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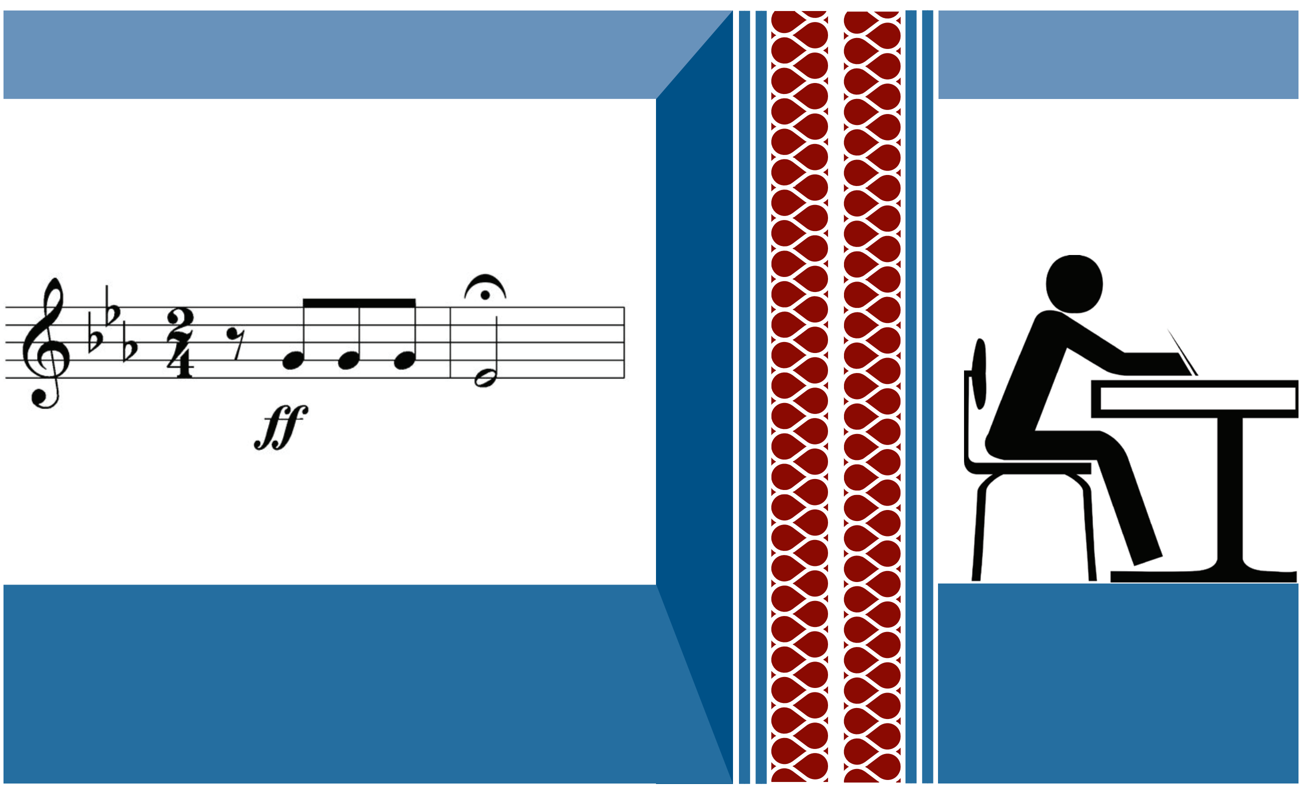
Steel Design Guide 30

Sound Isolation and Noise Control in Steel Buildings



Steel Design Guide

30

Sound Isolation and Noise Control in Steel Buildings

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Preface

This Design Guide provides guidance for achieving suitable acoustical environments in steel buildings. The control of sound transmission must be considered for every building under design. This Guide will provide a discussion of the issues involved and the tools available to assist the designer in selecting appropriate assemblies to address sound transmission in steel-framed buildings. A Glossary is provided at the end of this Design Guide to define terms that may be unfamiliar to the reader.

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Chapter 1
Introduction

Modern buildings must protect their occupants from excessive noise intrusion, ensure their acoustical comfort, and provide favorable conditions for listening and communication. To achieve these goals efficiently and economically, building designers need to take the relevant considerations into account, beginning early in the design process, and to pursue their proper implementation. Acoustical objectives enter into the design of every building, and recent years have seen increased stringency of acoustical requirements and increased emphasis related to “green” design.

The goal of this Guide is to provide the design community with an understanding of the issues involved and with tools to address these. It is important to note that it is not the material types and the framing systems that establish the acoustical performance of a building, but how the relevant building elements are selected and assembled. Thus, the desired acoustical performance of a building can be achieved by appropriate design, while framing and materials can be chosen on the basis of the usual design considerations, such as structural efficiency, design flexibility, cost, schedule and environmental impacts.

The Guide begins with a road map that lays out a logical approach toward achieving suitable acoustical environments in buildings, proceeding from the selection of quantitative goals to identification of noise sources to be considered and to delineation of how to deal with the noise intrusions. Noting that noise is unwanted sound, the Guide then introduces the reader to the behavior of sound and to some acoustics terminology, together with metrics for the perception and acceptability of sound. The Guide goes on to address criteria for acoustical comfort and privacy in rooms intended for various occupancies, including the related codes and standards. After providing quantitative information on widely encountered noise sources inside and outside of a building, the Guide discusses sound isolation in detail—including the related metrics, effects of structural parameters and acoustical treatments, the effects of “weak links” such as acoustically inappropriate windows and gaps at doors, and the isolation performance of wall configuration that are widely used in steel buildings. Finally, it deals with the control of noise that the mechanical equipment produces in a building and in the building surroundings. The considerations presented in this Guide are applicable to buildings of all structural types, but the Guide’s focus regarding some details is on steel structures.

Chapter 2
Road Map: How to Proceed with a Design

An ideal, logical approach toward achieving desired acoustical environments in buildings is outlined in this section with the intent of providing general guidance regarding how a design may proceed. However, in many practical situations, some of the steps outlined here may be abbreviated considerably.

A rational starting point is to determine what needs to be achieved in various spaces. For example, how quiet does an office need to be, and what are the requirements for a large conference room? Quantitative acoustical criteria for all spaces of interest may then be selected. These matters are discussed in Chapters 4 and 5 of this Guide.

Next, consider what elements might interfere with achieving the desired acoustical conditions. What sources of intruding noise are there inside and outside the building? Where are loud conversations or amplified presentations likely? What mechanical (HVAC) equipment serves the various rooms? Where are impacts from extensive foot traffic expected? Quantitative data on the noise from commonly encountered sources appears in Chapter 6.

Once there is an understanding of the salient noise sources and of the spaces of interest, the paths by which the noise travels from a given source to a given space can be considered, and the noise in each space of interest from each source that affects it can be predicted. By comparing the predicted noise to the aforementioned criteria, the amount of noise reduction that is needed can then be determined. Then consider how to obtain the desired noise reduction taking into account all of the contributing sources and paths. For example, exterior noise can get into a building via the building's envelope, including its façade and roof, particularly through any openings or weak components. Noise can be transmitted from room-to-room via the separating walls, particularly via openings such as gaps under doors. Impact sounds from footfalls can be transmitted via the floor and ceiling construction. These considerations are discussed in Chapter 7, and practical guidelines for building assemblies are presented in Chapter 8.

Noise and vibration from mechanical systems also need to be taken into consideration. Noise from mechanical equipment tends to travel in and along ducts. In addition, this equipment and attached piping and conduits can make walls and floors to which they are attached vibrate, causing these structures to radiate noise much like large loudspeaker membranes. These issues are discussed in Chapter 9.

Chapter 3
Some Basics

3.1 NOISE, SOUND, SOUND PRESSURE

Noise is unwanted sound. Sound may be visualized as a propagating vibration of the air. It involves small pressure fluctuations above and below atmospheric pressure; human hearing senses these fluctuations. These fluctuations are referred to as sound pressure. (At 3 ft from a person speaking normally, the sound pressure is about one-millionth of the atmospheric pressure.) Fluctuations may be produced by irregularities in air flows (e.g., turbulence, chopping or modulation of flows by fan blades, reeds of musical instruments, or human vocal chords) or by vibrating structures (e.g., loudspeaker membranes, drum heads, window panes, walls and floors of buildings).

3.2 FREQUENCY, SPECTRA, FREQUENCY BANDS

In a pure tone, the sound pressure varies sinusoidally with time. (See the Glossary for definitions of terms such as pure tone and sinusoidal.) The pressure fluctuation associated with a pure tone is characterized by its magnitude and frequency. Frequency, measured in cycles per second (or Hertz, abbreviated as Hz) is simply the number of times per second the pressure cycles from positive to negative values and back again. The frequency of a tone is perceived as its pitch. The magnitude of the pressure fluctuation is related to the tone's loudness, as described further in Section 3.3.

Most pressure fluctuations associated with noise of practical interest consist of a multitude of components with different magnitudes and frequencies. Such a complex sound may be described in terms of its spectrum—the distribution of magnitude versus frequency of its components. Because most complex sounds encountered in practice are made up of many components, it has become common practice to group the components into bands of frequency and to determine for each band a representative pressure magnitude that is a measure of the total sound pressure of all components in the band. Details of how this representative pressure is determined are given in textbooks [e.g., see Long (2014)] and are beyond the scope of this introduction; it suffices to indicate here that, generally, a greater representative pressure may be expected in a wider frequency band that encompasses more frequency components.

Various frequency band arrangements may be used for the aforementioned grouping of components. For some applications, it may be convenient to use bands of constant width (e.g., 1 Hz or 10 Hz), but for the wide range of frequencies involved in audible sound, it is advantageous to employ an arrangement of bands where the widths of successive bands differ by a constant factor. In the most widely used arrangement—that of standard octave bands—the frequency bandwidths differ by a factor of 2: the first extends from 11 to 22 Hz, the second from 22 to 44 Hz, the third from 44 to 88 Hz, etc. These bands customarily are referred to by their center frequencies: 16 Hz for the first band, 31.5 Hz for the second, 63 Hz for the third, etc. The standard center frequencies are the rounded-off geometric averages of the frequencies at the lower and upper bounds of the band. Third-octave bands may be used where finer frequency resolution is desired; here, successive bands differ by a factor of $\sqrt{2}$, and the successive center frequencies are 16, 20, 25, 31.5, 40, 50, 63 … Hz.

