two bedrooms or between a bedroom and a bathroom, field measurements should be made with both doors closed -- the doorway/hallway/doorway transmission path would usually provide adequate noise attenuation to meet Criterion C.5.1.2 provided the integrity of the common partition between the rooms in question has not been breached, e.g., by improperly installed air ducts. The Noise Isolation Class between living room or kitchen and the bedroom or bathroom may present a more serious problem since living rooms and kitchens typically would not have doors. However, it is felt that adequate acoustical isolation between these room combinations is important enough to warrant the additional sound control measures (e.g., acoustically-better bathroom and bedroom doors) which may be required. Noise isolation between bedrooms and the kitchen or living room is needed so that some members of the family (e.g., children) can sleep without disturbance from other family activities. Acoustical isolation of bathrooms is needed to minimize possible embarrassment to persons, especially guests, who are using the bathroom facilities.

5.4. Supplementary Guide Criteria

The remainder of the acoustic environment guide criteria for Operation BREAKTHROUGH are intended to ensure that consideration is given to the possible effect of other building elements on the acoustic environment. These additional criteria are listed below.

- Requirement G.5.1
  Fixtures and hardware should perform their intended function without excessive additional noise generation or compromise of the acoustical performance of other building elements.
- Criterion G.5.1.1
  The fixture should neither prevent attainment of nor compromise the NC requirement established for the space; see L.5.1.1.
- Criterion G.5.1.2
  Installation of the fixture should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- Requirement H.5.1
  The plumbing system should perform its intended function without excessive additional noise generation or any compromise of the acoustical performance of other building elements.
- Criterion H.5.1.1
  The plumbing system should neither prevent attainment of nor compromise of the NC requirement established for the space; see L.5.1.1
- Criterion H.5.1.2
  Installation of the plumbing system should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- **Requirement I.5.1**
  Mechanical equipment and appliances should perform their intended functions without excessive additional noise or compromise of the acoustical performance of other building elements.
- **Criterion I.5.1.1**
  Mechanical equipment or appliances should neither prevent attainment of nor compromise the NC requirement established for any habitable space; see L.5.1.1.
- **Criterion I.5.1.2**
  Installation of mechanical equipment or appliances should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- **Requirement J.5.1**
  Power, electrical distribution, and communications systems should perform their intended functions without excessive additional noise generation or compromise of the acoustical performance of other building elements.
- **Criterion J.5.1.1**
  These systems should neither prevent attainment of nor compromise the NC requirement established for the space; see L.5.1.1.
- **Criterion J.5.1.2**
  Installation of these systems should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- **Requirement K.5.1**
  Lighting elements should perform their intended function without excessive noise generation and without compromising the acoustical performance of other building elements.
- **Criterion K.5.1.1**
  The lighting elements should neither prevent attainment of nor compromise the NC requirement established for the space; see L.5.1.1.
- **Criterion K.5.1.2**
  Installation of the lighting elements should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

6. Discussion of Noise Criterion Curves

Noise Criterion Curves [2,3], are the basis for Criterion L.5.1.1 which establishes maximum noise levels in habitable spaces. These curves, given in Figure 1, present octave-band sound pressure level plotted versus the octave-band center frequencies. The shape of the curves is intended to take both speech interference and annoyance into consideration. What is done in practice is to measure the space-time averaged sound pressure levels in an unoccupied room and then plot the octave-band sound pressure level versus frequency on Figure 1. The appropriate NC-rating is the lowest NC curve which is not exceeded by any of the eight octave band levels having center frequencies from 63 to 8000 hertz (cycles per second).

The right-hand ordinate on Figure 1 represents the approximate A-weighted sound level corresponding to each NC curve.[4/] A-weighted sound levels were not used for the guide criteria because the same level may be obtained for a wide variety of spectrum shapes. However, A-weighted level (in units of dB(A)) is frequently used as a single-figure measure of the noise in a space and hence it is worthwhile to show the approximate relationship to the NC-curves.

Noise Criterion Curves were originally developed for use in describing the desired acoustic environment in offices; they since have been frequently used for other habitable spaces. Table 1 indicates the recommended noise criteria for offices while Table 2 indicates the recommended value for other types of rooms.[2]

[4/] The apparent loudness that we attribute to a sound varies not only with the sound pressure but also with the frequency of the sound. In addition, the way it varies with frequency depends on the sound pressure. This effect is taken into account to some extent by "weighting" networks included in an instrument designed to measure sound-pressure level. The instrument then is called a "sound-level meter". A weighting network designated as "A", which discriminates against lower frequencies, has been found to yield sound levels which correlate reasonably well with subjective response to sound. Since A-weighted sound levels (expressed, for compactness, in units of "dB(A)") can easily be read from a meter, they are often used in lieu of more complicated measures which may correlate still better with human response.

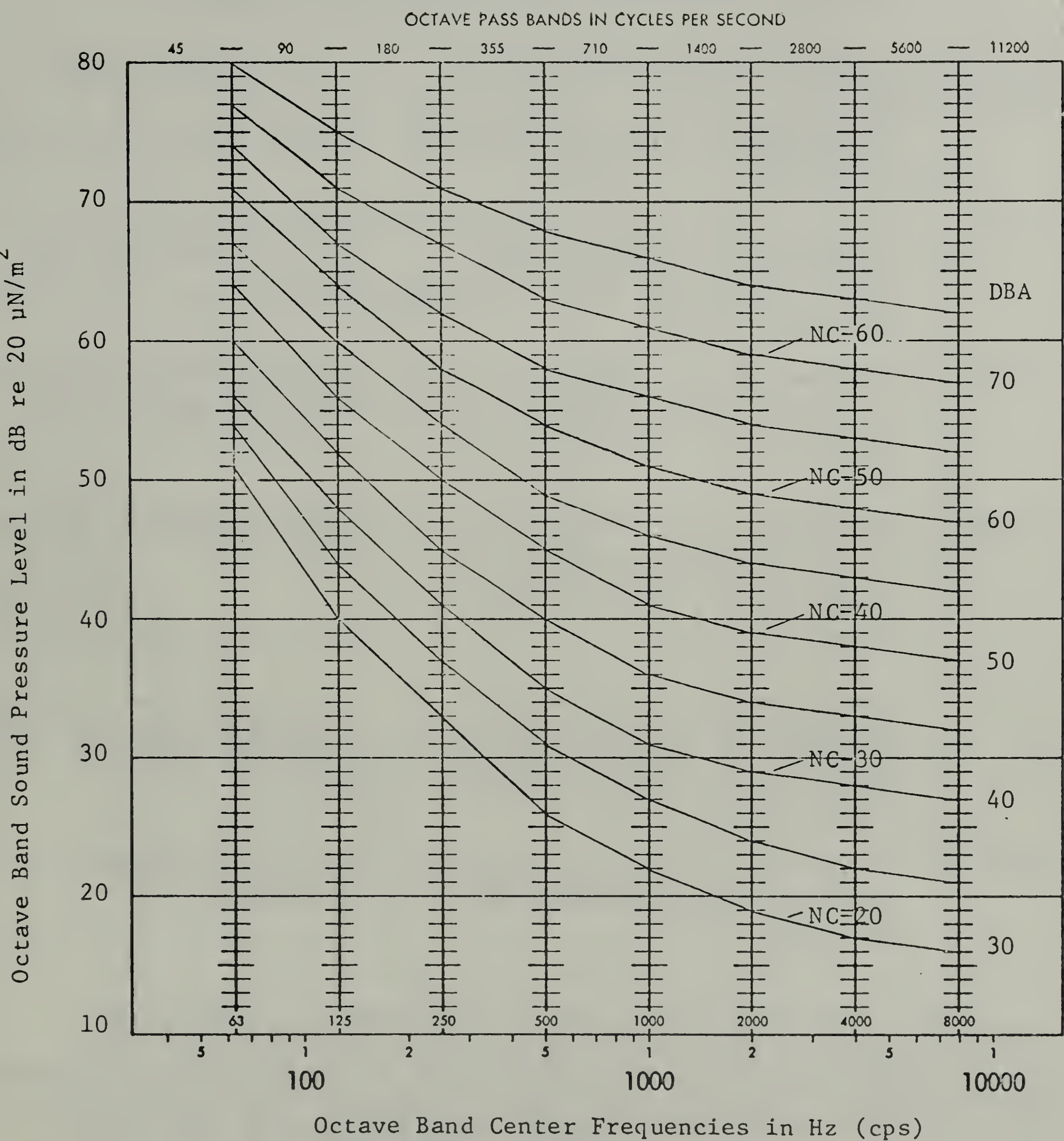

Figure 1. Indoor Noise Criterion "NC" Curves Plotted on Preferred Frequency Scale.

Table 1. Recommended Noise Criteria for Offices

NC Curve	Communication Environments	Typical Applications
20-30	Very quiet office -- telephone use satisfactory -- suitable for large conferences	Executive offices and conference rooms for 50 people
30-35	"Quiet" office; satisfactory for conferences at a 15-ft table; normal voice 10 to 30 ft; telephone use satisfactory	Private or semiprivate offices, reception rooms and small conference rooms for 20 people
35-40	Satisfactory for conferences at a 6- to 8-ft table; telephone use satisfactory; normal voice 6 to 12 ft	Medium-sized offices and industrial business offices
40-50	Satisfactory for conferences at a 4- to 5-ft table; telephone use occasionally slightly difficult; normal voice 3 to 6 ft; raised voice 6 to 12 ft	Large engineering and drafting rooms, etc.
50-55	Unsatisfactory for conferences of more than two or three people; telephone use slightly difficult; normal voice 1 to 2 ft; raised voice 3 to 6 ft	Secretarial areas (typing), accounting areas (business machines), blueprint rooms, etc.
Above 55	"Very noisy"; office environment unsatisfactory; telephone use difficult	Not recommended for any type of office

Note: Noise measurements made for the purpose of judging the satisfactoriness of the noise in an office by comparison with these criteria should be performed with the office in normal operation but with no one talking at the particular desk or conference table where speech communication is desired (i.e., where the measurement is being made). Background noise with the office unoccupied should be lower, say by 5 to 10 units.

Table 2. Recommended Noise Criteria for Rooms

Type of Space	Recommended NC Curve	Computed Equivalent Sound Level, dB(A)*
Broadcast studios	15-20	25-30
Concert halls	15-20	25-30
Legitimate theaters (500 seats, no amplification)	20-25	30-35
Musicrooms	25	35
Schoolrooms (no amplification)	25	35
Television studios	25	35
Apartments and hotels	25-30	35-40
Assembly halls (amplification)	25-35	35-40
Homes (sleeping areas)	25-35	35-45
Motion-picture theaters	30	40
Hospitals	30	40
Churches (no amplification)	25	35
Courtrooms (no amplification)	25	30-35
Libraries	30	40-45
Restaurants	45	55
Coliseums for sports only (amplification)	50	60

*If there were relatively less noise in the low-frequency bands than indicated by the recommended noise criterion curve, the dB(A) numbers would be lower by about 5 dB. All numbers in this column should be dropped by 5 dB is they are to be used to estimate the compliance of a normally encountered noise level with an NC criterion; these numbers should not be used for specification purposes.

Note: Noise levels are to be measured in unoccupied rooms. Each noise criterion curve is a code for specifying permissible sound-pressure levels in eight octave bands. It is intended that in no one frequency band should the specified level be exceeded. The computed equivalent dB(A) numbers in the right-hand column are presented for information only and are not recommended for use in specifications. Ventilating systems should be operating, and outside noise sources, traffic conditions, etc., should be normal when measurements are made.

The rationale behind the selection of NC-40 for the daytime criteria for Operation BREAKTHROUGH housing is fairly evident from the descriptions of the communication environment given in Table 1. With an NC-40 environment, telephone use is satisfactory and conversations, using a normal voice, can be carried out with persons separated by distances typical of a living room, dining room, or kitchen.

The Sound Transmission Class and Impact Insulation Class criteria for interdwelling walls and floor-ceiling assemblies should attenuate noise from adjacent dwelling units to well below the specified Noise Criteria. Thus attainment of the NC-30 or NC-40 environment will be dependent upon the exterior shell of the building being able to adequately attenuate exterior noise and upon mechanical systems, especially HVAC and plumbing, being properly designed and installed so as not to degrade seriously the acoustic environment.

As shown in Figure 1, NC-40 corresponds approximately to a sound level of 50 dB(A). In congested urban areas, noise levels, at the exterior of a building, of 80 to 90 dB(A) probably are not uncommon. Thus an exterior shell which can attenuate external noises by roughly 30 to 40 dB would be needed. The actual acoustical characteristics needed for the exterior shell would depend upon the frequency spectra of the offending outdoor noises but, as a rough rule-of-thumb, a Sound Transmission Class of STC-35 or better might be needed in urban environments.

7. Discussion of STC, NIC, and IIC

7.1. Sound Transmission Class (STC)

Generally speaking, a partition, such as a wall or floor/ceiling assembly, which will provide adequate sound insulation in a given situation is one which will reduce the transmitted noise to a level below that of the normal background noise. This sound insulating property of a partition is called the "sound transmission loss", which is expressed in terms of decibels. The sound transmission loss, STL, is equal to the number of decibels by which sound energy incident on one side of a partition is reduced in transmission through it. The satisfactory performance of a wall in a given situation hinges primarily on three factors:

1. the sound level on the source or noisy side
2. the sound transmission loss of the wall
3. the background noise level on the receiving or quiet side.