3.3 SOUND PRESSURE LEVEL, DECIBELS

The sound pressure magnitudes encountered in most practical situations range between about 0.000000003 psi and 0.3 psi (or about 0.00002 Pa and 2,000 Pa).* Expressing the sound pressure magnitudes in terms of their logarithm does away with the tedious problem of keeping track of the decimal places and results in a scale that more closely aligns with perceived loudness. Accordingly, it has become standard practice to work with sound pressure in terms of the sound pressure level, *SPL,* a logarithmic measure expressed in decibels (dB). The sound pressure level in a given frequency band is related to the root-mean-square sound pressure, p, in that band as

$$SPL = 10\log\frac{p^2}{p_{ref}^2} = 20\log\frac{p}{p_{ref}} \qquad (3\text{-}1)$$

where

SPL = sound pressure level, dB
p = sound pressure, psi (Pa)
p_{ref} = reference value of pressure, psi (Pa)

A reference value is needed because the logarithm can only be taken of a dimensionless number. Because values other than the standard reference pressure cited here may be used in some cases, it is good practice to indicate the reference pressure when stating an *SPL* value—that is, to write *SPL* (dB re 20μPa) instead of just *SPL* (dB). Unfortunately,

* Both U.S. customary units and SI units are included in this paragraph and in Figures 3-1 and 3-2 for reference purposes. U.S. customary units are used throughout the remainder of the Design Guide.

this good practice is not always followed. If no reference value is given, the standard reference value is likely meant. The reference pressure value commonly used is 2.9×10^{-9} psi (20 μPa) and corresponds roughly to the weakest sound that can be heard under ideal conditions. Thus, the threshold of hearing perception corresponds to an *SPL* of 0 dB. In contrast, an *SPL* above 130 dB tends to produce pain in the ear; at 300 ft from a jet aircraft taking off, one is likely to be exposed to an *SPL* of about 130 dB. Note that doubling of the sound pressure results in a 6-dB increase in the sound pressure level; halving of the sound pressure results in a 6-dB decrease.

3.4 WAVE PROPAGATION, SPEED OF SOUND, WAVELENGTH

A localized pressure disturbance generates propagating waves, much like a stone dropped into a pond generates ripples that propagate concentrically from the source—except that in an open volume of air (a volume without obstructions), the disturbances spread spherically (i.e., in three dimensions), whereas ripples on a water surface spread in two dimensions. As the disturbances propagate further from the source, the energy they contain is spread over a larger area, resulting in a decrease in sound pressure with increasing distance. In open air, the sound pressure is inversely proportional to the square of distance from the source; the *SPL* decreases by 6 dB per doubling of the distance.

The small pressure fluctuations associated with sound propagate in air at the speed of sound (approximately 1,120 ft/s). As a single-frequency wave passes a fixed point in space, the sound pressure at that point fluctuates between a minimum and a maximum. The time between the arrivals of successive maxima is called the period, which is equal to the reciprocal of the frequency. The distance the wave travels during the time interval it takes for successive maxima to reach a fixed point (or the distance between successive pressure maxima at a given instant) is called the wavelength. The wavelength, λ, period, T, frequency, f, and sound speed, c, are related by

$$\lambda = \frac{c}{f} = cT \qquad (3\text{-}2)$$

where

T = period, s
c = sound speed, ft/s
f = frequency, Hz
λ = wavelength, ft

As is well known from physics, propagating waves are affected only minimally by obstacles that are considerably smaller than a wavelength. Thus, for example, the transmission of noise at 50 Hz—the wavelength of which is about 20 ft—cannot be reduced appreciably by a 3-ft-wide shield.

3.5 SOUND FIELDS IN ROOMS

Unlike in the open air, sound pressure fluctuations resulting from a localized source in the confined air volume of a room generally do not propagate without being affected by the room's boundaries, among other obstacles. Sound emanating from such a source may propagate as it does in the open air outdoors only until it impinges on a solid surface; there it may be partly absorbed and partly reflected. The reflected sound wave then suffers a similar fate when it, in turn, encounters an obstacle, and the process is continued. Where many reflected waves cause the sound to be evenly distributed throughout the room (as averaged over a small volume of the room), essentially independent of the distance from the source, it is called a diffuse sound field.

A sound pressure field is often also characterized relative to a source. In a limited area near a sound source in a room, the sound pressure may vary as it does outdoors, with the sound pressure level decreasing by 6 dB per doubling of distance; the field in this area is often called the free field or near field. The field in the rest of the room is called the far field relative to the source. The field that is far from all sources is called reverberant.

Sound may be radiated into a room not only from localized sources, such as TVs or HVAC duct outlets, but also as structure-borne sound from extended structures (such as floors, ceilings, walls, windows) that may be set into vibration by sources that can be at some distance from the room. Such sources (described at length in Chapter 6) may impart structural vibration directly (e.g., impact sources) or via the air (e.g., an audio system loud enough to vibrate the ceiling or walls substantially). Structurally transmitted sound can be more significant than sound transmitted directly through a separating wall or ceiling; it is then said to flank the direct transmission. The transmission (and attenuation) of sound via structures is determined by the details of the structure—mass and stiffness, in particular. As such, structure-borne sound behaves differently in different constructions (steel, concrete, wood, etc.)

3.6 SOUND PERCEPTION AND METRICS

Humans of normal hearing are able to perceive sound at frequencies from approximately 20 Hz to approximately 20,000 Hz, although the onset of hearing loss limits the upper end of that range significantly for many people. In terms of sound pressure level, human hearing ranges from approximately 0 dB to approximately 140 dB at mid-frequencies (around 1,000 Hz), but our sensitivity to sound and our thresholds of perception vary with frequency. Figure 3-1 shows the extent of human hearing graphically, from the threshold of hearing to the threshold of pain.

As Figure 3-1 illustrates, humans are more sensitive to sound at 2,000 Hz (where we can hear sound at 0 dB) than we are at 50 Hz (where sound pressure level must exceed 40 dB to be audible). Similarly, audible sounds of the same sound pressure level at different frequencies are not perceived as equally loud. For broadband or mid-frequency sound, a change in *SPL* of roughly 3 dB corresponds to a just-noticeable difference in loudness. A 10-dB change corresponds to a doubling (or halving) of loudness.

As described in Section 3.2, typical sounds have a complex spectrum with many frequency components. It is nonetheless useful for some purposes to express a sound level in terms of a single number. Several metrics exist that attempt to describe complex sound spectra with a single value, taking into account the frequency dependence of human hearing. The two most common of these metrics are A-weighted decibels (dBA) and noise criteria (NC) ratings.

A-weighted decibels can be measured directly with a sound level meter outfitted with the appropriate filters and weighting functions. They may be calculated by applying a weighting factor to the sound pressure level measured in each octave or third-octave band and then logarithmically summing the individual weighted levels. The weighting factors, defined in ANSI/ASA S1.4, *Specification for Sound Level Meters* (ASA, 2014), are based on research into sound levels that listeners perceive as being equally loud. The A-weighted sound pressure level has been shown to correlate well with subjective assessment of loudness for typical low to moderate sound levels. (The correlation breaks down somewhat for very loud sounds like rock concerts and jet engines.) In common practice, A-weighted levels are used to characterize outdoor noise (e.g., in state and local noise regulations) and are sometimes provided by equipment manufacturers to describe the loudness of their products.

NC ratings were developed to characterize background sound in buildings due to mechanical equipment and other building systems. NC ratings are determined by comparing measured or expected sound levels against a series of standard NC curves shown in Figure 3-2 by the tangency method. The lowest standard NC curve that is not exceeded by the measured sound level in a room is the NC rating. The spectrum in the example in Figure 3-2 has a rating of NC 30, as governed by its 250-Hz value.

The specific curves and the tangency method described here are defined in ANSI/ASA S12.2 (ASA, 2008). A range of similar or derivative metrics exist, but NC ratings are most