Although the best method for selecting a construction with the proper sound-insulating properties for a given installation is the study of the entire sound transmission loss curves of a number of constructions and it is difficult to describe completely the acoustical properties of structures with a single value, single figure ratings are useful and much more readily used for general categorization. Over the years, several single-figure rating schemes have been proposed and used with varying degrees of success. In recent years, the Sound Transmission Class (STC), which appears in ASTM E90-66, Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions, has been used in this country with reasonably successful results. The STC rating system provides a computation scheme which decreases the probability that the STC value of a given partition is determined solely by a single sound transmission loss value at some particular frequency.

To determine the STC of a test specimen, the sound transmission loss values, as determined in the contiguous sixteen 1/3-octave bands with center frequencies in the range 125-4000 Hz, are compared with the values of the STC reference contours, Figure 2, according to the following conditions:

1. A single unfavorable deviation (i.e., an STL value which falls below the contour) may not exceed 8 dB.
2. The sum of the unfavorable deviations shall not be greater than 32 dB.
3. The STC for the specimen is the numerical value which corresponds to the STL value at 500 Hz of the highest contour for which the above conditions are fulfilled.

For many wall and floor/ceiling assemblies the sound transmission class has been well documented[1] and is available in lieu of laboratory tests for determining compliance with the criteria for interior space dividers.

There appears to be a great spread in cost versus STC rating for various walls and floor/ceiling assemblies commonly in use. Figures 3 and 4 and Appendices C and D illustrate how judicious selection of the proper type of wall or floor/ceiling assembly can provide the STC rating of a partition at minimal cost.

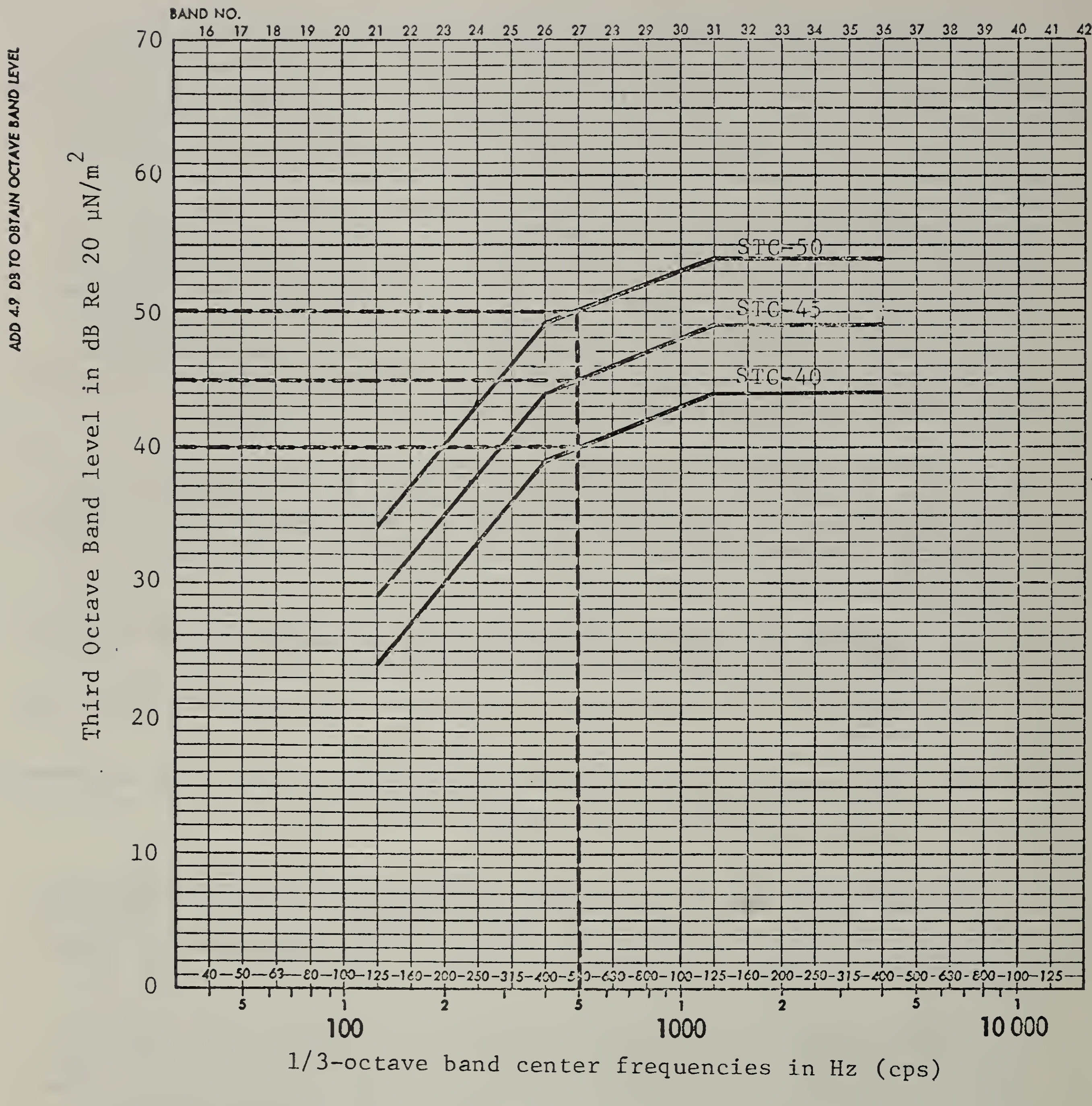

Figure 2. Sound Transmission Class Contours

Typical Walls

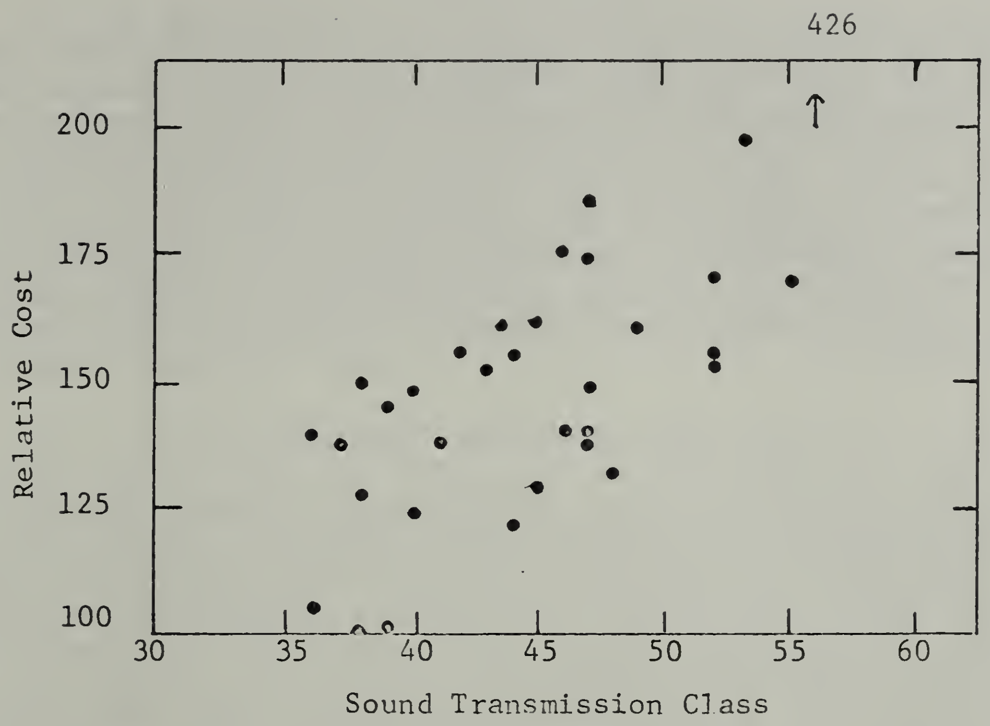

Figure 3. Sound Transmission Class versus Relative Cost for Typical Walls.

Floor-Ceiling Assemblies

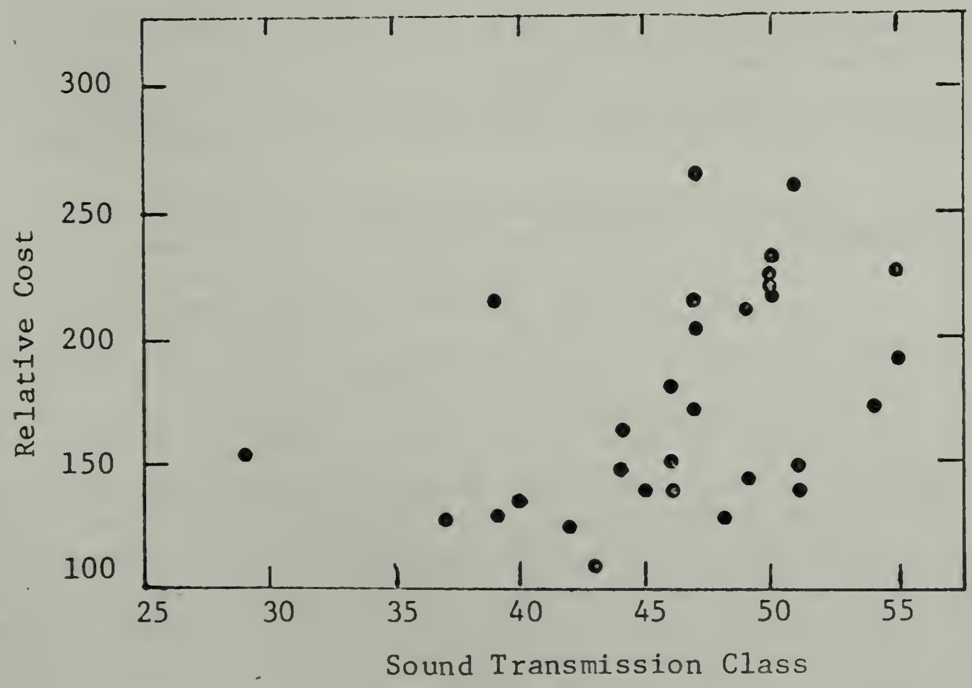

Figure 4. Sound Transmission Class versus Relative Cost for Typical Floor-Ceiling Assemblies.

A common fallacy is to assume that if one wall will give a certain STC rating, two walls very close together will give double this STC rating. The assumption is false because of the interactions between the two walls. The STC value not only depends on the various resonant frequencies and the damping characteristics of each panel but also the degree of elastic coupling presented by the air space between the panels. This linkage is dependent on the distance between the partitions, the amount of sound-absorption in the interspace, and the structural ties between the panels, even if they exist only along the base or perimeter of the structure.

7.2. Noise Isolation Class (NIC)

The noise isolation class is the field measurement sequel to the laboratory measurement for STC and is determined in much the same manner. NIC, which is ultimately what we are striving for, is a measurement of the noise reduction in a building, the difference in average sound pressure levels in rooms on opposite sides of a test partition, and would include problems encountered by sound arriving in the space of the receiving side of the dividing partition by paths other than the one directly through the partition, i.e., flanking paths. A procedure for determining the noise isolation class of a partition is outlined in ASTM E336-67T, Tentative Recommended Practice for Measurement of Airborne Sound Insulation in Buildings, Appendix A1, Measuring Noise Reduction or Field Insertion Loss. The noise reduction between a pair of rooms, as determined in the contiguous sixteen 1/3-octave bands with center frequencies in the range 125-4000 Hz, are compared with the values of the STC reference contours according to the same conditions as the sound transmission loss values are compared for STC ratings. The concept of noise reduction is based upon a "furnished" space. A procedure for normalization of the data is given in the text of the criteria.

Since field installations do not permit as good control of various parameters as during laboratory installations of the same partition, it would be unrealistic to expect the NIC rating between spaces to be the same as the STC rating of the partition which separates the spaces. STC measurements are made in an environment in which the parameters are more easily controlled and thus can be expected to give a higher number rating than the NIC rating between the spaces separating the partition.

The integrity of the structural element or partition which separates two spaces is paramount in obtaining the highest possible NIC rating between the spaces. Inferior workmanship probably accounts for a high percentage of paths for sound leakage. If we consider a partition that has a sound transmission loss of 45 dB at a given frequency in the laboratory, a hole of 0.1% of the total area of the partition will result in a sound transmission loss of approximately 30 dB at that frequency for all other things being equal. A hole of 1% of the total area of the partition would drop the sound transmission loss down to approximately 20 dB.

Other possibilities of flanking paths would be short sections of ducts between registers going between rooms, a common duct with back-to-back registers, false ceilings with a void above the wall separating rooms, paths between doors or exterior windows of adjacent rooms, improper sealing around the periphery of a partition or the panels of a partition, and improper sealing around pipes. Short circuits in the transmission chain which also reduce the NIC value include such things as back-to-back medicine cabinets in adjacent bathrooms, back-to-back electrical boxes, pipes or other hard materials going through a partition, and mounting of equipment or appliances to walls in a manner such as to defeat the purpose of resilient clips.

Doors present a special problem as flanking paths. Since most HVAC systems have a common air return, it is necessary that the doors be undercut to allow for the necessary circulation of air. A door usually represents the "weak link" in the sound insulating performance of a composite interior wall assembly (i.e., a door as an integral part of a standard wall assembly). However, it is false to assume that the insulation of the wall need be no better than that of the door. If the wall area is much greater than the area of the door or "weak link", the sound transmission loss of the composite wall will be substantially higher than that of the door. In order to compute the average sound transmission loss of the composite wall structure it is necessary to know the sound transmission loss (STL) in dB of the wall and door for each frequency or 1/3-octave band in question. The sound transmission loss of the composite wall can then be computed from the following equation:

$$STL_{composite\ wall} = 10 \log_{10} \frac{S_w + S_d}{(\tau_w S_w + \tau_d S_d)}$$

where τ_w and τ_d are the transmission coefficients of the wall and door, respectively, defined by:

$$STL_w = 10 \log_{10} \frac{1}{\tau_w} \quad \text{and} \quad STL_d = 10 \log_{10} \frac{1}{\tau_d}$$

and S_1 and S_2 are the corresponding surface areas.

7.3. Impact Insulation Class (IIC)

A problem at least as serious as that of providing a proper partition with regard to STC or NIC rating is the problem of providing a floor/ceiling assembly with adequate insulation against impact noise. Because of the inherent complexity of the generation and transmission of impact noise, the measurement and specification of the insulating properties of structures against such sounds, and the determination of subjective reaction to these noises, the development of impact sound insulation criteria for floor/ceiling structures is a very controversial topic. The occupant, however, does not care how the intruding noises are generated and transmitted. If his apartment is bombarded with impact noises from the apartment above he is unhappy until the intruding sounds are reduced to an acceptable level.

The specification of criteria for impact sound insulation requires a standard method for assessing the insulating properties of floor/ceiling structures. Unfortunately, a standard method of test has not yet been adopted in the United States although Committee C-20 of the American Society for Testing and Materials is presently working toward that end. A method patterned after the International Organization for Standardization, ISO Recommendation R140-1960(E), Field and Laboratory Measurements of Airborne and Impact Sound Transmission, January 1960, is to be included in ASTM Part 14, 1971 as a proposed method, for information only. This proposed method differs from the ISO document in that is is more stringent in its methods of test and technique, it uses a different rating scheme, and it is for laboratory measurements only. This test method involves the operation of a "standard" tapping machine described in the ISO document which produces repeatable excitations of floor/ceiling structures and the resultant "impact sound pressure levels" produced in a reverberation room are measured.

Since ASTM has not yet proposed a field measurement for Impact Sound Transmission it is suggested that for compliance to the criteria the method proposed by ASTM for laboratory measurements be used for field measurements as well.

In choosing the proper floor/ceiling structure to meet the impact sound insulation requirements of a particular installation, the impact sound pressure level should be examined with relationship to frequency. When frequency is not considered the rank order of two structures based on some sort of single-figure rating can occasionally be reversed. A single-figure rating designated as the Impact Insulation Class, IIC, considers frequency and can be used with some discretion in categorizing structures according to impact insulation properties. It can be useful to architects, builders and code authorities for acoustical design purposes in building construction.

As in the STC system, the Impact Insulation Class (IIC) rates floor structures with positive numbers in ascending degrees of impact sound insulation, i.e., the larger the number the greater the insulation. This avoids the confusing practice of dealing with "negative insulation values", which arise from the use of a zero-valued reference contour. Thus, for all practical purposes, the numerical values and significance assigned to the contours of the IIC rating system are about the same in terms of impact sound insulation as the values and significance associated with the contours of the airborne sound insulation STC system.

For the criteria the sound pressure levels, averaged over time and space, in 16 contiguous 1/3-octave bands with center frequencies in the range 100-3150 Hz are to be measured at six stationary microphone positions or with a slowly moving microphone in the receiving room with the tapping machine placed successively in at least three locations on the floor. The impact sound pressure levels (ISPL) result from normalizing the measurements to a reference room absorption of $A_o = 10\ m^2$ or 107.6 sabins.

To determine the IIC of a test specimen, the impact sound pressure levels are compared with the values of IIC reference contours as shown in Figure 5 according to the following conditions:

1. A single unfavorable deviation (i.e., an ISPL value which lies above the contour) may not exceed 8 dB.
2. The sum of the unfavorable deviations shall not be greater than 32 dB.
3. The IIC for the specimen is the numerical value which corresponds to the ISPL value at 500 Hz of the lowest contour for which the above conditions are fulfilled.

Currently, there is some criticism of the efficacy of the tapping machine as an appropriate source of impact excitation, since it does not simulate that produced by walking nor in fact, any other domestic activity or accident. In this regard, we are faced with some very penetrating questions. Shall we standardize a method of test which utilizes actual walkers? Shall we develop a device which simulates the characteristics of the statistically "average" walker? Shall we subject each floor/ceiling structure to a test under all the known actual sources of impact, other than footsteps? Can we develop a device which simulates the characteristics of all these sources? These among other questions relating to the "standard source of impacts" and the subsequent associated rating systems must be answered before this issue can be adequately resolved. However, the problem exists now and until better schemes are developed and proven, we must of necessity use those methods presently available, which indeed have been reasonably successful in Europe and elsewhere for a number of years.

Impact noises usually constitute a serious problem because such noises generally are of high intensity and transient or impulsive in character. The problem is particularly acute in floors of light frame construction. Because of their flexibility and lightweight, such floors are easily set into vibration by impact excitation. Under heavy foot traffic such floors will generally produce a thumping or booming noise which tenants find more irritating. Whereas the high frequency components of impact noise can be attenuated quite easily by various resilient types of floor surface coverings such as carpeting, cork or rubber tile, the attenuation of low frequency impact noise requires the modification of the basic structural floor with some form of discontinuous construction. The basic types of discontinuous structures and construction techniques used in the control of impact and structure borne noise are listed below.

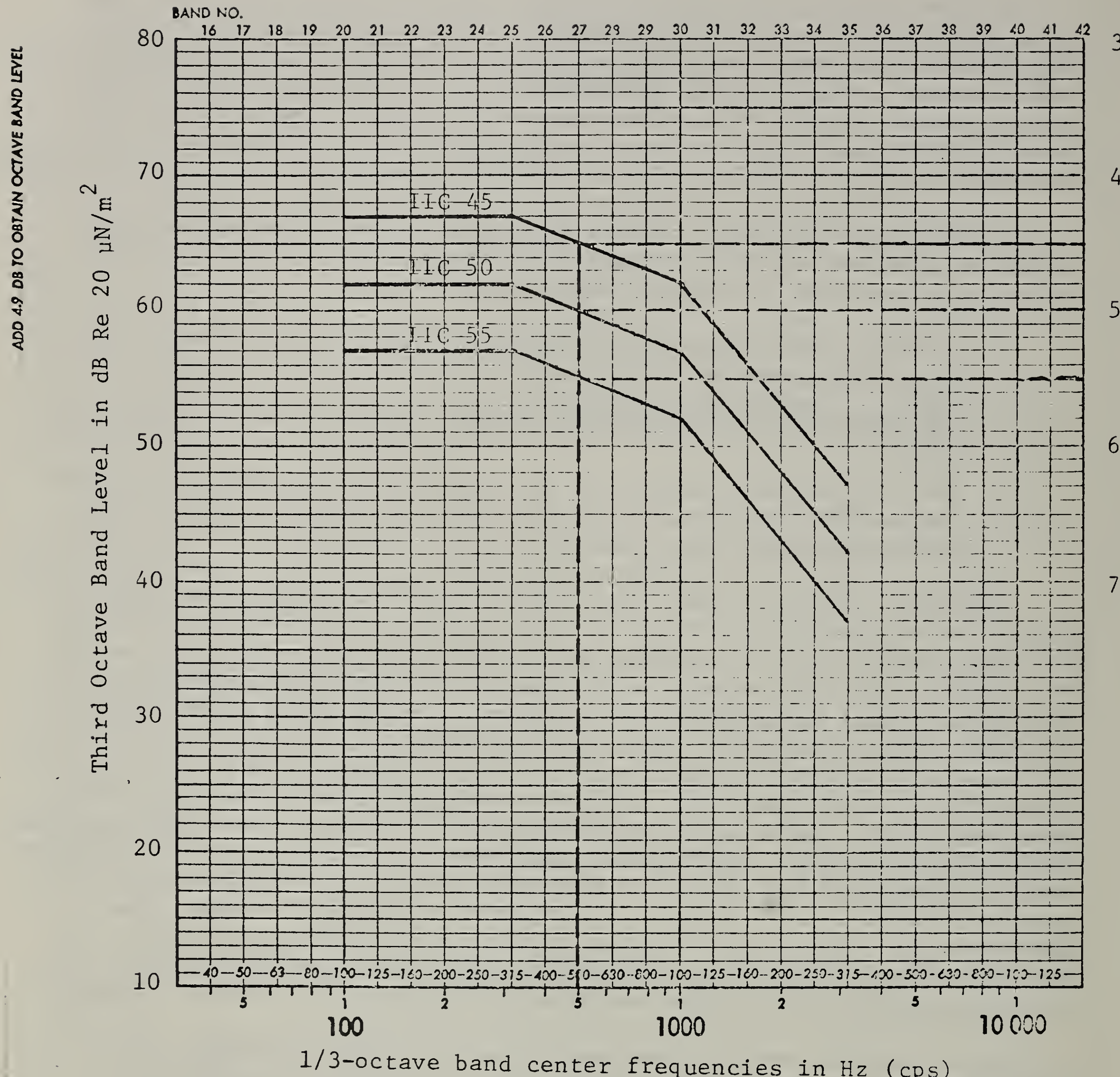

Figure 5. Impact Insulation Class Contours

1. Cushion the impact: This can be accomplished by the use of soft resilient surfacing materials. However, the effectiveness of the insulation is dependent upon the construction of the basic floor structure. The same cushion will perform differently on wood floors than on cement floors.

2. Float the floor: This represents a type of discontinuous construction which can be highly effective in reducing the transmission of impact noise.

3. Suspend the ceiling: To be effective the floor/ceiling structure must be vibrationally decoupled from supporting walls.

4. Sound absorber in cavity: Insert sound absorbing material in the floor/ceiling cavities.

For many floor/ceiling assemblies, the impact insulation class has been well documented [1] and is available in lieu of laboratory tests for determining compliance with the criteria for interior space dividers.

There appears to be a great spread in cost versus IIC rating for various floor/ceiling assemblies commonly in use. Figure 6 and Appendix D illustrate how judicious selection of the proper type of floor/ceiling assembly can provide the required IIC rating of a floor/ceiling assembly at minimal cost.

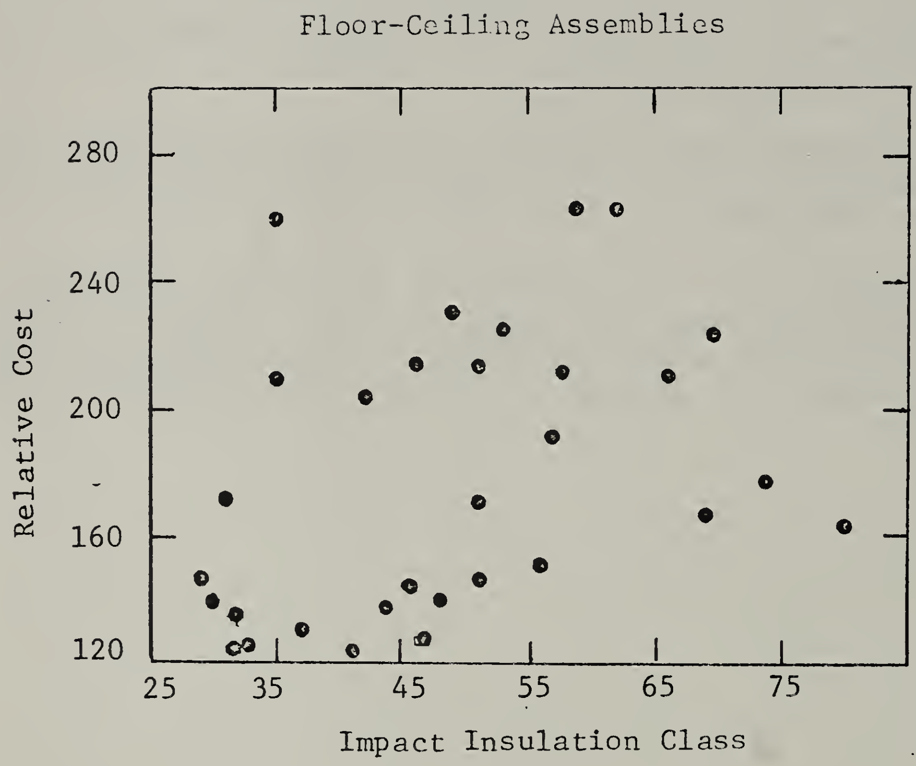

Figure 6. Impact Insulation Class versus Relative Cost for Typical Floor-Ceiling Assemblies.