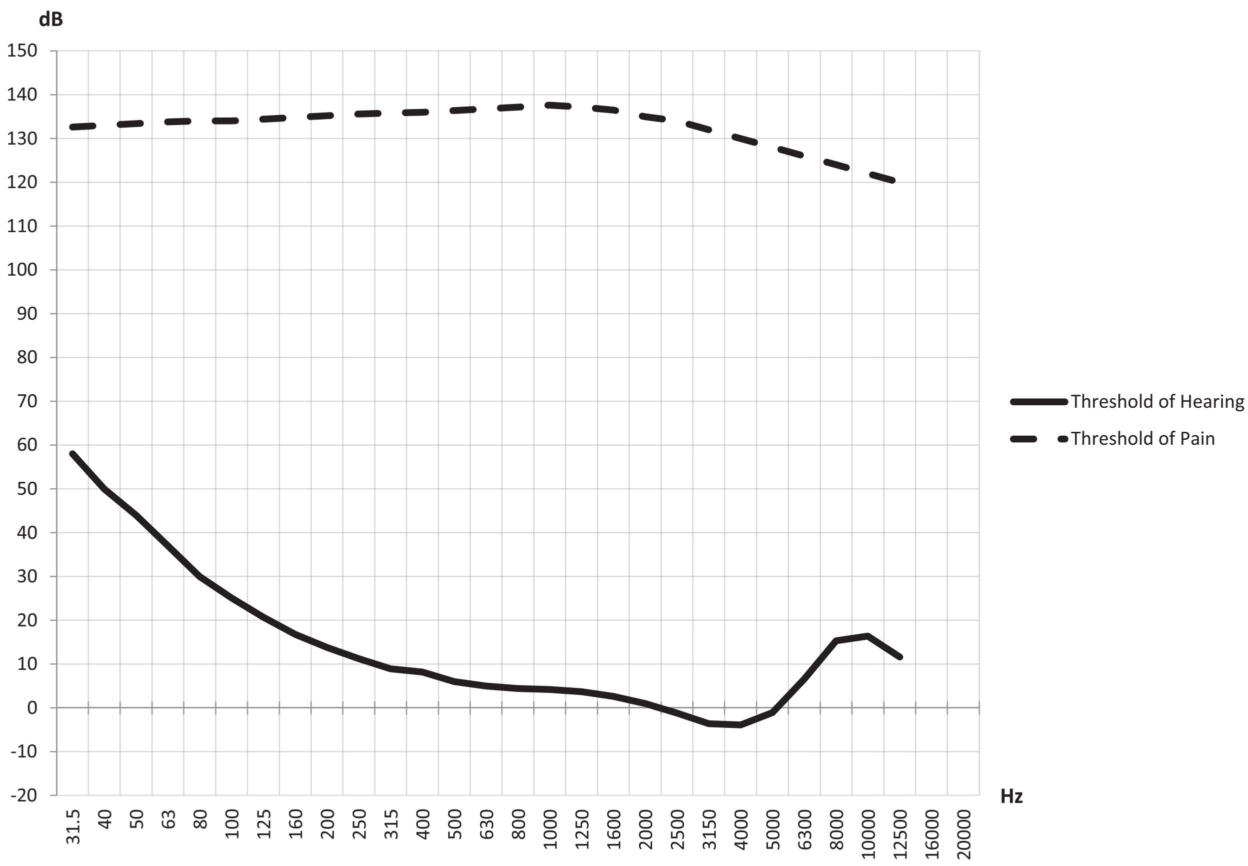
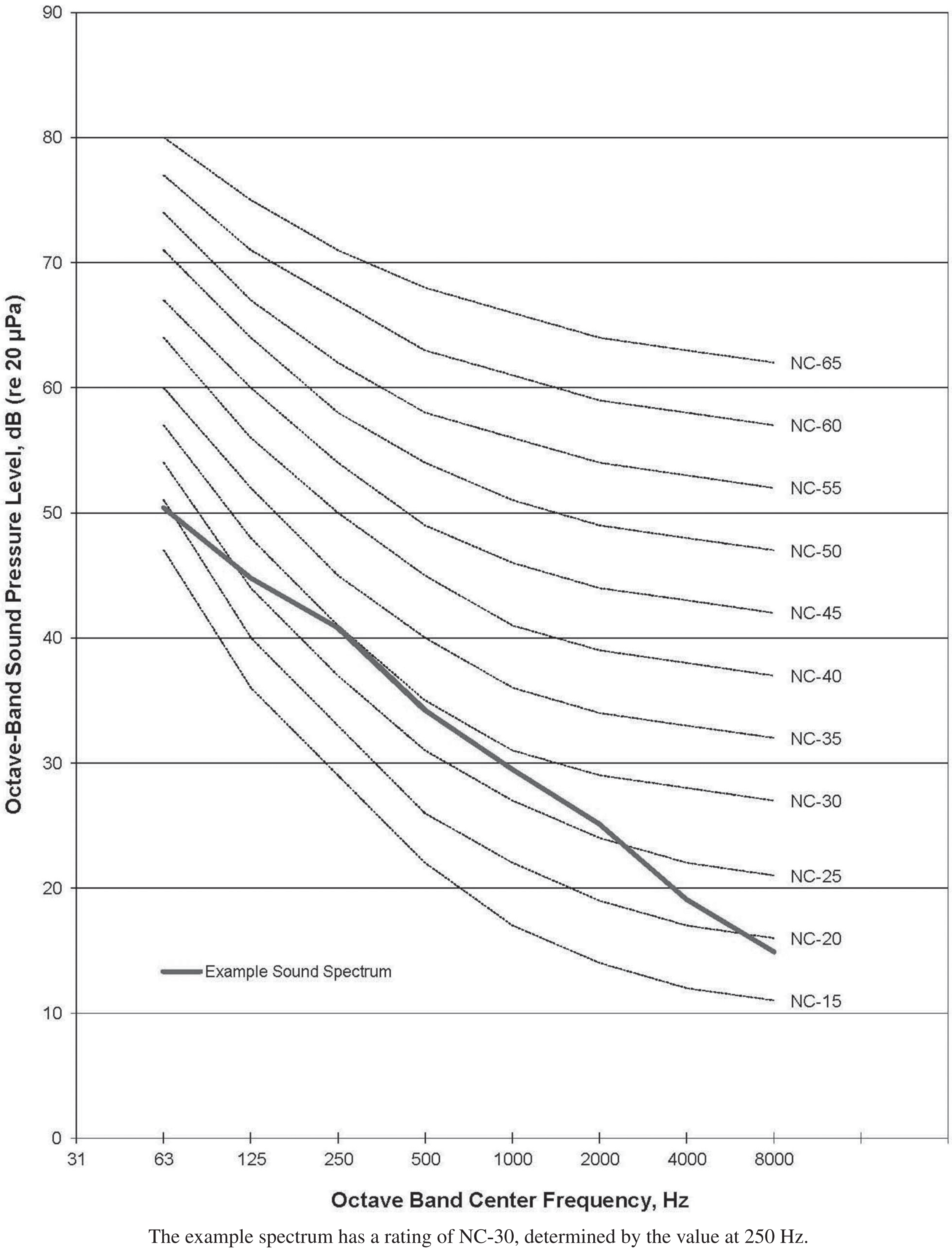


Fig. 3-1. Range of human hearing (Zwicker and Fastl, 1999; Yost and Killian, 1997).



The example spectrum has a rating of NC-30, determined by the value at 250 Hz.

Fig. 3-2. Standard noise criteria (NC) curves with example sound spectrum.

Table 3-1. Sound Absorption of Common Building Finishes							
Material	Absorption Coefficients, Hz						Noise Reduction Coefficient
	125	250	500	1000	2000	4000	
Wood floor	0.15	0.11	0.10	0.07	0.06	0.07	0.10
Carpet, on concrete	0.02	0.06	0.14	0.37	0.60	0.65	0.30
⅝-in. gypsum board on 3⅝-in. steel studs, insulation in cavity	0.13	0.06	0.04	0.03	0.03	0.03	0.04
1-in. fabric-wrapped glass fiber panel, wall-mounted	0.05	0.32	0.82	1.0	1.0	1.0	0.80
2-in. fabric-wrapped glass fiber panel, wall-mounted	0.29	0.82	1.0	1.0	1.0	1.0	1.00
Suspended mineral fiber acoustic ceiling tile (typical)	0.25	0.30	0.50	0.75	0.75	0.75	0.60
Suspended glass fiber acoustic ceiling tile (typical)	0.75	0.90	0.80	0.95	1.00	1.00	0.90

common in practice in the United States. The principal utility of NC ratings is to establish simple single-number criteria for mechanical system background sound levels during design; noise levels achieved in the field can then be assessed against these criteria.

Both A-weighted levels and NC ratings suffer for their simplicity; because they are single numbers that describe complex sound spectra, various sounds that do not sound the same will have the same A-weighted level or NC rating. Further, because the methods are different, two sound spectra with the same A-weighted level may have different NC ratings, and vice versa. Where it is critical to understand or regulate sound levels precisely, octave or third-octave band levels or criteria are more appropriate than any single-number metric.

3.7 CONTROL OF NOISE IN ROOMS

There is an important difference between blocking sound and absorbing it. A bunker lined with thick steel plates may block out noise from the exterior very effectively (thanks to the mass), but it will be highly reverberant inside the bunker because steel plates are highly reflective of sound, not sound absorptive. This Guide is primarily about sound isolation, and absorption can be very helpful as part of a sound isolation strategy as discussed in Chapter 7: absorption between mass layers (Section 7.3.2) can improve transmission loss, *TL,* and sound-absorbing finishes in the receiver room can improve noise reduction, (NR). Sound absorption is important to the acoustical character of rooms as well as how reverberant or lively the sound is. Absorption can reduce reverberation, and in so doing improve the intelligibility of speech in a lecture hall or control the buildup of activity noise in a restaurant or banquet hall.

3.7.1 Sound Absorption of Materials

All materials can be assigned an absorption coefficient, typically represented with the symbol α. The absorption coefficient is a number between 0 and 1 that defines the percentage of sound that is absorbed by the material, with 0 representing total reflectivity and 1 representing perfect absorption. In this case, perfect absorption can be conceived of as an open window—sound will go out and no portion of that sound will be reflected back.

Absorption varies with frequency. A mid-frequency average in common use, suitable for evaluating the absorptive properties of materials in the speech frequencies, is called the noise reduction coefficient (NRC). The NRC is simply the arithmetic average of the absorption coefficients in the 250-, 500-, 1,000- and 2,000-Hz octave bands. The total quantity of absorption provided by a material is equal to its absorption coefficient times its surface area. The product, symbolized by the letter a, is in units of sabins.

Sound absorption can be measured in a laboratory reverberation chamber following ASTM C423 (ASTM, 2009a), using material mounting conditions defined in ASTM E795 (ASTM, 2005). Materials affixed directly to a substrate tend to absorb less sound than those mounted on furring or otherwise suspended away from the substrate, particularly at low frequencies. The benefit of furring can be increased if sound-absorbing insulation is added to the cavity behind the absorptive finish.

The absorption coefficients of typical building materials may be found in standard acoustics textbooks [e.g., Long (2014) and Egan (1988)]; consult manufacturer's literature for data on specialty sound-absorbing finishes. Data for particularly common materials are provided in Table 3-1.

3.7.2 Reverberation Time

The amount of time it takes for an impulsive sound in a room to decay 60 dB is called its reverberation time. An empirical formula for reverberation time was set forth by Wallace Clement Sabine at Harvard (after whom the unit of sound absorption is named):

$$RT = 0.049\ \frac{V}{a} \tag{3-3}$$

where

RT = reverberation time, s
V = room volume, ft^3
a = total absorption, sabins

A large room with mostly hard surfaces (e.g., a cathedral) will have a long *RT*—5 seconds or more—while a smaller room with many sound-absorbing surfaces (e.g., a recording studio) will have a short *RT*—under a half second. Classrooms have an *RT* of 0.6 to 0.7 second or less (depending on their size) in order to comply with ANSI/ASA S12.60 (ASA, 2010) requirements; concert halls typically have an *RT* on the order of 2 seconds fully occupied. Requirements for reverberation time may be found in many of the standards cited in Chapter 5 of this Guide alongside the sound isolation requirements.

Chapter 4
Acoustical Criteria for Rooms

4.1 STEADY-STATE CRITERIA: NC RATINGS

A variety of textbooks and other references suggest typical limits on interior background sound levels due to mechanical systems (predominately) or other continuous and steady building systems noise. Table 4-1 presents some of these criteria.

It is advisable that the criteria applied on a building project be confirmed by a qualified acoustical consultant; this is particularly critical for performing arts centers, recording facilities, educational facilities and other low-noise spaces.

4.2 CRITERIA FOR TRANSMITTED TRANSIENT SOUND

Except for mechanical noise, noise transmission in buildings typically is transient: speech sounds, residential activity, music, footfall, etc. In some cases, regulations or guidelines that specifically apply to the sound isolation performance of building constructions must be met; these are discussed in Chapter 5. In most scenarios, however, criteria for sound isolation performance of building elements must be determined by taking account of the background sound in the noise-sensitive room in question. Even where sound isolation regulations or guidelines exist, it is appropriate to check these for compatibility with the room background noise and likely source levels. Sources are described in Chapter 6; criteria for transmitted transient sound levels in relation to steady-state ambient sound level are described in this section.

Humans can perceive certain instantaneous noise (especially tones—sounds with spectrum characterized by a particularly prominent frequency component) at levels as much as 10 dB below the steady-state broadband ambient noise level of a room. As such, the criterion for the maximum sound level of transient sounds in a highly noise-sensitive environment, such as a music space or professional recording studio, should be 10 dB more stringent than the criterion for steady-state background sound level—unless the background sound criterion is already at or near the threshold of audibility, in which case the audibility threshold defined in ANSI/ASA S12.2 (ASA, 2008) Appendix E would apply. In contrast, some rooms can tolerate a certain level of transient noise that is audible above the ambient sound. A faintly audible airplane overhead might be unacceptable during a professional orchestra rehearsal but would be unlikely to draw notice or complaint in a hotel lobby. The acceptable difference between the level of a transient sound signal and the background sound level is shown in Table 4-2 for various room usages.

In the absence of specific sound isolation performance criteria (Chapter 5), decisions about the sound isolation requirements of walls, floor/ceiling assemblies, windows, and other building elements can be made on the basis of an understanding of the source level (Chapter 6) and the background sound requirements. For example, assume that aircraft flying near a proposed new academic building produces 80 dB in the 500-Hz octave band at the site. Table 4-1 indicates that in classrooms the background level should be NC-30, while in a research lab it could be NC-45. Table 4-2 indicates that intruding sound from an exterior source like aircraft should result in interior noise levels that are −5 to 0 NC points from the background sound in a teaching environment (say, NC-25), but a more relaxed criterion (0 to +5 dB) is suitable for research (NC-50 in our example). This analysis indicates that classroom windows and façade construction should provide as much as 55 decibels of sound attenuation at 500 Hz: 80 dB exterior noise minus 25 dB noise criterion equals 55 dB of required attenuation. (NC-25 corresponds to 25 dB at 500 Hz; NC levels are named after their values in the 500-Hz octave band.) By contrast, the façade of the research laboratory need only provide 30 dB of sound attenuation at 500 Hz: 80 dB exterior noise minus 50 dB criterion equals 30 dB of required attenuation. (The steps of these sample calculations are tabulated in Table 4-3.)

4.3 PRIVACY

Acoustical privacy— the sense of being separate from and undisturbed by sound in an adjacent area—is a function not just of the sound isolation created by intervening structures, but also of the background sound level in the listener's space. This is because continuous background sound masks otherwise intruding sound levels. The preceding example illustrates the point—a research laboratory with a continuous background sound level of NC-45 can achieve sufficient privacy with building constructions that provide only 30 to 40 dB of attenuation at 500 Hz, whereas a classroom with a background sound level of NC-30 will require more robust building constructions to achieve the same level of freedom from intruding noise. It is a common misconception that privacy equates to quiet; in fact, privacy results from achieving a sufficiently low transient-to-background noise ratio and often benefits from significant levels of steady background noise.

Table 4-1. Background Noise Criteria (NC) for Various Occupancies			
Building Types	**Rooms**	**NC Rating**	**Reference(s)**
Residences	Living areas	30	*ASHRAE Handbook: HVAC Applications*, Ch. 48 (ASHRAE, 2011)
	Bathrooms, kitchens	35	*ASHRAE Handbook: HVAC Applications*, Ch. 48
Hotels	Guestrooms, suites	30	*ASHRAE Handbook: HVAC Applications*, Ch. 48
	Meeting/banquet rooms	30	*ASHRAE Handbook: HVAC Applications*, Ch. 48
	Lobby/support/service	40	*ASHRAE Handbook: HVAC Applications*, Ch. 48
Office buildings	Private offices	30	*ASHRAE Handbook: HVAC Applications*, Ch. 48; P-100: Facilities Standards for the Public Buildings Service (GSA, 2010)
	Teleconference rooms	20 to 25	*ASHRAE Handbook: HVAC Applications*, Ch. 48; P-100: Facilities Standards for the Public Buildings Service
	Open-plan offices	40	*ASHRAE Handbook: HVAC Applications*, Ch. 48; P-100: *Facilities Standards for the Public Buildings Service*
Recording studios, performing arts centers	Performance spaces, studios	Below 15 or threshold of hearing	ANSI/ASA S12.2 Annex E: "Criteria for Recording Studios and Other Low-Noise Situations" (ASA, 2008)
	Rehearsal spaces	20 to 25	*Acoustical Design of Music Education Facilities* (McCue and Talaske, 1990)
Hospitals	Patient rooms, exam rooms, doctors' offices	30 to 40	*Guidelines for Design and Construction of Health Care Facilities* (FGI, 2010)
	Teaching lab	35 to 45	*Guidelines for Design and Construction of Health Care Facilities*
	Multiple-occupant patient care areas	35 to 45	*Guidelines for Design and Construction of Health Care Facilities*
	NICU	25 to 35	*Guidelines for Design and Construction of Health Care Facilities*
Courts	Courtroom	25 to 30	*U.S. Courts Design Guide* (GSA, 2007)
Laboratories	Research lab[a]	35 to 50	*ASHRAE Handbook*
Schools	Classrooms	30	ANSI/ASA S12.60 (ASA, 2010) (35 dBA and NC-30 are roughly equivalent)
Religious facilities	Worship spaces	15 to 25	*Worship Space Acoustics* (Kleiner et al., 2010); *ASHRAE Handbook*

[a] Depending on communication requirements. Teaching labs should have lower background sound levels than pure research labs, with minimal requirements for speech communication.

4.3.1 Electronic Sound Masking

In some circumstances, background sound levels can be increased in a controlled manner to improve privacy by use of an electronic sound masking system. Such commercially available systems comprise loudspeakers and a control module configured to emit a continuous and uniform spectrum of background sound tailored specifically (in most cases) to mask speech, because speech and other sounds in the speech spectrum are the most typical sources of intrusive or distracting noise. Electronic sound masking systems may be suitable for open-plan offices (and some closed ones), library reading rooms, and other spaces where privacy is desired and speech communication is not required over significant distances.

4.3.2 Levels of Privacy and Privacy Metrics

Speech privacy requirements may range from freedom from distraction to confidentiality. In a large library reading room, freedom from distraction is a typical and reasonable goal; it is acceptable if nearby conversation is audible and even intelligible if one attends to it, but not distracting to a person reading or working. In an executive office, in contrast,

Table 4-2. Criteria for Transmitted Transient Sounds Based on Usage	
Room Usage	**Transient to Background Noise Difference (NC points or dB)**
Critical listening (music performance, sound editing, etc.) and confidential speech	–10 (or the threshold of hearing, whichever is greater)
Teaching, learning, studying	–5 to 0
Sleeping, residential activity	–5 to 0
Office work, research	–5 to +5
Circulation, waiting, support functions	+5 to +10

Table 4-3. Example Calculations of Sound Isolation Requirement (500 Hz)		
	Classroom	**Research Lab**
Steady-state criterion from Table 4-1	30 dB	45 dB
Plus transient criterion from Table 4-2	–5 dB	5 dB
Equals criterion for intruding sound level	25 dB	50 dB
Source level	80 dB	80 dB
Minus criterion for intruding sound level	25 dB	50 dB
Equals sound isolation requirement	55 dB	30 dB

Table 4-4. Relation of Speech Privacy to the AI and PI metrics		
Level of Speech Privacy	**AI**	**PI**
Confidential speech privacy	< 0.05	> 95%
Normal speech privacy, closed office	< 0.15	> 85%
Normal speech privacy, open plan	< 0.20	> 80%
Marginal or poor speech privacy	< 0.30	> 70%
No speech privacy	> 0.30	< 70%

one typically expects confidentiality—speech in such spaces must not be intelligible in adjacent spaces, and if audible, only very faintly so. In certain highly sensitive circumstances, an even higher level of privacy is required, such as security.

Several metrics exist to characterize speech privacy or its inverse, speech intelligibility. These include articulation index, the privacy index (ASTM, 2008b), sound transmission index (IEC, 2011), speech intelligibility index (ASA, 2012), and others. Articulation index (AI) ranges from 0.0 (total privacy) to 1.0 (perfect intelligibility); privacy index (PI) is simply equal to 1 − AI, expressed as a percentage, ranging from 0% (perfect intelligibility) to 100% (total privacy). AI values are calculated by taking a weighted sum of third-octave band signal-to-noise (transient-to-background) ratios. Various textbooks and references [e.g., FGI *Guidelines for Design and Construction of Health Care Facilities* (FGI, 2010)] have related these metrics to levels of speech privacy, as described in Table 4-4.

Speech privacy in closed rooms can be achieved by providing intervening structures that are highly sound isolating or by use of structures with limited (but nonzero) sound isolation performance and adding sufficient background sound. Guidelines for sound-isolating constructions are presented in Chapter 7 of this Guide. In the open plan, speech privacy can be achieved by using a combination of sound-absorbing ceiling finishes, barriers between sources and listeners, and elevated background sound (sound masking). Sound absorption (not to be confused with the blockage of sound transmission through a construction) is discussed in Section 3.7.

Chapter 5
Sound Isolation Codes and Standards

5.1 INTRODUCTION

Chapter 4 described an approach to determining sound isolation requirements based on background sound criteria and privacy requirements. This chapter describes requirements for sound isolation performance of building elements stipulated in building codes, federal or state regulations, and standards.

Sound isolation criteria are typically expressed in terms of sound transmission class (STC) and impact insulation class (IIC) ratings. STC is a laboratory measure of how much airborne sound a structure blocks; IIC is an analogous measure of insulation of noise resulting from impact, such as footfalls on structures. Because these metrics pertain only to laboratory measurements, some standards and regulations also reference in-situ metrics, including noise isolation class (NIC), normalized noise isolation class (NNIC), and normalized impact sound rating (NISR). For the attenuation of exterior noise, some references also use outdoor–indoor transmission class (OITC), a metric similar to STC but with a slightly different frequency content that more realistically characterizes sound transmission blocking of building façades. These metrics are discussed in greater detail in Chapter 7 of this Guide.

5.2 OFFICES

The U.S. General Services Administration (GSA) document P-100, *Facilities Standards for the Public Buildings Service* (GSA, 2010), defines a range of acoustical criteria for GSA offices. The document includes background sound level requirements, requirements for the use of sound-absorbing surfaces, and sound isolation criteria for walls and floor/ceiling assemblies. Unlike most references discussed in this chapter, which rely on laboratory-based STC values, the GSA stipulates minimum NIC requirements as shown in Table 5-1.

The P-100 standard goes on to recommend specific wall constructions that typically meet the NIC requirements shown in Table 5-1; these guidelines are summarized in Chapter 7.

5.3 MULTIFAMILY DWELLINGS

5.3.1 National Model Code Requirements

The International Building Code (IBC) (ICC, 2015) requires "walls, partitions, and floor/ceiling assemblies separating dwelling units from each other or from public or services areas" to meet a minimum of STC 50, or 45 if field-tested. The requirement applies to resident-corridor walls but not to unit entrance doors. Further, it requires that floor/ceiling assemblies meet a minimum IIC 50, or 45 if field tested.

In practice, designers compare building constructions to published laboratory-measured STC and IIC ratings of similar assemblies or rely on a qualified acoustical consultant. STC and IIC ratings of assemblies have been published by sound isolation product manufacturers and the California Department of Health Services Office of Noise Control (DuPree, 1981). DuPree (1981) is the "Catalog of STC and IIC Ratings for Wall and Floor/Ceiling Assemblies" and is no longer maintained by the State of California, but it is still a useful reference for certain assemblies. Additionally, some building trade organizations and others have published STC and IIC ratings of assemblies; examples and guidelines are also given in Chapter 7 of this Guide. Some published data are also obtained from tests on mock-ups or during building commissioning.