References

[1] R. D. Berendt, G. E. Winzer, and C. B. Burroughs, "A Guide to Airborne, Impact, and Structure Borne Noise -- Control in Multifamily Dwellings", HUD FT/TS 24, U.S. Government Printing Office, Washington, D.C. 20401.

[2] L. L. Beranek (ed.), Noise Reduction, McGraw-Hill, New York, 1960.

[3] M. Rettinger, Acoustics - Room Design and Noise Control, Chemical Publishing Co., New York, 1968.

Appendix A

Basic Acoustic Information

When an object moves back and forth, it is said to vibrate. This vibration disturbs the air particles near the object and sets them vibrating, producing a variation in normal atmospheric pressure. The resulting continuous train of disturbances traveling with a speed dependent on the properties of the medium is called a wave. The disturbance spreads, and when the pressure variations reach our ear drums, they too are set to vibrating. This vibration of our ear drums is translated by our complicated hearing mechanisms into the sensation we call "sound".

To put it in more general terms, sound in the physical sense is a vibration of particles either in a gas, a liquid, or a solid. The speed with which a sound disturbance spreads depends on the mass and on the elastic properties of the material. In air the speed of sound is about 1100 feet/second or about 340 meters/second. It effects are commonly observed in echoes and in the apparent delay between a flash of lightning and the accompanying thunder. In steel the speed of sound is about 16,000 feet/second or about 4950 meters/second.

The variation in normal atmospheric pressure that is a part of a sound wave is characterized by the rate at which the variation occurs and the extent of the variation. Thus, the standard tone "A" occurs when the pressure changes through a complete cycle 440 times per second. The frequency of this tone is then said to be 440 hertz, or 440 cycles per second (abbreviated "Hz" and "c/s", respectively). "Hertz" and "cycles per second" are synonymous terms, but most standardizing agencies have adopted "hertz" as the preferred unit of frequency.

When sound is incident at an interface separating two media, a reflected wave is produced in the first medium and a transmitted wave in the second medium. For the case where there is no reflection the wave is entirely transmitted. Whenever acoustic waves are transmitted through a medium there is a loss of acoustic energy. In dwellings this loss is mainly due to the direct absorption of acoustic energy by partitions, drapes, furniture, or other objects and persons. This loss, by direct absorption, is the most important factor in the dissipation of sound that occurs within and between rooms.

Sound is the variation in normal atmospheric pressure at a given location and can be described by the magnitude of the pressure variation and the rate at which the variation occurs. Because of the extremely large range of pressure variations to which we are exposed, the physical magnitude of a sound is generally expressed on a <u>decibel</u> (dB) scale which is logarithmic.

The sound pressure level (SPL) is defined as

$$SPL = 10 \log \frac{p^2}{p_o^2} = 20 \log \frac{p}{p_o} \text{ dB}$$

where p is an appropriate average value for the magnitude of the pressure variation associated with the sound and p_o is a reference sound pressure which in acoustics is usually taken as 20 micronewtons per square meter or 0.0002 microbar.

A number of possible situations require the combining of several noise levels stated in decibels. The number of decibels can never be directly added. The procedure that is correct is to combine on an energy basis. The procedure for doing this is to convert the number of decibels to relative pressure squared ratios, to add or subtract then as the situation may require, and then to convert back to the corresponding decibels. By this procedure it is easy to see that a noise level of 80 decibels combined with a noise level of 80 decibels yields 83 decibels and not 160 decibels.

The analysis of a signal into its distribution across the frequency spectrum can be performed in very fine or broad frequency bands, according to the characteristics of the source and the use to which the data will be put. The overall sound pressure level is a single figure which provides no information on the spectral content. The spectral content of a signal is usually analyzed using filters of suitable frequency band widths. Traditionally the widest frequency band used is an octave band. Octave bands have constant percentage bandwidths with the upper frequency limit of each band equal to twice the value of the lower frequency limit. The 1/3-octave band is usually used when a more exacting analysis is necessary. As the name implies, three consecutive 1/3-octave bands comprise one octave band. The upper frequency limit of each 1/3-octave is equal to the cube root of two times the value of the lower frequency limit. For a more exacting analysis, finer bandwidths are used. All of the bandwidths are specified by what is called the center frequency which is determined by the square root of the product of the frequency limits of the bandwidth. The choice of level of detail for analysis of a signal into frequency bands must be based on the characteristics of the source.

In order to determine the acoustical quality of a partition or space, the noise reduction must be determined. If a known sound source originates in one room (source room) and is measured in another room (receiving room), the noise reduction, NR, may be defined as the difference between the average sound pressure levels of the two rooms separated by a partition. Mathematically:

$$NR = L_S - L_R$$

where L_S = average sound pressure level in the source room

L_R = average sound pressure level in the receiving room

The transmission loss of the partition may be determined if the source and receiving rooms are acoustical laboratory test rooms. The transmission loss, TL, of the partition is determined from the measured noise reduction with a correction for surface area of the test partition and the total absorption of the receiving room. Mathematically:

$$TL = NR + 10 \log S/A$$

where S = surface area of the partition
A = absorption of the receiving room

S and A must be compatible units.

Because the TL of a partition varies with the test frequency, it has become practice to rank-order the insulating quality of partitions, by employing an average of the test results with respect to frequency. There have been many proposed methods of combining the transmission losses to derive some sort of a rating. The one most commonly used is the STC or Sound Transmission Class which takes into consideration the speech frequencies.

Sound Transmission Class is a term originated by the American Society for Testing and Materials. The classification is intended to overcome certain deficiencies that developed by classifying the insulating qualities of materials by means of other averaging methods which mask the effects of "dips" or "peaks" in the transmission loss at certain frequencies.

In addition to the transmission loss of partitions, impact on floor/ceiling assemblies must be determined. This is accomplished by the use of a standard source of impact, i.e., most prevalently, the ISO tapping machine. The separating partition is subjected to impact from the source room while the sound pressure level in the subjacent receiving room is measured at different test frequencies. The impact sound pressure level, IPSL, is defined as follows:

$$IPSL = L_I - 10 \log_{10} A_o/A$$

where L_I = average impact sound pressure level measured in the receiving room

A_o = reference absorption, usually 108 sabins (10 m^2)

A = absorption in the receiving room

Appendix B

Common Terminology for Building Acoustics

The definitions of some terms used in this report are assembled here for convenience.

ACOUSTICAL DESIGN. A consideration of all factors bearing on the achievement of a desirable acoustical environment, including the selection of building sites, orientation of buildings, space arrangements within buildings, and proper selection and installation of wall and floor assemblies, building equipment and services.

ACOUSTICAL PRIVACY. The assurance that there is sufficient insulation from intruding and disturbing noises.

ACOUSTICAL TREATMENT. The application or use of any sound absorbers, building materials or structures and construction techniques for purposes of controlling noise and improving the acoustical environment.

AIRBORNE SOUND. Sound radiated initially into and transmitted through air.

ATTENUATION, SOUND. The reduction of the energy or intensity of sound.

BACKGROUND NOISE. The sound level present in a room or space at any given time above which speech, music, desired signal or sound must be raised in order to be heard or made intelligible.

CAULK. An elastic non-setting material used for sealing cracks, seams and joints to prevent leakage of sound.

DECIBEL (dB). See "SOUND PRESSURE LEVEL".

FLANKING TRANSMISSION. The transmission of sound or noise from one room to another by indirect paths, rather than directly through an intervening partition.

FLEXIBLE COUPLER. A device to prevent or reduce the transmission of vibration, particularly between vibrating equipment and service distribution systems involving ductwork, piping and electrical lines.

FREQUENCY, SOUND. The number of complete to-and-fro vibrations that a source of sound makes in one second. Frequency is measured in hertz (cycles per second). The pitch of an audible sound depends mostly on its frequency.

IMPACT INSULATION CLASS (IIC). A single-figure rating which provides an estimate of the impact sound insulating performance of a floor/ceiling assembly.

IMPACT SOUND. The sound produced by the impinging or striking of one object with another, e.g., sound caused by footsteps.

NOISE. Unwanted sound.

PARTY WALL. A wall which separates two adjacent dwelling units within an apartment building.

RESILIENT MOUNTING. A mounting, suspension or attachment system which reduces or restricts the transmission of vibrational energy, e.g., between vibrating elements and building structures.

RESONANCE. The sympathetic vibration, resounding or ringing of enclosures, room surfaces, panels, etc. when excited at their natural frequencies.

REVERBERATION. The persistence of sound within a room or enclosure after a sound source has stopped radiating. This effect is very pronounced in large, relatively empty or partially furnished rooms with hard reflecting walls, ceilings and floor surfaces.

SOUND. (1) The sensation of sound. (2) A branch of physics concerned with the propagation of mechanical disturbances in matter and related subjects. In the present context sound is originated by vibrating bodies or aerodynamically, is propagated as an elastic disturbance at least partly in the air, and arrvies at the ear or other receiver (microphone, etc.).

SOUND INSULATION, ISOLATION. The use of building materials or constructions which will reduce or resist the transmission of sound.

SOUND LEAK. A hole, crack, or opening which permits the passage of sound.

SOUND PRESSURE. A fluctuation superimposed on the static atmospheric pressure by the passage of sound waves.

SOUND PRESSURE LEVEL (SPL). Expressed in decibels, the SPL is 20 times the logarithm to the base 10 of the ratio of the pressure of sound to the reference pressure 20 micronewtons per square meter (0.0002 microbar).

SOUND TRANSMISSION. The travel or propagation of sound into a room by any path, direct or indirect, from a sound source located outside the room.

SOUND TRANSMISSION CLASS (STC). A single-figure rating which provides an estimate of the airborne sound insulating performance of building partitions.

SOUND TRANSMISSION LOSS (STL). The decrease or attenuation in sound energy (expressed in decibels) of airborne sound as it passes through a building construction. In general, the transmission loss increases with frequency, i.e., the higher the frequency the greater the sound transmission loss.

STRUCTURE-BORNE SOUND. Sound energy imparted directly to and transmitted by solid materials, such as building structures.

Appendix C

Typical Wall Partitions

No.	Description	Relative* Cost Index	STC Rating
1	SOLID LIGHTWEIGHT AGGREGATE PLASTER PARTITION WITH METAL CHANNELS 3/4" metal channel studs 11" o.c., diamond mesh metal lath on one side, gypsum perlite plaster on both sides.	NA	31
2.	HOLLOW-CORE MOVABLE GYPSUM PARTITION 24" wide panels constructed of 5/8" gypsum core board strips, 7 1/2" and 4 3/8" wide, offset 1 1/2" at edges to form tongue and grove; 5/8", vinyl-faced, gypsum wallboard laminated to both sides of core board strips. Panels inserted into two piece metal floor and ceiling tracks. Gypsum to gypsum screws at 1/4 points along vertical edges of face.	NA	33
3.	2" SOLID PLASTER PARTITION 3/4" cold-rolled steel channels @ 12" o.c. w/3.4 lb. diamond mesh metal lath wire-tied to channels with gypsum sand plaster both sides; painted both sides.	140	36
4.	WOOD FRAME PARTITION 2x4 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; 5/8" gypsum wallboard nailed to studs both sides; joints reinforced and finished; painted both sides.	106	36
5.	2" SOLID PLASTER PARTITION 3/4" cold-rolled steel channels @ 16" o.c. w/3.4 lb. diamond mesh metal lath wire-tied with gypsum sand plaster both sides; painted both sides.	137	37
6.	2 1/2" SOLID PLASTER PARTITION 3/8" gypsum lath attached to floor and ceiling; 1 1/16" gypsum sand plaster both sides; painted both sides.	128	38
7.	STEEL FRAME PARTITION 1 5/8" metal channel studs @ 24" o.c. w/floor and ceiling channels; 5/8" gypsum wallboard screwed 12" o.c., both sides; joints reinforced and finished; painted both sides.	100	38

*The relative cost index is based on partition #7 as the base. NA indicates the relative cost index datum was not available.