5.3.2 HUD Guidelines

The U.S. Department of Housing and Urban Development (HUD) published "A Guide to Airborne, Impact, and Structure Borne Noise-Control in Multifamily Dwellings" in 1967 (Berendt et al., 1967). Although no longer maintained by HUD, this document continues to be a standard reference in the industry. It defines STC and IIC criteria for three grades of residences, ranging from luxury buildings and buildings in quiet areas (Grade I) to minimal requirements (Grade III). The latter have mostly been superseded by minimum code requirements (see Section 5.3.1). The requirements are based on adjacencies; a bedroom adjacent to a bedroom in an abutting residence has a different criterion from a kitchen adjacent to an abutting kitchen, for example. For Grade I, criteria range mostly from STC 55 to STC 60, depending on the adjacency, and from IIC 55 to IIC 65, again depending on the adjacency. A family room above a bedroom has the most stringent criteria (STC 60 and IIC 65); a living room above a living room should achieve STC 55 and IIC 55, and stacked corridors need only meet STC 50 and IIC 50.

HUD also published an exterior noise guidebook (HUD, 2009), which is used to regulate site selection of HUD-funded projects. The document establishes criteria for exterior noise levels and a standard method for calculating them based on proximity to airports, railways and highways. If the calculated exterior noise levels exceed certain thresholds, HUD stipulates sound isolation performance

Table 5-1. Sound Isolation Criteria in GSA P-100[a]	
Space	**Minimum Sound Isolation (NIC)**
Teleconference facility	53
Meeting rooms, training facilities	48
Private offices—confidential privacy	45
Private offices—normal privacy	40
Private offices—normal privacy, low voice level	31
Child care center	31

[a] Summarized from GSA P-100 Table 3-2 (GSA, 2010).

Table 5-2. Sound Isolation Criteria in ANSI/ASA S12.60—Part 1[a]	
Space Adjacent to a Core Learning Space	**Minimum Sound Isolation (STC)**
Another core learning space, therapy room, health care room or another space requiring acoustical privacy	50
Common-use and public-use toilet room	53
Corridor (not including the door), stair, office or conference room	45
Music room, performance space, mechanical equipment room, cafeteria or gymnasium	60

[a] Summarized from ANSI/ASA S12.60 Table 4 (ASA, 2010).

requirements for building envelope constructions in order to achieve a certain maximum interior sound level. Under most circumstances, the building envelope is required to provide an average attenuation of 25 dB to 30 dB.

5.4 SCHOOLS

The definitive standard for acoustical performance of classrooms and other spaces in schools is ANSI/ASA S12.60 (ASA, 2010). In addition to indicating background noise criteria (cited in Table 4-1), ANSI/ASA S12.60 mandates minimum sound isolation criteria. These include OITC criteria of walls with and without windows ranging from OITC 30 on a quiet site to OITC 50 on the noisiest permissible sites, and STC ratings for wall and floor/ceiling assemblies that separate core learning spaces from adjacent spaces, as shown in Table 5-2.

The Leadership for Energy and Environmental Design (LEED) for Schools guideline (USGBC, 2009b) and the Collaborative for High Performance Schools (CHPS) standards (NEEP, 2014) also contain guidelines for school sound isolation performance. These guidelines reference ANSI/ASA S12.60 but, in certain cases, deviate slightly from the ANSI standard.

5.5 HEALTH CARE FACILITIES

The Facilities Guidelines Institute *Guidelines for Design and Construction of Health Care Facilities* document (FGI, 2010) includes criteria for sound isolation performance between enclosed rooms (in terms of STC ratings) as well as criteria for speech privacy for both enclosed and open-plan spaces. The speech privacy criteria are stated in terms of PI, AI, speech transmission index and speech interference index, but essentially stipulate normal privacy in open-plan spaces and have criteria for both normal and confidential speech privacy in enclosed spaces that conform to Table 4-4 of this Guide.

The sound isolation performance design criteria are summarized in Table 5-3.

5.6 COURTS

The *U.S. Courts Design Guide* (GSA, 2007) stipulates background sound requirements (cited in Table 4-1) as well as noise isolation requirements. Like the GSA P-100, these criteria are stated in terms of the field-based noise isolation class (NIC) rating. Highlights from these requirements are summarized in Table 5-4.

Table 5-3. Sound Isolation Criteria in FGI[a]		
Adjacency		**Minimum Sound Isolation (STC)**
Patient room	Patient room (same floor)	50
Patient room	Patient room (above/below)	53
Patient room	Public space	50
Patient room	Service area	60
NICU	Patient room or corridor	50
Exam room	Public space	50
Treatment room	Room	50
Consultation room	Public space or patient room	50
MRI Room	Patient or exam room	60
MRI Room	Public space	50
Exam room	Exam room (no electronic masking)	50
Exam room	Exam room (with electronic masking)	40
Patient room, exam room, treatment room or consultation room	Corridor (with closed door)	35

[a] Summarized from *Guidelines for Design and Construction of Health Care Facilities* Table 1.2-3 (FGI, 2010).

Table 5-4. Sound Isolation Criteria in *U.S. Courts Design Guide*[a]	
Room	**Minimum Sound Isolation (NIC)**
Courtroom	55 to 60
Judge's chambers	50
Witness room	55
Most offices	35 to 40
Trial jury suite or grand jury hearing room	70
Interview rooms, certain offices requiring confidential speech privacy	55

[a] Summarized from the *U.S. Courts Design Guide* Table 14.2 (GSA, 2007).

5.7 OTHER REFERENCES AND GUIDES

5.7.1 International Code Council Guideline G2-2010

The International Code Council (ICC) developed the "Guideline for Acoustics," which is applicable to a wide range of commercial and multi-family buildings (ICC, 2010a). The guideline includes both acceptable and preferred criteria and states the criteria both in terms of field-tested ratings and laboratory-tested ratings. No distinctions are made based on adjacency or room use—the same preferred and acceptable criteria are applied to all adjacencies, which limits the practical utility of the guideline. The ICC guidelines are summarized in Table 5-5.

5.7.2 "Green Building" Standards and Guidelines

A Standard for the Design of High-Performance Green Buildings, Except Low-Rise Residential Buildings (ASHRAE, 2014) includes a number of acoustical criteria for interior sound isolation as well as sound isolation of the building envelope for buildings on noisy sites or near significant noise sources. The criteria, in Section 8.3.3 of the standard, are consistent with those summarized elsewhere in this section—residential criteria are equivalent to the International Building Code requirements, and criteria for school classrooms are consistent with ANSI/ASA S12.60. Similarly, the *International Green Construction Code* (ICC, 2010b)

Table 5-5. Sound Isolation Criteria in "Guideline for Acoustics"[a]		
Sound Isolation Metric	**Acceptable Performance**	**Preferred Performance**
Airborne, field tested (NNIC)	52	57
Airborne, lab tested (STC)	55	60
Impact, field tested (NISR)	52	57
Impact, lab tested (IIC)	55	60
[a] Summarized from "Guideline for Acoustics," Tables 1 and 2 (ICC, 2010a).		

includes sound isolation criteria as well. Section 807.4 stipulates background sound criteria (broadly consistent with ASHRAE and other sources) and also requires a minimum of STC 60 around mechanical or emergency generator equipment rooms.

The U.S. Green Building Council has published several LEED guidelines, and many of these reference acoustical criteria. The *LEED* 2009 *for Schools New Construction and Major Renovations* (USGBC, 2009b) includes sound isolation criteria that references ANSI/ASA S12.60 as part of an enhanced acoustical performance credit. *LEED Reference Guide for Green Building Design and Construction: Healthcare Supplement with Global ACPs* (USGBC, 2009a) includes a credit for an acoustical environment that references FGI (2010). LEED BD+C (v4) (USGBC, 2013) includes an "acoustic performance" credit that applies to new construction projects and highlights a range of acoustical criteria including sound isolation criteria. If a project is slated to meet green building standards or credits, the language of these credits should be carefully reviewed.

Chapter 6
Sound Sources

6.1 AIRBORNE SOUND SOURCES

In this section, the sound levels of various typical sound sources are presented in order to enable the reader to determine criteria for sound isolation performance of building constructions following the approach described in Chapter 2. References are cited in case the reader requires more detailed spectral information.

6.1.1 Typical Interior Sound Sources

The sound levels and spectra of speech are standardized in ANSI/ASA S3.5 (ASA, 2012), *Methods for Calculation of the Speech Intelligibility Index*. Four levels of vocal effort are standardized: normal, raised, loud and shout. The average male speech peaks at mid-frequencies (500 to 1,000 Hz) for normal, raised, loud and shouting speech are roughly 54 dB, 61 dB, 67 dB and 75 dB, respectively, measured 3 ft from the source. The normal and raised levels are in standard use in designing for speech privacy in offices and health care facilities and as a reference for residential sound isolation.

Large gatherings of people can, of course, become much louder than a single talker. The authors have measured the *SPL* of cocktail parties ranging from 75 dBA to over 85 dBA. The level depends on crowd size and density, as well as room volume and the presence or absence of sound-absorbing finishes. Lively restaurants (often playing background music) can exceed 85 dBA, and bars and nightclubs can exceed 100 dBA.

The sound levels of unamplified musical instruments vary significantly, but for most design purposes, assume that the *SPL* produced in appropriately sized rooms for music practice, rehearsal and performance is in the range of 90 to 95 dBA when ensembles suitable for those rooms are playing at near-peak loudness. At a distance of 5 ft in open air, a solo piano at fortissimo is at 90 dBA; at mezzo-piano/mezzo-forte, the piano is roughly at 80 dBA; and at pianissimo, about 73 dBA. Levels are highest between 125 Hz and 500 Hz, with the unweighted levels in those octave bands roughly equal to the overall A-weighted levels; *SPL* tapers off above 1,000 Hz. A violin at fortissimo is roughly at 92 dBA (with more energy in higher-frequency bands than the piano). Sound level measurements of fortissimo passages in individual practice rooms (one musician), large concert halls (100 orchestral musicians) and recital halls (at most, 30 musicians) all hover around 90 dBA; rooms that are subjectively too small for the size of the performing ensemble can be upwards of 5 dBA louder. The problem of excessive loudness is most acute in low-ceilinged rehearsal rooms with insufficient sound-absorbing treatments and overly large ensembles; in the worst cases, rooms can exceed 105 dBA (Pirn, 1973).

The loudness of amplified sound is quite variable—typical television usage may be only slightly louder than typical speech, while indoor pop music venues can exceed 110 dBA. Amplified music often contains significantly more low-frequency sound energy than unamplified music, and this is more difficult to isolate. Designing sound isolation for very loud sources—such as amplified music venues, nightclubs, and the like—typically requires thorough sound level measurements of the specific facility to characterize the source level and sometimes requires imposition of sound level limits.