No.	Description	Relative Cost Index	STC Rating
8.	STEEL TRUSS STUD, GYPSUM LATH AND LIGHTWEIGHT PLASTER 2 1/2 by 1/2" steel studs spaced 16" o.c. Galvanized wire clips, attached to studs on both sides, held 3/8" gypsum lath, 7/16" gypsum vermiculite plaster and 1/16" white-coat finish.	NA	38
9.	2 1/2" SOLID PLASTER PARTITION 3/4" cold-rolled steel channels @ 12" o.c. w/3.4 lb. diamond mesh (flat expanded) metal lath wire-tied to channels with gypsum sand plaster both sides; painted both sides.	144	39
10.	WOOD FRAME PARTITION 2x4 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; 1/2" gypsum wallboard nailed to studs both sides; joints reinforced and finished; painted both sides.	101	39
11.	STEEL TRUSS STUD, METAL LATH AND PLASTER 3 1/4" steel truss studs 16" o.c.; on both sides diamond mesh metal lath wire-tied to studs, 7/8" sanded gypsum plaster.	NA	39
12.	METAL CHANNEL STUD, GYPSUM BOARD 1 5/8" metal channel studs 24" o.c. attached to metal floor and ceiling runners, 1/2" gypsum wallboard screwed 12" on centers to both sides of studs. All joints taped and finished.	NA	39
13.	HOLLOW GYPSUM BLOCK PARTITION 3" hollow gypsum blocks w/3/8" mortar joints, 1/2" gypsum sand plaster both sides, painted both sides.	147	40
14.	WOOD FRAME PARTITION 2x4 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; double layer of 3/8" gypsum wallboard both sides, 1st layer nailed to studs and second laminated to first; exposed joints reinforced and finished; painted both sides.	124	40
15.	STEEL FRAME PARTITION 1 5/8" open truss steel studs @ 16" o.c. w/floor and ceiling channels; 3/8" gypsum lath screwed to studs and 1/2" gypsum sand plaster both sides; painted both sides.	138	41

No.	Description	Relative Cost Index	STC Rating
16.	METAL CHANNEL STUD, GYPSUM BOARD 3 5/8" metal channel studs 24" o.c. set into 3 5/8" metal floor and ceiling runners; 5/8" gypsum wallboard screwed to studs on both sides. All joints taped and finished.	NA	41
17.	HOLLOW GYPSUM BLOCK PARTITION 4" hollow gypsum block w/3/8" mortar joints, 1/2" gypsum sand plaster both sides; painted both sides.	157	42
18.	STEEL FRAME PARTITION 1 5/8" open truss steel studs @ 16" o.c. w/floor and ceiling channels; 3/8" gypsum lath attached w/resilient clips; 1/2" gypsum sand plaster both sides; painted both sides.	153	43
19.	DOUBLE CLAY BLOCK WALL - 2 1/2" CAVITY† Double wall: 4 1/4" thick hollow clay block leaves, 2 1/2" cavity, (wire ties between leaves); 1/2" plaster on each side.	NA	43
20.	HOLLOW CONCRETE BLOCK 6" hollow concrete blocks constructed with vertical mortar joints staggered.	NA	43
21.	STAGGERED WOODEN STUD, GYPSUM LATH AND PLASTER PARTITION 2x4" wooden studs 16" o.c. staggered 8" o.c. and offset 1/2". On each side 3/8" gypsum lath nailed to studs, 1/2" gypsum vermiculite plaster; machine-applied, and a hand-applied white-coat finish.	NA	43
22.	WOOD FRAME PARTITION 2x4 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; resilient clips @ 16" o.c. (horizontal and vertical) nailed to studs and holding 3/8" gypsum lath; 1/2" gypsum sand plaster w/white coat finish both sides; painted both sides.	156	44
23.	STAGGERED STUDS, WOOD FRAME PARTITION Staggered 2x3 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; two layers of 5/8" gypsum wallboard nailed to studs both sides, first layer nailed 7" o.c.; second layer 16" o.c.; joints reinforced and finished; painted both sides.	156	44

† Field Measurements

No.	Description	Relative Cost Index	STC Rating
24.	STAGGERED STUDS, WOOD FRAME PARTITION Staggered 2x3 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; 5/8" gypsum wallboard nailed @ 7" o.c. to studs both sides; joints reinforced and finished; painted both sides.	118	44
25.	STAGGERED WOODEN STUD, GYPSUM BOARD PARTITION 2- by 3" wooden studs 16" o.c., staggered 8" o.c., attached to 2- by 4" wooden plates at ceiling and floor; 1/2" gypsum wallboard nailed 7" o.c. on both sides to studs. All joints taped and finished.	NA	44
26.	SLOTTED WOOD STUD FRAME PARTITION 2x4 slotted studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; 3" mineral fiber blanket insulation stapled between studs; 3/8" gypsum lath nailed @ 7" o.c., 1/2" gypsum sand plaster w/white coat finish both sides; painted both sides.	160	45
27.	CONCRETE BLOCK WALL 6" x 8" x 16" hollow concrete block laid-up with vertical joints staggered; painted both sides.	129	45
28.	STEEL FRAME PARTITION 2 1/2" open truss steel studs @ 16" o.c. w/floor and ceiling channels; 3/8" gypsum lath attached w/resilient clips and 1/2" gypsum sand plaster both sides; painted both sides.	160	45
29.	HOLLOW GYPSUM BLOCK, RESILIENT ONE SIDE, PLASTER BOTH SIDES 3- by 12- by 30" hollow gypsum blocks with 1/2" mortar joints. On one side 7/16" sanded gypsum plaster; on the other side resilient clips, attached with 2" staples placed 24" o.c. horizontally and 28 1/4" o.c. vertically, held 3/4-in. horizontal metal channels wire-tied 28 1/4 in. o.c. to clips, 1/2" "V" edge long-length gypsum lath wire-tied to channels, and 11/16" sanded gypsum plaster; 1/16" white coat finish applied to both sides.	NA	45
30.	WOOD FRAME PARTITION 2x4 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; 3/8" gypsum lath nailed to studs both sides; 1/2" gypsum sand plaster w/white coat finish both sides; painted both sides.	141	46

No.	Description	Relative Cost Index	STC Rating
31.	CINDER BLOCK PARTITION 4" x 8" x 16" hollow cinder block with 5/8" gypsum sand plaster both sides; painted both sides.	175	46
32.	STAGGERED WOODEN STUD, GYPSUM BOARD WITH INSULATION 2- by 4" wooden studs 16" o.c., staggered 8" o.c., attached to 2- by 4 3/4" wooden floor and ceiling plates; 1/2" gypsum wallboard nailed on both sides to studs, 0.9" wood-fiber wool blanket stapled on the inside of one side of the wall. All joints taped and finished.	NA	46
33.	HOLLOW GYPSUM BLOCK, RESILIENT ONE SIDE, PLASTER BOTH SIDES 3- by 12- by 30" hollow gypsum blocks with 1/2" mortar joints. On one side 7/16" sanded gypsum plaster; on the other side resilient clips, spaced 18" o.c. vertically and 16" o.c. horizontally, held 3/4" metal channels 16" o.c., to which expanded metal lath was wire-tied; 11/16" sanded gypsum plaster. 1/16" white coat finish applied to both sides.	NA	46
34.	WOOD FRAME PARTITION 2x4 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; 1/2" gypsum wallboard w/layer of lead (3 lbs./ft^2) laminated to wall-board and nailed to studs both sides; joints reinforced and finished; painted both sides.	229	47
35.	STEEL FRAME PARTITION 2 1/2" open truss steel studs @ 24" o.c. w/floor and ceiling channels; 3/8" gypsum lath attached with galvanized wire clips and 1/2" gypsum sand plaster both sides; painted both sides.	138	47
36.	STAGGERED STUDS, WOOD FRAME PARTITION Staggered 2x3 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; 1/2" sound deadening board nailed to both sides; 1/2" gyp-sum wallboard laminated to sound deadening board both sides; joints reinforced and finished; painted both sides.	149	47

No.	Description	Relative Cost Index	STC Rating
37.	STEEL FRAME PARTITION† 3 1/4" open truss steel studs @ 16" o.c. w/floor and ceiling channels isolated with 1/2" continuous resilient gasket material; 3/8" gypsum lath attached w/resilient clips and 1/2" gypsum sand plaster w/white coat finish one side; 2" mineral fiber baanket insulation stapled in stud space, 3/8" gypsum lath attached w/galvanized wire clips and 1/2" gypsum sand plaster w/white coat on other side; perimeter caulking w/nonsetting resilient caulking compound; painted both sides.	174	47
38.	DOUBLE WALL, SOLID PLASTER LEAVES Double wall with 4 1/2" between leaves consisting of 3/4" cold-rolled metal channels 12" o.c. stiffened by a 1" horizontal metal channel half-way between floor and ceiling; 3.4 lb. diamond mesh metal lath and 3/4" gypsum sand plaster both sides; painted both sides.	185	47
39.	STEEL FRAME PARTITION 3 5/8" metal channel studs @ 24" o.c. w/floor and ceiling channels; 2 layers of 5/8" gypsum wallboard, first layer screwed to studs, second layer laminated to first; joints reinforced and finished; painted on both sides.	141	47
40.	WOODEN STUD, RESILIENT CHANNELS, GYPSUM BOARD 2- by 4" wooden studs 16" o.c. attached to 2- by 4" wooden floor and ceiling plates, resilient channels nailed horizontally to both sides of studs 24" o.c., 5/8" gypsum wallboard screwed 12" o.c. to channels. All joints taped and finished.	121	47
41.	HOLLOW GYPSUM BLOCK, RESILIENT ONE SIDE, PLASTER BOTH SIDES 3- by 12- by 30" hollow gypsum blocks with 1/2" mortar joints. On one side 7/16" sanded gypsum plaster; on the other side, slotted resilient metal furring runners placed 25" o.c., nailed to mortar joints 12" o.c. 1/2" long-length gypsum lath wire-tied to the runners, and 11/16" of sanded gypsum plaster; 1/16" white coat finish applied to both sides.	NA	47

No.	Description	Relative Cost Index	STC Rating
42.	HOLLOW GYPSUM BLOCK, GYPSUM LATH AND RESILIENT CLIPS ONE SIDE† 4- by 12- by 30" hollow gypsum blocks isolated around perimeter with 1/2" thick continuous resilient gaskets. On one side, 3/8" gypsum lath attached with resilient clips 16" o.c., 1/2" sanded gypsum plaster with white coat finish applied to lath; on the other side, 5/8" sanded gypsum plaster with white coat finish applied directly to gypsum blocks. The 1/4" clearance around the perimeter closed with a non-setting resilient caulking compound.	NA	47
43.	METAL CHANNEL STUD, TWO LAYERS GYPSUM BOARD† 3 5/8" metal channel studs 27 3/4" o.c. set into metal floor and ceiling tracks; stud at each adjoining wall and metal runners set on beads of non-setting resilient caulking compound. Two layers of 1/2" gypsum wallboard attached to both sides of studs; each layer screwed 12" o.c. with screws staggered 6" in reference to each other. Joints of gypsum board staggered 24" with all exposed joints taped and finished. The 1/2" perimeter clearance around both layers closed with a non-setting resilient caulking compound.	NA	47
44.	STEEL FRAME PARTITION 3 1/4" open truss steel studs @ 16" o.c. w/floor and ceiling channels; 3/8" gypsum lath attached w/galvanized wire clips both sides; 3/8" gypsum wallboard laminated to gypsum lath; joints reinforced and finished; painted both sides.	131	48
45.	HOLLOW CONCRETE BLOCK 12" wall made of hollow 8- by 8- by 12" and 8- by 4- by 16" concrete blocks.	NA	48
46.	STAGGERED STUDS, WOOD FRAME PARTITION Staggered 2x4 studs @ 16" o.c. w/single 2x6 floor plate and double ceiling plate; 1 1/2" blanket insulation woven between studs; 1/2" gypsum wallboard nailed to both sides; joints reinforced and finished; painted both sides.	159	49
47.	DOUBLE BRICK WALL - 2" CAVITY† Double wall with 4 1/2" thick brick leaves separated by a 2" cavity (wire ties between leaves); 1/2" plaster on exposed sides.	NA	49

No.	Description	Relative Cost Index	STC Rating
48.	METAL CHANNEL STUD, FIBER BOARD, GYPSUM BOARD† 3 5/8" metal channel studs 12" o.c. Top, bottom and side channels isolated from concrete floor and ceiling with a resilient caulking compound. 1/2" mineral fiber board screwed 24" o.c. to alternate studs on both sides such that both faces were not screwed to the same stud. 1/2" gypsum wallboard laminated and screwed 8" o.c. along panel periphery and 12" o.c. in field; lamination strips offset from screws. All exposed joints taped and finished.	NA	50
49.	STEEL TRUSS STUD, GYPSUM LATH AND PLASTER 3 1/4" steel truss studs 24" o.c. attached to metal floor and ceiling tracks; on both sides 3/8" perforated gypsum lath attached with wire clips wire-tied to studs, 1/2" sanded gypsum plaster.	NA	51
50.	METAL CHANNEL STUD, GYPSUM BOARD WITH INSULATION, RESILIENT 3 5/8" metal channel studs 24" o.c. set in 3 5/8" metal floor and ceiling runners; 5/8" gypsum wallboard screwed to studs on both sides. On one side, resilient channels screwed horizontally 24" o.c. to inner layer; 5/8" gypsum wallboard screwed to channels. On the other side, 5/8" gypsum wallboard laminated directly to inner layer. 3" mineral fiber blankets hung between studs. All exposed joints taped and finished.	NA	51
51.	WOOD FRAME PARTITION 2x4 studs @ 16" o.c. w/single 2x4 floor plate and double ceiling plates; resilient clips @ 16" o.c. (horizontal and vertical) nailed to studs and holding 3/8" gypsum lath; 1/2" gypsum sand plaster w/white coat finish both sides; painted both sides.	156	52
52.	STEEL FRAME PARTITION 2 1/2" metal channel studs @ 24" o.c. w/floor and ceiling channels set on beads of non-setting resilient caulking compound; 3 1/2" glass fiber blanket insulation (2 lbs./cu. ft.) stapled between studs, two layers of 1/2" gypsum wallboard screw attached @ 12" o.c. w/staggered joints, perimeter caulking w/non-setting resilient caulking compound, joints reinforced and finished; painted both sides.	153	52

No.	Description	Relative Cost Index	STC Rating
53.	HOLLOW GYPSUM BLOCK PARTITION 3" x 12" x 30" hollow gypsum block with 1/2" mortar joints, resilient clips stapled @ 16" o.c. vertically and horizontally, 3/8" gypsum lath and 1/2" gypsum sand plaster with white coat finish one side, on the other side 1/2" gypsum sand plaster with white coat finish; painted both sides.	169	52
54.	POURED CONCRETE WALL† 6" poured concrete wall, 1/2" gypsum sand plaster applied both sides, painted both sides.	196	53
55.	STEEL FRAME PARTITION† 3 5/8" metal channel studs @ 24" o.c. w/floor and ceiling channels isolated with continuous bead of non-setting resilient caulking compound; 1 1/2" mineral fiber blanket insulation stapled between studs; two layers of 5/8" gypsum wallboard attached to both sides, first layer screwed @ 8" o.c. at edges and @ 12" o.c. in the field area, second layer screwed @ 24" o.c. and laminated to first layer, joints staggered or offset 24"; perimeter caulking w/non-setting resilient caulking compound; joints reinforced and finished; painted both sides.	169	55
56.	BRICK WALL 12" solid brick wall, 3 tiers of standard brick, flemish bond.	426	56

Appendix D

Typical Floor/Ceiling Assemblies

No.	Description	Relative* Cost Index	STC	IIC
1.	WOOD FRAME FLOOR SYSTEM WITH CARPET† 2x8 joists @ 16" o.c.; 1 1/2" T & G wood fiber board nailed, pad and carpet; 1/2" gypsum wallboard ceiling nailed 6" o.c. with joints reinforced and finished, painted.	153	29	56
2.	WOOD FRAME FLOOR AND CEILING SYSTEM† 2x8 joists @ 16" o.c.; 7/8" x 3 1/4" T & G wood floor sanded and finished; 3/8" gypsum wallboard ceiling nailed with joints reinforced and finished, painted.	100	34	32
3.	WOODEN FRAME FLOOR AND CEILING SYSTEM 2- by 10" wooden joists 16" o.c. On the floor side, 1/2" thick plywood subfloor nailed 6" o.c. along edges and 10" o.c. in field, building paper underlayment, 25/32- by 2 1/4" oak wood flooring nailed at each joist intersection and midway between joists. On the ceiling side, 5/8" thick gypsum wallboard nailed 6" o.c. to joists; all joints taped and finished.	NA	37	32
4.	WOOD FRAME FLOOR AND CEILING SYSTEM 2x10 joists @ 16" o.c.; 5/8" plywood subfloor, 1/2" plywood underlayment nailed with staggered joints, 1/8" x 9" x 9" vinyl asbestos tile laid in mastic; 1/2" gypsum wallboard ceiling nailed, joints reinforced and finished, painted.	128	37	33
5.	WOOD FRAME FLOOR AND CEILING SYSTEM WITH CARPET AND PAD 2- by 10" wooden joists 16" o.c. On the floor side, 1/2" thick plywood subfloor nailed 6" o.c. along edges and 10" o.c. in field, building paper underlayment, 25/32- by 2 1/4" oak wood flooring nailed at each joist intersection and midway between joists; carpet, 44 oz/yd^2, with hair felt pad, 40 oz/yd^2, placed on wood flooring. On the ceiling side, 5/8" thick gypsum wallboard nailed 6" o.c. to joists; all joints taped and finished.	NA	38	56

*The relative cost index is based on partition #2 as the base. NA indicates the relative cost index datum was not available.

†Field Measurements

No.	Description	Relative Cost Index	STC	IIC
6.	WOOD FRAME FLOOR AND CEILING SYSTEM 2x8 joists @ 16" o.c.; 1/2" C-D plywood subfloor, 25/32" x 2 1/4" hardwood floor sanded and finished; 1/2" gypsum wallboard ceiling nailed to joists, 1/2" acoustical tile laminated to gypsum wallboard.	131	39	37
7.	WOOD FRAME INSULATED FLOOR SYSTEM WITH CARPET AND PAD 2x10 joists @ 16" o.c.; 3" mineral fiber batt insulation stapled between joists, 1/2" plywood subfloor, building paper underlayment; 25/32" x 2 1/4" hardwood flooring sanded and finished, 40 oz/yd.^{2} hair felt pad, 44 oz./yd.^{2} carpet; 5/8" gypsum wallboard ceiling joints reinforced and finished, painted.	216	39	58
8.	WOOD FRAME FLOOR AND CEILING SYSTEM WITH INSULATION 2x10 joists @ 16" o.c. with 3" thick mineral fiber batt insulation stapled between joists; 1/2" plywood subfloor nailed @ 6" o.c. @ edges and 10" o.c. in the field, building paper underlayment, 25/32" x 2 1/4" oak flooring sanded and finished; 5/8" gypsum wallboard ceiling nailed @ 6" o.c., joints reinforced and finished, painted.	135	40	32
9.	CONCRETE CHANNEL FLOOR SLAB[†] Prefabricated concrete channel slabs mortared together 20" o.c. Each slab had a 3" deep trapezoidal channel with bases of 11 and 14 3/4". On the floor side, 3/4" thick sand-cement finish.	NA	42	32
10.	PRESTRESSED CONCRETE CHANNEL FLOOR SLAB 3" prestressed concrete channels with joints grouted full; 3/4" concrete topping; ceiling painted.	126	42	32
11.	ISOLATED 4" CONCRETE SLAB 4" concrete slab reinforced with 6x6-10/10 welded wire fabric, 1/8" vinyl floor tile laid in mastic, ceiling painted.	148	44	29
12.	REINFORCED CONCRETE STRUCTURAL SLAB WITH WOOD BLOCK FLOORING 4" concrete slab reinforced with 6x6-10/10 welded wire fabric; 1/2" x 9" x 9" prefinished oak block flooring laid in mastic; ceiling painted.	125	44	41

No.	Description	Relative Cost Index	STC	IIC
13.	CONCRETE FLOOR SLAB WITH CARPET AND PAD 4" concrete slab reinforced with 6x6-10/10 welded wire fabric; 1/4" foam rubber pad and wool carpeting (1/4" wool loop pile with 1/8" woven jute backing), ceiling painted.	163	44	80
14.	WOOD FRAME FLOOR AND RESILIENT CEILING SYSTEM 2x8 joists @ 16" o.c., 3/4" plywood subfloor, layer of building paper, 7/8" x 3 1/4" T&G fir flooring sanded and finished; on the ceiling, resilient channels @ 24" o.c. nailed @ 12" o.c., 5/8" gypsum wallboard screwed to channels, joints reinforced and finished, painted.	140	45	44
15.	PRESTRESSED CONCRETE FLOOR SLABS† 20" x 6" deep prestressed pumice concrete slabs; 3/8" leveling grout, 3/4" sand-cement topping; 3/8" gypsum sand plaster ceiling painted.	141	46	30
16.	RIBBED CONCRETE FLOOR SLAB† 7 1/4" ribbed concrete floor. The ribs were 5 1/4- by 3 3/4", spaced 21" o.c., with 1- by 2" wooden nailing strips cast into ends. On the floor side, the slab was 2" thick with a 3/4" thick sand-cement screed. On the ceiling side, 5/8" thick wooden laths nailed to nailing strips, held 5/8" thick reeds and plaster.	NA	46	42
17.	STEEL FRAME CONCRETE FLOOR WITH CARPET AND PAD 7" steel bar joists @ 27" o.c.; 3/8" rib lath, 2" concrete slab, foam rubber pad with woven jute fiber cloth, nylon carpet with woven backing and 1/4" looped pile; on the ceiling, 3/4" cold-rolled channels wire-tied, 3/8" plain gypsum lath attached with clips, 7/16" gypsum sand plaster and 1/16" white-coat finish, painted.	178	46	74
18.	HOLLOW TILE BEAM† 5" thick tile beams, 15 3/4" wide, held together with steel reinforcement and cement mortar. On the floor side, linoleum adhered to 3/4" thick sand-cement screed. On the ceiling side, 3/8" layer of plaster.	NA	47	40

No.	Description	Relative Cost Index	STC	IIC
19.	REINFORCED CONCRETE SLAB[†] 6" reinforced concrete slab; 5/8" mastic asphalt floor; 3/4" gypsum sand plaster ceiling, painted.	171	47	31
20.	STEEL JOIST WITH CONCRETE FLOOR SLAB 2 1/2" thick perlite concrete 72 lb/ft^3, on 28 gauge corrugated steel units supported by 14" steel bar joists; 1/8" thick asphalt tile cemented to concrete. On the ceiling side, 3/4" furring channels, 13 1/2" o.c., wire-tied to joists, 3.4 lb/yd^2 diamond mesh metal lath wire-tied to furring channels, 9/16" coat of plaster with 1/16" white-coat finish.	NA	47	37
21.	PRECASTED CONCRETE CHANNELS WITH WOOD BLOCK FLOORING[†] 7" deep x 14" wide precast trapezoidal concrete channels; spaces between channels filled and 1 1/2" concrete topping slab, 1" thick wood block floor covering; 3.4 lbs/yd.^{2} expanded metal lath and 3/4" gypsum sand plaster ceiling, painted.	203	47	42
22.	STEEL FRAME CONCRETE FLOOR WITH CARPET AND PAD 14" steel bar joists @ 16" o.c.; 28 gauge corrugated steel deck, 2 1/2" perlite concrete slab, felt pad, carpet; on ceiling, 3/4" cold-rolled channels 13 1/2" o.c. wire-tied to joists, diamond mesh metal lath (3.4 lbs./yd.^{2}) wire-tied, 9/16" perlite gypsum plaster with 1/16" white-coat finish, painted.	265	47	59
23.	STEEL FRAME CONCRETE FLOOR SYSTEM WITH CARPET AND PAD 18" steel bar joists @ 16" o.c.; 5/8" plywood 1 5/8" lightweight concrete topping, 40 oz./ft.^{2} all-hair pad, 44 oz./yd.^{2} all-wool pile carpet; 5/8" gypsum wallboard ceiling, joints reinforced and finished, entire periphery caulked and sealed, painted.	264	47	62
24.	WOOD FRAME FLOOR WITH CARPET AND PAD AND RESILIENT CEILING SYSTEM 2x10 joists @ 16" o.c.; 1/2" plywood subfloor, building paper underlayment, 25/32" x 2 1/4" hardwood flooring sanded and finished, 40 oz./yd.^{2} pad, 44 oz./yd.^{2} carpet; resilient channels attached to joists, 5/8" gypsum wallboard ceiling, joints reinforced and finished, painted.	215	47	66

No.	Description	Relative Cost Index	STC	IIC
25.	WOOD FRAME INSULATED FLOOR WITH CARPET AND PAD AND RESILIENT CEILING SYSTEM 2x8 joists @ 16" o.c.; 3" mineral fiber batt insulation stapled between joists, 5/8" T&G plywood subfloor, 40 oz./yd.^{2} hair felt pad, 44 oz./yd.^{2} carpet; 5/8" gypsum wallboard ceiling, screwed to resilient channels spaced 24" o.c., joints reinforced and finished, entire periphery caulked and sealed, painted.	169	47	69
26.	CONCRETE FLOOR SLAB IN STEEL JOISTS 7" steel bar joists spaced 27" o.c. On the floor side, 3/8" metal rib lath attached to top of joists, and 2" thick poured concrete floor. On the ceiling side, resilient clips attached to joists held 3/4" metal furring channels 16" o.c.; 3/8- by 16' by 48" plain gypsum lath held with wire clips and sheet metal end joint clips; 7/16" sanded gypsum plaster and 1/16" white-coat finish.	NA	48	32
27.	CONCRETE FLOOR SLAB ON STEEL JOISTS WITH FLOOR COVERINGS 7" steel bar joists spaced 27" o.c. On the floor side, 3/8" metal rib lath attached to top of joists, and 2" thick poured concrete floor. On the ceiling side, 3/4" metal furring channels wire-tied to joists 16" o.c.; 3/8- by 16- by 48" plain gypsum lath held with wire clips and sheet metal end joint clips; 7/16" sanded gypsum plaster and 1/16" white-coat finish.	NA	48	33
28.	REINFORCED CONCRETE STRUCTURAL SLAB SUSPENDED CEILING SYSTEM 4 3/8" reinforced concrete slab; 3/4" concrete topping; metal lath suspended 4" with wire hangers, 7/8" gypsum sand plaster, painted.	128	48	47
29.	STEEL FRAME CONCRETE FLOOR 14" steel bar joists @ 16" o.c; 2 1/2" concrete slab, 1/8" asphalt tile laid in mastic; on ceiling, 3/4" cold-rolled channels 13 1/2" o.c. wire-tied to joists, diamond mesh metal lath (3.4 lbs./yd.^{2}) wire-tied, 9/16" perlite gypsum plaster with 1/16" white-coat finish, painted.	210	49	35