6.1.2 Typical Exterior Sound Sources

For design of building façades for sound isolation, one needs to know the exterior noise levels at the building site. For noise-sensitive buildings or at sites with high levels of ambient noise (typically due to proximity to major transportation infrastructure or to industrial facilities), on-site sound level measurements are needed because exterior noise levels can vary significantly. For more typical applications, an approximation of likely site sound level may be sufficient.

A variety of tools are available to estimate noise exposure from aircraft, road and rail. These include the Federal Highway Administration (FHWA) traffic noise model (TNM), a software application used to predict noise exposure from highways that is required to be used for all federally funded highway projects. Similarly, the Federal Aviation Association's integrated noise model (INM) is used to predict noise in areas surrounding airports and heliports. Many airports publish noise contour data (maps of noise levels surrounding the airport) that are based on the INM. In addition to these, the U.S. Department of Housing and Urban Development (HUD) published a noise assessment calculation methodology for predicting noise at a proposed building site with proximity to highways, rail or airports; noise analysis using the HUD calculation procedures is required for HUD-funded projects. A variety of commercially available software packages also exist with more sophisticated modeling options (in many cases extensions of TNM and INM).

These models and procedures project day–night average noise levels (L_{dn})—a daily averaged A-weighted sound level that places a 10-dB penalty on noise exposure at night. HUD bases its recommendations for exterior sound isolation on the criterion that interior residential space should not exceed L_{dn} 45. Residences and schools within the L_{dn} 65 contour surrounding airports may qualify for certain federally funded sound isolation programs; new residences or schools within these areas typically must demonstrate that building envelopes are designed to achieve no greater than L_{dn} 45 indoors. For other facilities, sound isolation criteria may be based on peak or 10th percentile noise levels rather than daily averages; some of the software-based modeling programs can predict these statistics.

Levels from transportation sources depend on the type of vehicles, their speed, the frequency of the pass-bys, the type of the condition of the surface (in the case of highway and rail noise), and the distance and topography (including presence or absence of barriers) between the site and the noise source. For very long trains and for highway sources in particular, sound levels tend to fall off at a rate of 3 dB per doubling of distance rather than the 6 dB per doubling described in Section 3.4; this is because a highway source is a line source rather than a point source and, as such, radiates sound cylindrically rather than spherically.

An individual diesel locomotive will produce up to 75 dBA at idle and up to 90 dBA at full load at a distance of 100 ft. The A-weighted sound level of a freight train on straight unwelded track at a distance of 100 ft may be approximated by:

$$L_A = 72 + 30\log\frac{V}{20} \tag{6-1}$$

where

L_A = A-weighted sound level at 100 ft from the track, dBA

V = train speed, mph

Further estimates of train noise can be found in Bender et al. (1974) or by using the HUD train noise estimation procedure.

A few rules of thumb can aid a basic understanding of highway noise:

- A truck is roughly as loud as 32 cars.
- There is roughly a 10-dB increase with a 10-fold increase in traffic volume; that is, 2,000 cars per hour is roughly double the loudness of 200 cars per hour.
- Traffic at 55 mph is about twice as loud (10 dB higher *SPL*) as traffic at 15 mph.

A medium-sized truck at 55 mph at 50 ft away on a traditional road surface produces about 80 dBA. The FHWA has set a criterion of 70 dBA for 10th percentile exterior noise levels at residential property (FHWA, 2010).

6.2 IMPACT SOUND SOURCES

The most common impact sound source is footfall associated with people walking. Other common sources include rolling carts, floor impacts in fitness centers or gymnasiums, and rain.

Sound levels resulting from impact sources are difficult to predict and can vary widely. For example, sound levels due to footfall vary with walker weight and stride, shoe type and floor/ceiling assembly details. A process for converting impact insulation class (IIC) ratings of floor/ceiling assemblies into *SPL* in the receiver room is presented in Warnock (1992). Warnock found that the footfall of a typical walker wearing leather-sole shoes with rubber-tipped heels produces about 55 dBA in the room below a floor/ceiling assembly that achieves IIC 45.

In most cases, criteria for insulation from impact noise are based on those summarized in Chapter 5 of this Guide. In cases of more extreme impact sources (e.g., fitness centers), in-situ measurements of impact sound levels at existing or comparable facilities are needed to determine the extent of required impact isolation. Rain impact noise on lightweight metal roof decks varies with the intensity of the downpour and can range from 40 dBA to nearly 80 dBA if the roof/ceiling assembly is not treated. It extends over a wide frequency range, with peak levels typically between 250 and 500 Hz. Roof assemblies to address rain noise are described in Chapter 7.

6.3 MECHANICAL EQUIPMENT

Noise from mechanical equipment often is a critical component requiring sound isolation. For most major building HVAC equipment, noise data can be obtained from manufacturers. Such data are typically either measured directly in certified laboratories or calculated or extrapolated from other data. Measured data are most reliable; data that have been calculated or extrapolated can sometimes vary from actual conditions by as much as 10 dB or more in critical octave bands. When making sound isolation design decisions based on equipment noise data, it is important to verify the origin of the noise data.

6.3.1 Converting Sound Power Level to Sound Pressure Level

The data provided by manufacturers are typically given in terms of sound power rather than sound pressure. The difference is analogous to the difference between the wattage of a light bulb and its light intensity (e.g., in lumens or foot-candles) at a given distance. In the open air, if the source is sitting on a flat plane (e.g., the earth or a rooftop), sound will radiate hemispherically, and sound power level (often abbreviated *PWL* or L_w) and sound pressure are related by:

$$SPL = PWL - 10\log\left(2\pi d^2\right) + 10.3 \tag{6-2}$$

where

SPL = sound pressure level, dB

PWL = sound power level, dB

d = distance from the source, ft

(The constant factor 10.3 dB in this equation is simply a unit correction; this correction factor is 0 dB if d is in meters.) The equation is based on the surface area of a hemisphere ($2\pi d^2$); the *PWL* of sources with other directivity patterns can be converted to *SPL* using a similar function based on the surface area of the particular sound radiation pattern. Indoors, the conversion from *PWL* to *SPL* depends not only on distance from the source, but also on the characteristic of the room and a source directivity factor (e.g., whether the source is in the middle of the room or in a corner), per Equation 6-3:

$$SPL = PWL + 10\log\left(\frac{Q}{4\pi d^2} + \frac{4}{R}\right) + 10.3 \qquad (6\text{-}3)$$

where

Q = directivity factor
= 2 for a source on a flat surface
= 4 for a two-surface corner
= 8 for a three-surface corner

R = room constant, ft^2, given by Equation 6-4

$$R = \frac{a}{1-\overline{\alpha}} \qquad (6\text{-}4)$$

where

a = total acoustic absorption, sabins

$\overline{\alpha}$ = average absorption coefficient, equal to a divided by the total room surface area

Sound absorption (a and $\overline{\alpha}$) is discussed in Section 3.7 of this Guide.

6.3.2 Estimating Mechanical Equipment Sound Power Levels

If noise data from the manufacturer are not available or not reliable, estimates of noise levels of various equipment (refrigeration equipment, air handling equipment, heating equipment, cooling towers, pumps, engines, generators, and transformers) can be found in Miller (1980), Long (2014) and other noise control textbooks. The following summary table of approximate sound level data represents relatively conservative (high) estimates of mechanical equipment noise: per Miller, 80 to 90% of mechanical equipment will be of equal or lesser *SPL* than the values presented in Table 6-1.

In addition to airborne noise generated by mechanical equipment, secondary noise generated in roof decks or other structures by equipment vibration can be a significant source of noise. Chapter 9 of this Guide includes guidelines for the control of both noise and vibration of mechanical equipment.

Noise in ducted air systems results from fans, fan coil units, variable-air-volume boxes and other terminal boxes, and turbulence in the airflow (associated with airflow velocity, duct geometry and disturbances in the airstream caused by dampers, grilles, registers and diffusers). The prediction and control of noise in duct systems is beyond the scope of this Guide; the reader is referred to the *ASHRAE Handbook: Heating, Ventilation and Air Conditioning Applications*, Chapter 48, "Noise and Vibration Control" (ASHRAE, 2011), for a fairly comprehensive treatment of the subject.

6.3.3 Plumbing Noise

Plumbing can generate significant noise when pipes are rigidly mounted to walls and other building structures that reradiate the pipe vibrations as audible sound. Depending on the water pressure and the manner in which the pipe is mounted, supply piping can generate between 30 and 55 dBA. Corresponding to water and effluent flow through plastic (e.g., PVC) waste pipes, levels as high as 60 to 65 dBA have been measured in residences below the source. Cast iron waste pipes can avoid this issue, and flexible decoupling and heavy pipe lagging can be used to address existing noise problems associated with plastic pipes.

6.4 CALCULATING SOUND LEVELS FROM SEVERAL SIMULTANEOUS SOURCES

To obtain the total sound levels associated with multiple sources (e.g., multiple pieces of equipment in a mechanical room or multiple exterior noise sources), add the sound pressure or sound power. Recalling that levels expressed in decibels are unitless logarithms of actual sound pressure (or power) divided by a reference value, decibel levels cannot be added arithmetically. One option for adding *SPL* or *PWL* values is to convert the quantities from decibels to basic units (e.g., pressure squared or power), then add resultant values and take 10 times the log of the sum. A simpler process is to use Table 6-2: to add two decibel quantities, simply take the numerical difference between the two and add the corresponding value from the table to the greater of the two.

For example, if it is determined that the *SPL* in a mechanical room is 80 dBA due to one of two identical air handling units in the space, the total *SPL* can be found using Table 6-2: the difference in level between the two sources is 0 dBA (80 dBA − 80 dBA = 0 dBA), and thus we add 3 dB to the louder source to find the total level in the room is 83 dBA.

The process using Table 6-2 can be repeated to obtain the level corresponding to multiple sources. The calculated result may vary by 1 or 2 dB, depending on the order of operation, but this variation generally is not significant. Where greater precision is required, add the values logarithmically as described in the preceding text.