No.	Description	Relative Cost Index	STC	IIC
30.	WOOD FRAME FLOOR AND CEILING SYSTEM WITH INSULATION AND RESILIENT CHANNELS 2x10 joists @ 16" o.c. with 3" thick mineral fiber batt insulation stapled between joists; 1/2" plywood subfloor nailed @ 6" o.c. @ edges and 10" o.c. in the field, building paper underlayment, 25/32" x 2 1/4" oak flooring sanded and finished; on the ceiling, resilient channels @ 24" o.c., 5/8" gypsum wallboard screw attached @ 12" o.c., joints reinforced and finished, painted.	144	49	46
31.	REINFORCED HOLLOW TILE FLOOR 15 3/4" wide x 5" deep hollow tile beams reinforced; prefinished wood parquet flooring laid in mastic; 1x3 ceiling furring @ 19" o.c., 3/8" gypsum lath, 3/8" reeds and gypsum sand plaster, painted.	219	50	46
32.	PRESTRESSED CONCRETE FLOOR SLAB WITH ISOLATED WOOD FINISH FLOOR† 14" x 12 1/2" x 5" deep trapezoidal prestressed concrete slabs @ 14 1/2" o.c. with spaces between grouted full; 1" glass wool quilt, 2x2 sleepers @ 20" o.c., 7/8" x 3 1/4" T&G wood flooring sanded, linoleum floor covering; 5/8" gypsum sand plaster ceiling, painted.	231	50	49
33.	PRESTRESSED CONCRETE FLOOR SLABS† 14" x 12 1/2" x 5" deep trapezoidal prestressed concrete slabs @ 14 1/2" o.c.; grouted and topped with 1" sand-cement topping, 3/16" cork tile laid in mastic; on the ceiling, 1x2 furring strips @ 16" o.c. attached with metal clips, 3/8" gypsum wallboard, joints reinforced and finished, painted.	218	50	51
34.	WOOD FRAME INSULATED FLOOR WITH CARPET AND PAD AND RESILIENT CEILING SYSTEM 2x10 joists @ 16" o.c.; 3" mineral fiber batt insulation stapled between joists, 1/2" plywood subfloor, building paper underlayment, 25/32" x 2 1/4" hardwood flooring sanded and finished, 40 oz./yd.^{2} hair felt pad, 44 oz./yd.^{2} carpet; 5/8" gypsum wallboard ceiling screwed to resilient channels spaced 24" o.c., joints reinforced and finished, painted.	224	50	70

No.	Description	Relative Cost Index	STC	IIC
35.	STEEL FRAME CONCRETE FLOOR SYSTEM 7" steel bar joists @ 27" o.c.; 3/8" rib lath, 2" concrete slab; on ceiling, resilient clips and 3/4" cold-rolled channels 16" o.c., 3/8" plain gypsum lath attached with wire clips, 7/16" gypsum sand plaster and 1/16" white-coat finish, painted.	259	51	35
36.	REINFORCED CONCRETE FLOOR SLAB† 5" thick reinforced concrete. On the floor side, linoleum on bitumen-felt underlayment. On the ceiling side 1/2" thick paper fiber board.	NA	51	47
37.	REINFORCED CONCRETE STRUCTURAL SLAB† 4 3/8" reinforced concrete slab; 3/4" concrete topping, 1/8" linoleum floor covering; 3/8" gypsum sand plaster ceiling, painted.	141	51	48
38.	CONCRETE SLAB, WOOD SLEEPERS, WOOD FINISH FLOOR† 5 1/2" reinforced concrete slab; 2x2 wood sleepers laid in asbestos lined metal clips anchored to slab, 3/4" T&G wood flooring, 1/2" gypsum sand plastered ceiling, painted.	173	54	51
39.	CONCRETE JOIST FLOOR SYSTEM WITH FILLER BLOCKS, FLOATING TOPPING AND SUSPENDED CEILING† 2 1/2" x 5 1/2" deep concrete joists @ 14 1/2" o.c. with 1 1/2" slab over 4 x 12" hollow filler blocks; 1" glass wool quilt covered with building paper laid in mastic, 1 1/2" concrete topping reinforced, plastic tile laid in mastic; 1/4" x 1 1/4" steel bars suspended 6" below the underside of slab, 3.4 lbs./yd.^{2} expanded rib lath, 1/2" gypsum sand plaster, painted.	226	55	53

No.	Description	Relative Cost Index	STC	IIC
40.	CONCRETE WITH HOLLOW BLOCKS, FLOATING FLOOR, SUSPENDED CEILING† 5 1/2" thick reinforced concrete with 4- by 12" hollow masonry blocks embedded 15" o.c. On the floor side, 1 1/2" thick wire mesh reinforced sand-cement screed floating on 1" thick bitumen-bonded glass-wool quilt covered with building paper; thermoplastic tile floor covering. On the ceiling side, 1/2" layer of plaster on ribbed expanded metal lath attached to 1/4 by 1 1/4" steel bars suspended 6" from the concrete slab by 1/4" steel rods, spaced 48" o.c.	NA	55	53
41.	REINFORCED CONCRETE SLAB WITH WOOD FINISH FLOOR† 6" reinforced concrete slab; 1" glass wool quilt, 2x2 wood sleepers @ 16" o.c., 3/4" x 3 1/2" T&G wood flooring nailed, sanded and finished; 1/2" gypsum sand plaster ceiling, painted.	190	55	57
42.	REINFORCED CONCRETE WITH FLOOR COVERING 4" thick reinforced concrete slab with carpeting and pad. The carpeting was of 1/4" wool loop pile with 1/8" woven jute backing 0.49 lb./ft.^{2}; the foam fubber pad was 1/4" thick and weighed 0.53 lb./ft^2.	NA	44	80

Appendix E*

Acoustical Guide Criteria

A STRUCTURE

5 ACOUSTIC ENVIRONMENT

- **Requirement A.5.1**
  There should be control of generation and transmission of vibration that results in airborne sound radiation.

- **Criterion A.5.1.1**
  Structure-borne noise radiation should not exceed noise criterion established for the space as given in L.5.1.1 (See Criterion A.1.5.1 for control of vibration)

- **Tests**
  Design computation and documentation.

  Field inspection and documentation of prototype buildings during construction.

  ANSI S1.2-1962, "Standard Method for the Physical Measurement of Sound" (Used to determine conformance of entire building with Noise Control Criterion; see L.5.1.1)

- **Commentary on A.5.1.1**
  Structural design should include consideration of vibration from the standpoints of structural safety and serviceability and the transmission of structure-borne vibration to partitions, curtains, walls, etc., that ultimately is radiated as airborne sound.

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*Contains changes not in NBS Guide Criteria through December 1 update. Except for the NC number change of Criterion L.5.1.1 the changes are editorial in nature.

■ Requirement B.5.1
Provision should be made for acoustical privacy between dwelling units.

■ Criterion B.5.1.1
The sound transmission class (STC) of inter-dwelling space dividers, determined by documentation or by laboratory measurement, should be equal to or greater than Grade II Criteria of Table 10-2 of "A Guide to Airborne, Impact and Structureborne Noise Control in Multifamily Dwellings", HUD FT/TS-24, Table 10-2 follows:

Criteria for Airborne Sound Insulation of
Wall Partitions Between Dwelling Units

Partition Function Between Dwellings			Grade II
Apt. A		Apt. B	STC
Bedroom	to	Bedroom	52
Living room	to	Bedroom (1,2)	54
Kitchen (3)	to	Bedroom (1,2)	55
Bathroom	to	Bedroom (1,2)	56
Corridor	to	Bedroom (2,4)	52
Living room	to	Living room	52
Kitchen (3)	to	Living room (1,2)	52
Bathroom	to	Living room (1)	54
Corridor	to	Living room (2,4,5)	52
Kitchen	to	Kitchen (6,7)	50
Bathroom	to	Kitchen (1,7)	52
Corridor	to	Kitchen (2,4,5)	52
Bathroom	to	Bathroom (7)	50
Corridor	to	Bathroom (2,4)	48

NOTES RE TABLE

1. The most desirable plan would have the dwelling unit partition separating spaces with equivalent functions, e.g., living room opposite living room, etc.; however, when this arrangement is not feasible, the partition should have greater sound insulating properties.

2. Whenever a partition wall might serve to separate several functional spaces, the highest criterion should prevail.

3. Or dining, or family, or recreation room.

4. It is assumed that there is no entrance door leading from corridor to living unit.

5. A common approach to corridor partition construction correctly assumes the entrance door as the acoustically weakest "link" and then incorrectly assumes that the basic partition wall need be no better acoustically than the door. However, the basic partition wall may separate the corridor from sensitive living areas such as the bedroom and bathroom without entrance doors, and should therefore have adequate insulating properties to assure acoustical privacy in these areas. In areas where entrance doors are used, the integrity of the corridor-living unit partition should be maintained by utilizing solid-core entrance doors, with proper gasketing. The most desirable arrangement has the entrance door leading from the corridor to a partially enclosed vestibule or foyer in the living unit.

6. Double-wall construction is recommended to provide, in addition to airborne sound insulation, isolation from impact noises generated by the placement of articles on pantry shelves and the slamming of cabinet doors. Party walls which utilize resilient spring elements to achieve good sound insulation may be used, providing wall cabinets are not mounted on them. It is not practical to use such walls for mounting of wall cabinets because the sound insulating performance of the walls can be easily short-circuited unless specialized vibration isolation techniques are used. See HUD FT/TS-24 regarding proper installation of cabinets and recommended isolation procedures for appliance installations.

7. See HUD FT/TS-24 regarding vibration isolation of plumbing in kitchen and bathrooms and recommended installation of cabinets, medicine chests, etc.

■ Test

ASTM E90-66, Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

Field inspection and documentation of prototypes during construction.

■ Commentary on B.5.1.1

When the STC value cannot be documented by literature values on similar partitions or by computation using appropriate analysis, laboratory measurements are indicated. Results of laboratory measurements should be obtained prior to construction of prototype. The results of laboratory measurements usually are indicative of the optimum performance capability of a partition type. These, along with field inspection and documentation followed by final performance measurement of completed prototype, will be used to confirm adequate acoustical privacy.

■ Criterion B.5.1.2

Noise Isolation Class of 4 less than STC values of Criteria B.5.1.1 and B.5.1.3 to be determined by field test of prototypes.

■ Test

Appendix A1 of ASTM E336-67T, Tentative Recommended Practice for Measurement of Airborne Sound Insulation in Buildings.

Field inspection and documentation of prototypes during construction.

■ Commentary on B.5.1.2

The Noise Isolation Class (NIC) is based upon the Noise Reduction (NR) which is a measure of the isolation between two enclosed spaces and is not necessarily a product of the dividing partition alone. It may or may not include flanking paths. As the concept of noise reduction is generally based upon a "furnished" space, and as it is anticipated that field performance measurements of the prototypes will be conducted on the site prior to occupancy, the necessity of normalization is apparent. The noise reduction measurement results should be normalized and referred to as Normalized Level Differences, D_N. The recommended procedure is normalization to a reference absorption value of $A_o = 10 m^2$ or $108 ft^2$ according to the following equation:

$$D_N = L_1 - L_2 - (10 \log_{10} \frac{A}{A_o})$$

where: $D_N = D_{A_o}$ = Normalized Level Difference

L_1 = space-time averaged sound pressure level measured in the source space

L_2 = space-time averaged sound pressure level measured in the receiving space

A = total sound absorption of the receiving space calculated by $A = \frac{0.9210\ Vd}{c}$

where: V = total volume

d = average rate of decay in decibels per second

c = speed of sound

(Metric or English units must be consistent)

A_o = Reference equivalent absorption $10\ m^2$ or $108\ ft^2$

(See ASTM C423-66, "Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms", Section 9.1, for measurement of decay rate procedure.)

C INTERIOR SPACE DIVIDERS; WALLS AND DOORS, INTRA-DWELLING

5 ACOUSTIC ENVIRONMENT

■ Requirement C.5.1

There should be acoustical privacy within the dwelling unit to create and allow for development of personal and family relationships.

■ Criterion C.5.1.1

The sound transmission class (STC) of intra-dwelling space dividers, determined by documentation or by laboratory measurements, should be equal to or greater than the following:

Criteria for Airborne Sound Insulation within a Dwelling Unit*

Partition Function Between Rooms	Minimum Desirable STC	Minimum Acceptable STC
Bedroom to bedroom	40	36
Living room to bedroom	42	36
Bathroom to bedroom	45	36
Kitchen to bedroom	45	36
Bathroom to living room	45	36
Bathroom to bathroom	45	36

*The minimum desirable STC values represent the absolute minimum STC value that should be strived for. These values can, in many cases, be met using conventional methods in conjunction with optimal arrangement of rooms using closets as "buffer" zones. It is recognized, however, that certain forms of conventional construction do not, even meet these minimum desirable levels. Therefore, on an interim basis, the minimum acceptable STC values are given. These values should be met by the partition itself exclusive of the use of "buffer" zones.

■ Test

ASTM E90-66, Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

Field inspection and documentation of prototypes during construction.

- Commentary on C.5.1.1

  When the STC value cannot be documented by literature values on similar partitions or by computation using appropriate analysis, laboratory measurements are indicated. Results of laboratory measurements should be obtained prior to construction of prototype. The results of laboratory measurements usually are indicative of the optimum performance capability of a partition type. These, along with field inspection and documentation followed by final performance measurement of completed prototype, will be used to confirm adequate acoustical privacy.

  Laboratory test specimen should include weak links, (e.g., doors) in transmission chain. In the case where a bathroom door opens directly into a bedroom, such as a master bedroom/master bathroom combination, it is not necessary for the STC-criteria to be met for this partition.

- Criterion C.5.1.2

  Noise Isolation Class of 8 less than corresponding STC values of Criterion C.5.1.1 to be determined by field test of prototypes.

- Test

  Appendix A1 of ASTM E336-67T, Tentative Recommended Practice for Measurement of Airborne Sound Insulation in Buildings.

  Field inspection and documentation of prototypes during construction.

- Commentary on C.5.1.2

  Special attention should be directed to doors and ducts with reference to room-to-room sound isolation. See Commentary on B.5.1.2.

D INTERIOR SPACE DIVIDERS; FLOOR-CEILING

5 ACOUSTIC ENVIRONMENT

■ Requirement D.5.1
Provision should be made for acoustical privacy between dwelling units.

■ Criterion D.5.1.1
Grade II Criteria of Table 10-3 of "A Guide to Airborne, Impact and Structureborne Noise Control in Multifamily Dwellings", HUD FT/TS-24.

Table 10-3, which follows, includes most of the floor/ceiling assembly combinations found in multifamily buildings as well as some which are clearly undesirable for several reasons. In addition, the importance of impact noise insulation is emphasized by giving separate criteria for reciprocal functional relationships.

Criteria for Airborne and Impact Sound Insulation of Floor/Ceiling Assemblies Between Dwelling Units

Partition Function Between Dwellings			Grade II	
Apt. A		Apt. B	STC	IIC
Bedroom	above	Bedroom	52	52
Living room	above	Bedroom (1,2)	54	57
Kitchen (3)	above	Bedroom (1,2,4)	55	62
Family room	above	Bedroom (1,2,5)	56	62
Corridor	above	Bedroom (1,2)	52	62
Bedroom	above	Living room (6)	54	52
Living room	above	Living room	52	52
Kitchen	above	Living room (1,2,4)	52	57
Family room	above	Living room (1,2,5)	54	60
Corridor	above	Living room (1,2)	52	57
Bedroom	above	Kitchen (1,4,6)	55	50
Living room	above	Kitchen (1,4,6)	52	52
Kitchen	above	Kitchen (4)	50	52
Bathroom	above	Kitchen (1,2,4)	52	52
Family room	above	Kitchen (1,2,4,5)	52	58
Corridor	above	Kitchen (1,2,4)	48	52
Bedroom	above	Family room (1,6)	56	48
Living room	above	Family room (1,6)	54	50
Kitchen	above	Family room (1,6)	52	52
Bathroom	above	Bathroom (4)	50	48
Corridor	above	Corridor (7)	48	48

NOTES RE TABLE

1. The most desirable plan would have the floor/ceiling assembly separating spaces with equivalent functions, e.g., living room above living room, etc.: however, when this arrangement is not feasible the assembly should have greater acoustical insulating properties.
2. This arrangement requires greater impact sound insulation than the converse, where a sensitive area is above a less sensitive area.
3. Or dining, or family, or recreation room.
4. See HUD FT/TS-24 for proper vibration isolation of plumbing fixtures and appliances.
5. The airborne STC criteria in this table apply as well to vertical partitions between these two spaces.
6. This arrangement requires equivalent airborne sound insulation and perhaps less impact sound insulation than the converse.
7. See HUD FT/TS-24 for proper treatment of staircase, hall and corridors.

■ Test

ASTM E90-66, Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

ASTM RM14, Proposed Tapping Machine Method for Laboratory Measurement of Impact Sound Transmission Through Floor/Ceiling Assemblies, to be published December 1971, preprints available from ASTM.

■ Commentary on D.5.1.1

Results of laboratory tests should be obtained prior to construction of prototype. The floor/ceiling assembly is to be completed with all surfacing, etc., for tests.

■ Criterion D.5.1.2

Noise Isolation Class and Impact Insulation Class of 4 less than STC and IIC values respectively of Criteria D.5.1.1 and D.5.1.3 to be determined by field test of prototypes.

■ Test

Appendix A1 of ASTM E336-67T, Tentative Recommended Practice for Measurement of Airborne Sound Insulation in Buildings.

ASTM RM14, Proposed Tapping Machine Method for Laboratory Measurement of Impact Sound Transmission Through Floor/Ceiling Assemblies, to be published December 1971, preprints available from ASTM.

Field inspection and documentation of prototypes during construction.

ANSI S1.2-1962, Standard Method for the Physical Measurement of Sound.

D INTERIOR SPACE DIVIDERS; FLOOR-CEILING

5 ACOUSTIC ENVIRONMENT

- **Requirement D.5.2**
  In the case of a multi-level dwelling unit, there should be acoustical privacy between different levels within the dwelling unit to create and allow for development of personal and family relationships.

- **Criterion D.5.2.1**
  Sound Transmission Class, STC-40, and Impact Insulation Class, IIC-40, to be determined by laboratory test of floor/ceiling assembly.

- **Test**
  ASTM E90-66, Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

  ASTM RM14, Proposed Tapping Machine Method for Laboratory Measurement of Impact Sound Transmission Through Floor/Ceiling Assemblies, to be published December 1971, preprints available from ASTM.

- **Commentary on D.5.2.1**
  Results of laboratory tests should be obtained prior to construction of prototype. The floor/ceiling assembly is to be completed with all surfacing, etc., for tests.

- **Criterion D.5.2.2**
  Noise Isolation Class, NIC-35, and Impact Insulation Class, IIC-35, to be determined by field test of prototypes.

- **Test**
  Appendix A1 of ASTM E336-67T, Tentative Recommended Practice for Measurement of Airborne Sound Insulation in Buildings.

  ASTM RM14, Proposed Tapping Machine Method for Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies, to be published December 1971, preprints available from ASTM.

  Field inspection and documentation of prototypes during construction.

E EXTERIOR ENVELOPE; WALLS, DOORS AND WINDOWS

5 ACOUSTIC ENVIRONMENT

■ Requirement E.5.1

Protection should be provided from noise generated by and radiated from the multiplicity of sources outside of the home.

■ Criterion E.5.1.1

The exterior envelope should attenuate sound of exterior origin at a given site to permit attainment of the specified NC environment; see L.5.1.1.

■ Test

Design computations and documentation. Certain composite structures that include the "weakest transmission barriers", doors, windows, etc., should be laboratory-tested according to ASTM E90-66, Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

Field inspection and documentation of prototypes during construction.

ANSI S1.2-1962, The Physical Measurement of Sound, see L.5.1.

■ Commentary on E.5.1.1

It is assumed that the noise environment of specific sites will be measured and documented.

F EXTERIOR ENVELOPE; ROOF/CEILING, GROUND FLOOR

5 ACOUSTIC ENVIRONMENT

Please see E.5.1.

G FIXTURES AND HARDWARE

5 ACOUSTIC ENVIRONMENT

- **Requirement G.5.1**
  Fixtures and hardware should perform their intended function without excessive additional noise generation or compromise of the acoustical performance of other building elements.

- **Criterion G.5.1.1**
  The fixture should neither prevent attainment of nor compromise the NC requirement established for the space; see L.5.1.1.

- **Test**
  Design documentation and/or field measurement with fixture installed and in operation.

- **Commentary on G.5.1.1**
  The doors of kitchen cabinets or other cabinets when slammed should not transmit audible sound to adjacent or subjacent units.

- **Criterion G.5.1.2**
  Installation of the fixture should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- **Test**
  Design documentation and/or field measurement with fixture installed and in operation.

- **Commentary on G.5.1.2**
  Installation of kitchen or other cabinets should not degrade performance of partition wall below Criterion B.5.1.2.

  Doorbells, buzzers, etc., should not be audible in adjacent or subjacent units.

H PLUMBING

5 ACOUSTIC ENVIRONMENT

- **Requirement H.5.1**
  The plumbing system should perform its intended function without excessive additional noise generation or any compromise of the acoustical performance of other building elements.

- **Criterion H.5.1.1**
  The plumbing system should neither prevent attainment of nor compromise of the NC requirement established for the space; see L.5.1.1.

- **Test**
  Design documentation and/or field measurement with plumbing system installed and in operation.

- **Criterion H.5.1.2**
  Installation of the plumbing system should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- **Test**
  Design documentation and/or field measurement with plumbing system installed and in operation.

I MECHANICAL EQUIPMENT, APPLIANCES

5 ACOUSTIC ENVIRONMENT

■ Requirement I.5.1

Mechanical equipment and appliances should perform their intended functions without excessive additional noise or compromise of the acoustical performance of other building elements.

■ Criterion I.5.1.1

Mechanical equipment or appliances should neither prevent attainment of nor compromise the NC requirement established for any habitable space; see L.5.1.1.

■ Test

Design documentation and/or field measurement with mechanical equipment and appliances installed and in operation.

■ Commentary on I.5.1.1

HVAC systems are among the worst noise-generating sources in residential construction. Careful attention to detail in the design stages, as well as during the installation process, is extremely important. Refer to ASHRAE Guide and Data Book 1967, Chapter 31.

Appliances (e.g., dishwashers and garbage disposer), whose operation is completely under the control of a resident, may impair attainment of the established NC requirement within his dwelling unit. However, these appliances should not impair attainment of the established NC requirement in adjacent or subjacent dwelling units. Mechanical equipment (e.g., HVAC) which is not under the control of residents should not impair attainment of the established NC requirement in any dwelling unit.

Devices that are sources of structure- or airborne noise radiation should have isolation at the source.

■ Criterion I.5.1.2

Installation of mechanical equipment or appliances should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

■ Test

Design documentation and/or field measurement with mechanical equipment and appliances installed and in operation.

J POWER, ELECTRICAL DISTRIBUTION, COMMUNICATIONS

5 ACOUSTIC ENVIRONMENT

- Requirement J.5.1
  Power, electrical distribution, and communications systems should perform their intended functions without excessive additional noise generation or compromise of the acoustical performance of other building elements.

- Criterion J.5.1.1
  These systems should neither prevent attainment or nor compromise the NC requirement established for the space; see L.5.1.1.

- Test
  Design documentation and/or field measurement with systems installed and in operation.

- Criterion J.5.1.2
  Installation of these systems should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- Test
  Design documentation and/or field measurement with systems installed and in operation.

- Commentary on J.5.1.2
  Telephone and electrical utility installations should not reduce acoustical integrity of wall systems.

K LIGHTING ELEMENTS

5 ACOUSTIC ENVIRONMENT

- **Requirement K.5.1**
  Lighting elements should perform their intended function without excessive noise generation and without compromising the acoustical performance of other building elements.

- **Criterion K.5.1.1**
  The lighting elements should neither prevent attainment of nor compromise the NC requirement established for the space; see L.5.1.1.

- **Test**
  Design documentation and/or field measurement with lighting elements installed and in operation.

- **Commentary on K.5.1.1**
  Fluorescent lamp ballasts, for example, should be selected to avoid noise intrusion above recommended noise criterion environment.

- **Criterion K.5.1.2**
  Installation of the lighting elements should not prevent attainment of required noise reduction between dwelling units; see B.5.1.2 and D.5.1.2.

- **Test**
  Design documentation and/or field measurement with lighting elements installed and in operation.

L ENCLOSED SPACES

5 ACOUSTIC ENVIRONMENT

■ Requirement L.5.1

Noise levels in residential interior spaces should be controlled.

■ Criterion L.5.1

Daytime Noise Criterion Contour (0700-2200 hours) of NC-40, and Nighttime Noise Criterion Contour (2200-0700 hours) of NC-30; see Chapter 20 of "Noise Reduction", edited by L. L. Beranek, McGraw-Hill, 1960.

■ Test

Design computations, methods and results that predict anticipated sound pressure levels based upon total systems analysis.

Measurement of space-time averaged sound pressure levels in unoccupied prototypes after completion. ANSI S1.2-1962, ANSI Standard Method for the Physical Measurement of Sound.

■ Commentary on L.5.1.1

System includes, but is not limited to, site considerations, exterior shell attenuation, mechanical sources, HVAC, and plumbing. Specific criterion is dependent upon ambient noise characteristics of specific sites. These NC Contours represent the maximum permissible noise levels in a given space, irrespective of source, excluding human activity in adjacent space.

Attainment of these NC Contours at some sites may only be possible, by keeping windows closed; this could require inclusion of appropriate ventilation or air-conditioning.

■ Criterion L.5.1.2

The reverberation time of public corridors, hallways and stairwells should be less than 0.8 seconds at frequencies of 500 Hz and above, and less than 1.5 seconds at frequencies below 500 Hz.

■ Test

Design computations, methods and results that predict anticipated reverberation times at each of six frequencies (at octave intervals beginning with 125 Hz) based on the average sound absorption coefficient of the space expressed in sabins.

■ Commentary on L.5.1.2

The reverberation time is the time for the sound pressure level to fall 60 dB, and is calculated by the equation

$$T = \frac{.043V}{A}$$

where: T = reverberation time (sec)
V = volume of space (ft^3)
A = average absorption (sabins)

and : $A = a_1S_1 + a_2S_2 + a_3S_3 + \ldots.$
a = absorptivity of surface (sabins/ft^2)
S = surface area (ft^2).

Absorptive materials should be evenly distributed along the corridors, hallways and stairwells.

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