Table 6-1. Sound Power Level (*PWL*) Estimates for Common Mechanical Equipment		
Equipment	**A-Weighted *PWL***	**Spectral Characteristics**
Chillers with reciprocating compressors	97 dBA (under 30 tons) to 103 dBA (over 80 tons) [a]	Significant *SPL* throughout the audible range; greatest in the 500-Hz octave band
Chillers with rotary-screw compressors	90 dBA [a]	Significant peak at 250 to 500 Hz
Chillers with centrifugal compressors	93 dBA (direct-drive, 100 tons) to 111 dBA (direct-drive, 1600 tons) [a]	Greatest *SPL* at 250 Hz, except for the largest chillers, where energy is greatest at 1000 to 2000 Hz
Boilers, 50 to 300 BHP	96 dBA	Greatest *SPL* at 31- and 63-Hz bands, tapering off at 3 dB/octave at 250 Hz and above
Boilers, 301 to 2000 BHP	99 dBA	Greatest *SPL* at 31- and 63-Hz bands, tapering off at 3 dB/octave at 250 Hz and above
Cooling towers,[b] propeller-type, under 100 HP	90+8 log (fan hp) dBA	Greatest *SPL* at 63- and 125-Hz bands, tapering off at 3 dB/octave outside those bands
Cooling towers,[b] propeller-type, over 100 HP	86+10 log (fan hp) dBA	Greatest *SPL* at 63- and 125-Hz bands, tapering off at 3 dB/octave outside those bands
Cooling towers,[b] centrifugal fans, under 80 HP	77+11 log (fan hp) dBA	Greatest *SPL* at 31- and 63-Hz bands, tapering gradually (~ 2dB/octave) above the 63 Hz band
Cooling towers,[b] propeller-type, over 80 HP	85+7 log (fan hp) dBA	Greatest *SPL* at 31- and 63-Hz bands, tapering gradually (~ 2dB/octave) above the 63 Hz band
Air-cooled condensers	77+12 log (CC[c]) dBA	Greatest *SPL* at 63- and 125-Hz bands, tapering off at 3 dB/octave outside those bands
Packaged HVAC rooftop units with compressor/condenser sections	81+12 log (CC[c]) dBA	Greatest *SPL* (roughly flat) from 63 to 500 Hz

[a] Noise data for chillers are typically available from manufacturers that are more reliable than these estimates.
[b] Cooling towers produce substantially more noise on the inlet and discharge (top) sides than on the enclosed sides of the tower. See Miller (1980) for additional information about cooling tower sound radiation directivity.
[c] CC is cooling capacity, tons (1 ton = 12,000 BTU/hr.)

Table 6-2. Simple Method for Decibel Addition											
Difference (dB)	0	1	2	3	4	5	6	7	8	9	10
Amount (dB) to be added to louder source	3	3	2	2	1	1	1	1	1	1	0

6.5 SAMPLE CALCULATION: MECHANICAL NOISE IN A ROOM

Consider a conference room that is 25 ft long, 15 ft wide, and 9 ft tall with a carpet floor, painted gypsum board on steel stud walls, and a suspended mineral fiber acoustic ceiling tile (ACT). The room has two floor-mounted fan coil units: one near the center of each of the longer walls, approximately 15 ft from an entrance door near the center of one of the shorter walls. Each fan coil unit has a sound power level of 50 dB at 500 Hz. What is the sound pressure level at 500 Hz at the door?

First, calculate the total amount of absorption in the room, as shown in Table 6-3. Absorption coefficients for carpet, gypsum board, and mineral fiber ACT can be found in Table 3-1.

The average absorption coefficient is the total absorption (sabins) divided by the total surface area:

$$\bar{\alpha} = \frac{270 \text{ sabins}}{1{,}470 \text{ ft}^2}$$
$$= 0.184 \ \frac{\text{sabins}}{\text{ft}^2}$$

Table 6-3. Sample Mechanical Noise Calculation			
	Area, ft^2	**Absorption Coefficient at 500 Hz**	**Absorption, sabins**
Walls	4 walls: 720 ft^2 total	Gypsum board: 0.04	720 $ft^2 \times 0.04 = 29$ sabins
Floor	375 ft^2	Carpet: 0.14	375 $ft^2 \times 0.14 = 53$ sabins
Ceiling	375 ft^2	Mineral fiber ACT: 0.50	375 $ft^2 \times 0.50 = 188$ sabins
Totals	**1,470 ft^2**		**270 sabins**

The room constant, per Equation 6-4, is:

$$R = \frac{a}{1-\bar{\alpha}} \tag{6-4}$$

$$= \frac{270 \text{ sabins}}{1-0.184 \text{ sabins/ft}^2}$$

$$= 331 \text{ ft}^2$$

With the fan coil units on the floor in the center of a long wall, the directivity factor, Q, is 4, per the definition provided in Equation 6-3. Per Equation 6-3, the sound pressure level at the door as the result of a single fan coil unit is:

$$SPL = PWL + 10\log\left(\frac{Q}{4\pi d^2} + \frac{4}{R}\right) + 10.3 \tag{6-3}$$

$$= 50 \text{ dB} + 10\log\left[\frac{4}{4\pi(15 \text{ ft})^2} + \frac{4}{331 \text{ ft}^2}\right] + 10.3 \text{ dB}$$

$$= 41.6 \text{ dB}$$

$$\cong 42 \text{ dB}$$

There are two such fan coil units equidistant from the door. Per Table 6-2, 3 dB is added to account for the second source of equal *SPL*. Thus, the *SPL* at the door at 500 Hz is:

$$SPL \cong 42 \text{ dB} + 3 \text{ dB}$$

$$= 45 \text{ dB}$$

From Figure 3-2, this sound level at 500 Hz corresponds to approximately NC-40. Per Table 4-1, this background sound level substantially exceeds typical noise criteria for private offices or teleconference rooms.

Chapter 7
Airborne Sound Isolation

7.1 BASIC CONCEPTS

7.1.1 Transmission Coefficient and Transmission Loss

As sound encounters a structure (a wall, a floor/ceiling assembly, a window, etc.), a fraction of the sound is transmitted through it. The fraction of sound pressure transmitted through a structure at a given frequency is called the coefficient of transmission, τ. The unit-less coefficient of transmission ranges from 1 (100% of sound is transmitted) to 1/1,000,000 or less for structures that transmit very little sound.

In buildings, there is typically more of a concern regarding how much a building's construction blocks sound than with how much it transmits. A measure of how much sound a structure blocks is transmission loss. The transmission loss, *TL*, expressed in decibels, is related to the transmission coefficient by

$$TL = 10 \log \frac{1}{\tau} \qquad (7\text{-}1)$$

For example, the transmission coefficient of a brick wall at 500 Hz may be roughly 10^{-4}. Per Equation 7-1, its *TL* at that frequency is equal to 40 dB.

7.1.2 Multi-Component Constructions

In many cases, building constructions are composites, made up of several elements—an exterior wall with windows or an interior partition with a door, for example. The sound transmission of the composite construction is a function of the transmission coefficient of each component, weighted according to its percentage of the total area of the intervening construction:

$$\tau_{comp} = \Sigma \frac{\tau_n S_n}{S_{total}} \qquad (7\text{-}2)$$

where

S_n = surface area of the nth component, ft^2

S_{total} = total surface area of the intervening construction common to both the source and receiver sides, ft^2

τ_{comp} = transmission coefficient of the overall composite construction

τ_n = transmission coefficient of the nth component

Using the composite transmission coefficient, the composite *TL* can be calculated using Equation 7-1.

A sample composite construction *TL* calculation illustrates an important consideration in building acoustics—the effect of cracks and gaps. Assume that a 10-ft by 10-ft brick wall has a *TL* of 40 dB at 500 Hz. Also assume that there is a gap or crack in the wall with an area totaling 0.01 ft^2, perhaps 10 ft long and .001 ft wide (.012 in. wide). Solving Equation 7-1 for τ, the transmission coefficient of a wall with a *TL* of 40 dB is 10^{-4}. The transmission coefficient of a crack is 1.0 (total transmission). From Equation 7-2, we find:

$$\tau_{comp} = \Sigma \frac{\tau_n S_n}{S_{total}} \qquad (7\text{-}2)$$

$$= \frac{\left(10^{-4}\right)\left(100 \text{ ft}^2\right)}{\left(100 \text{ ft}^2 + 0.01 \text{ ft}^2\right)} + \frac{(1)\left(0.01 \text{ ft}^2\right)}{\left(100 \text{ ft}^2 + 0.01 \text{ ft}^2\right)}$$

$$\approx 2 \times 10^{-4}$$

Using this value of τ in Equation 7-1, the composite *TL* of the assembly is then calculated to be 37 dB. Although the crack represents only 0.01% of the total area, the overall *TL* of the brick wall is reduced from 40 to 37 dB—a 3-dB reduction, constituting a considerable degradation.

7.1.3 Noise Reduction

Transmission loss is a function solely of the properties of the blocking structure (e.g., partition or floor/ceiling assembly). But the properties of the receiver room also affect the sound level. (The receiver room is on the opposite side of the blocking structure from the source room—the room with the sound source in it.) If the receiver room is small with highly sound-reflective surfaces (e.g., a bathroom), the sound levels will be greater than if the receiver room is large with sound-absorptive surfaces (like a well-treated classroom). The difference between sound levels on the source side and those on the receiver side of an intervening construction is called the noise reduction, *NR*; it takes properties of the receiver room into account. Noise reduction is related to transmission loss by Equation 7-3:

$$NR = TL + 10 \log \frac{a_2}{S} \qquad (7\text{-}3)$$

where

NR = noise reduction, the difference between sound levels on the source side and those on the receiver side of an intervening construction, dB

S = surface area of the intervening construction common to both the source and receiver sides, ft^2

TL = transmission loss per Equation 7-1, dB

a_2 = total acoustic absorption in the receiver space, sabins (see Section 3.7)

For example, a classroom with a sound-absorbing ceiling may have roughly 700 sabins at 500 Hz. The size of the wall between adjacent classrooms may be 250 ft^2. Per Table 5-2, the sound isolation performance of such a wall should be STC 50 or greater. At 500 Hz, an STC 50 wall has a *TL* of approximately 50 dB. The actual noise reduction between classrooms with an STC 50 wall will be (per Equation 7-3)

$$NR = TL + 10\log\frac{a_2}{S} \tag{7-3}$$

$$= 50\text{ dB} + 10\log\left(\frac{700\text{ sabins}}{250\text{ ft}^2}\right)$$

$$= 54.5\text{ dB}$$

Note that Equation 7-3 applies to the far field of the receiver space, one or more wavelengths from the sound isolating assembly in question; at listener locations very near the intervening assembly, the characteristics of the room are not as prevalent and *NR* is roughly equal to *TL*. Simple derivations of Equation 7-3 can be found in Kinsler et al. (1999) and other acoustics textbooks.

7.2 METRICS

As indicated in Chapter 6, sound transmission class (STC) is a metric of blocking of sound transmission of constructions determined from idealized laboratory measurements. Outdoor–indoor transmission class (OITC) is a more realistic measure of real-world sound transmission isolation of building façades. Noise isolation class (NIC) is a simple measure, taken in the field, of airborne noise reduction across a building structure. These and other metrics are described in greater detail in this section.

7.2.1 The Sound Transmission Class Metric

STC is a single-number rating used to evaluate the transmission loss of building constructions; it is measured in a laboratory environment. Just as *SPL* is dependent on frequency and NC ratings or A-weighted decibels are single-number approximations of overall *SPL*, *TL* is frequency dependent, and the STC rating is a single-number approximation of overall *TL*.

The process for measuring airborne transmission loss in a laboratory is standardized in ASTM Test Method E90 (ASTM, 2009b), and the process for calculating the resultant STC is standardized in ASTM E413 (ASTM, 2010). The calculation process involves fitting a reference STC contour to measured (or calculated) third-octave-band *TL* data. The STC rating is taken as the value of the shifted reference contour at 500 Hz.

Like any single-number metric, the STC does not fully characterize the transmission loss of a structure or assembly. Because the STC value is calculated based only on *TL* data from 125 Hz to 4,000 Hz, STC is not a sufficient metric for conditions where low-frequency sound transmission is important (e.g., at a nightclub or adjacent to a diesel engine). Also, because the metric is a single number, it does not differentiate between assemblies that are weak in one frequency range only (but otherwise may be quite robust) and those that are generally weak throughout the spectrum. Furthermore, because STC can only be measured in a laboratory under highly controlled conditions, it does not account for the variations and weaknesses that inevitably are introduced during construction of actual buildings. Despite these limitations, STC is in widespread use, as evident from the many regulatory criteria outlined in Chapter 5 of this Guide. STC is a useful metric to characterize the capacity of common, well-constructed assemblies to block typical sound, such as speech.

7.2.2 Outdoor–Indoor Transmission Class and Other Ratings

OITC, standardized in ASTM E1332 (ASTM, 2003), is a measure of the A-weighted sound level reduction of a building specimen in the frequency range from 80 to 4,000 Hz measured using ASTM laboratory test method E90 or derived from measurement results obtained in the field using ASTM E966 (ASTM, 2004). The third-octave-band weightings used by this method are based on measured spectra of aircraft takeoff, freeway and railroad pass-by sounds. OITC is a single-number metric in common use to evaluate building façade constructions.

OITC is a more realistic indicator of façade performance than STC ratings. But OITC is insufficient in cases where significant noise levels below 80 Hz are a concern (e.g., adjacent to some industrial sites, rock concert venues, etc.). In such cases, no standard single-number sound isolation metric is appropriate; rather, building isolation performance should be evaluated at the specific frequencies of interest.

In Europe, the weighted sound reduction index, R_w, is in common use in ways analogous to the use of STC ratings in the United States. R_w and several other related metrics are standardized in ISO 717 (ISO, 2006).

Ceiling attenuation class (CAC) is a specific measure describing how much sound is blocked by acoustic ceiling tile. The test method, described in ASTM E1414 (ASTM, 2006), measures the “double-pass” through the ceiling tiles. (Sound is generated in a source room with the ceiling tiles in place; the adjacent receiver room has the same ceiling tiles in it. A highly sound-isolating wall between the source room and the receiver room extends to, or through, the ceiling but is not sealed off above the ceiling; thus, sound transmits up through the tile on one side of the wall, crosses through the ceiling plenum, and then passes back down through the ceiling tile on the other side of the wall.) Mineral fiber ceiling tile typically is rated CAC 35. Glass fiber ceiling tile is more sound absorptive than mineral fiber tile but blocks less sound transmission—its CAC rating is typically below CAC 20. Certain specialty and composite tile products have been rated above CAC 40.

7.2.3 Field-Based Metrics of Airborne Sound Isolation

STC and other laboratory-measured ratings are useful for comparing alternative configurations, but other measures assess sound isolation performance in actual buildings. These include noise isolation class (NIC), normalized noise isolation class (NNIC), field sound transmission class (FSTC), and apparent sound transmission class (ASTC).

Unlike STC, NIC (standardized in ASTM test methods E336 and E596) is a measure of *NR* rather than *TL* (ASTM, 2009c; ASTM, 2009e). NIC is determined from the difference between the *SPL* in the source room and that in the receiver room, and the same standard contour used to calculate STC is fitted to the measured *NR* data.

NNIC and ASTC (ASTM E336) are measured in a manner similar to NIC, but the measured *NR* results are normalized based on measured reverberation time of the receiver room. (More information on reverberation time can be found in Section 3.7 of this Guide.) ASTC is based on the apparent *TL*. The measured *NR* is adjusted using Equation 7-3 to calculate the *TL*, which requires a measure of the total sound absorption of the receiver room and the surface area of the partition common to both sides. FSTC is similar to ASTC, except that additional steps are taken in the field to isolate the partition being tested from the influence of any flanking paths—paths that transmit sound in a way that circumvents the assembly being tested (e.g., the floor under a wall being tested). In common practice, measures of FSTC are exceedingly rare.

Reported values of NIC depend on the acoustical conditions of the receiver room and correlate well to occupants' subjective impressions of sound isolation. ASTC is substantially independent of the acoustical conditions of the receiver room and more closely represents the performance of the partition under testing (irrespective of the receiver room conditions).

In actual construction, weaknesses (sound leaks) inevitably occur that are not present in laboratory tests. Examples include electrical outlets, lighting fixtures, cracks and pores, and, most especially, structural flanking paths As such, it is reasonable to expect that field-based measures of sound isolation (e.g., ASTC) will fall short of laboratory-based measures of nominally identical assemblies. As discussed in Chapter 5, the IBC (ICC, 2015) accounts for this fact by stipulating that assemblies must achieve STC 50, but only 45 if field measured.

7.3 CONSIDERATIONS FOR AIRBORNE SOUND ISOLATION IMPROVEMENT

7.3.1 Mass per Unit Area, Stiffness and Damping

The transmission of sound through a practical extended structure, such as a partition (without openings), depends primarily on the structure's stiffness and mass. At relatively low frequencies (in the audible range), stiffness plays a predominant role; whereas at high frequencies it is, in essence, mass that determines the sound-blocking capability of the structure. In most practical situations, building assemblies block high-frequency sound far more effectively than low-frequency sound so that noise problems tend to be related to low-frequency sound transmission. This is why it's the bass part of a neighbor's stereo that can be heard through the party wall and not the vocal track.

Mass of building constructions can be increased relatively easily, if necessary. For example, the number of layers of gypsum wall board (GWB) on a metal stud partition can be increased, concrete masonry unit (CMU) partitions can be grouted, additional concrete can be poured onto structural decks and window glass can be thickened. But stiffness also plays a role—stiffer structures tend to transmit high-frequency sound better. For example, single-stud walls with metal studs spaced at 24 in. on center isolate sound at mid- to high-frequencies consistently better than walls with studs at 16 in. on center (assuming all else is equal); similarly, walls with lighter gauge studs outperform partitions with stiffer studs.

The foregoing discussion does not take into account resonances—matching of a frequency of the incident sound with a natural frequency of a partition structure. At resonances, the transmission loss is reduced considerably; this effect is particularly pronounced if the pressure distribution associated with the impinging sound matches the deflection distribution of the structure. The frequency region in which these distributions coincide, the so-called coincidence region, depends on the mass and bending stiffness of the structure. In dual-panel arrangements, such as double-pane windows, select panels with different coincidence regions (e.g., lites of different thicknesses) to avoid low transmission loss due to the coincidence regions in the two elements occurring at the same frequency.

Damping—the capability of a structure to dissipate energy—reduces the severity of vibrations at resonances and thus also the degradation of transmission loss in the coincidence region. For example, the intermediate layers in laminated glass assemblies contribute considerable damping, resulting in laminated glass that provides greater transmission loss than monolithic glass panes of the same thickness. Some suppliers of gypsum board have demonstrated improved transmission loss due to a damping layer applied to the gypsum board. If two partitions are mounted in contact with each other, without a damping layer between them, the friction between them may be expected to provide an increase in damping and, thus, greater transmission loss.

For a more detailed discussion of the role of mass, stiffness and coincidence dip, refer to Long (2014), Chapter 9.

7.3.2 Separation

Sound impinging on one side of a partition sets that partition into motion; as a result of this vibratory motion, the partition radiates sound from its other side similar to a loudspeaker membrane. (Actually, the partition radiates sound from both of its sides, but the sound radiating from the impinged side is negligible compared to the incident sound.) If another partition is located near the first one, then the sound radiated from the first will impinge on the second, setting the second partition into motion and causing it to radiate sound. The sound radiated from the second partition tends to be much reduced, having been attenuated by each of the partitions. Thus, double-partition arrangements can provide considerably more transmission loss than single panels of much greater weight.

Sound can be reflected back and forth in the space between two partitions, resulting in a buildup of the pressure field and reduced noise isolation performance of the assembly. This buildup and the attendant loss of isolation performance can be reduced by partially filling the space with a sound-absorptive material, such as fiberglass batts. (Nonporous insulation, such as polystyrene rigid insulation, is not absorptive and, thus, does not provide these benefits.) Care should be taken, however, to ensure that this interstitial material does not provide a bridge along which vibrations can be transmitted between the two partitions.

In a steel building, it is typical to have a ceiling (e.g., a suspended gypsum board ceiling) separate from a concrete/metal deck structure. The separation is most effective if the two components are decoupled. The ceiling can be suspended with a spring or other resilient hanger, for example, and sometimes the ceiling can be supported from isolated wall framing without contacting the deck above at all. Even simple wire ceiling hangers are more effective than studs or rigid furring because they decouple the ceiling from the structure more effectively. It is because of this separation that certain floor/ceiling assemblies in steel buildings can block as much or more sound than certain structural concrete assemblies, despite their considerably smaller mass.

The greater and more complete the separation, the better the acoustical performance will be—particularly at low frequencies. Windows with a deep air gap between lites block significantly more low-frequency sound energy than windows of equal mass where the separation between lites is modest. Double-stud partitions where the studs are truly separate from one another block significantly more sound than single-stud partitions (or partitions where the separation between nominally separate stud rows is compromised by gusset plates or other means of bridging) and can provide greater transmission loss than much more massive CMU walls.

True double-stud partitions achieve separation more reliably than any other stud wall design, but alternatives may be useful where space is limited and the need for sound isolation is not quite as critical. Just as ceilings can be suspended with spring or neoprene resilient hangers, wall facings like gypsum board can be attached to framing with resilient channels or clips. Resilient channels are in common use but are not as effective and not as reliable in the field as resilient sound isolating clips. These clips contain neoprene or another resilient material. They are installed onto stud framing (or CMU) directly and accept a standard metal hat channel; the gypsum board is then fastened onto the hat channel. Where resilient channels are used in lieu of better-performing resilient elements (whether in wall or ceiling installation), only the thinnest gauge (least stiff) single-leg resilient channels should be used, and care must be taken to fasten the gypsum board to the resilient channel only, without driving the fastener into the framing (which defeats the decoupling). One further note of caution about resilient channels: Installation of cabinets, wall-mounted televisions, or other items that must be anchored into stud framing will also short-circuit the resilient channel and defeat the decoupling. This problem can occur with resilient clips as well, although, in those instances, a detail can be developed more easily to support the cabinet or television without defeating the isolation.

Partitions framed with light gauge metal studs block more sound than wood-framed walls because the metal studs are less stiff—they transmit energy less efficiently across the wall. Similarly, wide (24 in.) spacing is better acoustically than narrow (16 in.) stud spacing. The STC values in Table 8-1, found later in Chapter 8, illustrate the effects of stud gauge and spacing on sound isolation performance.

7.3.3 Minimizing Gaps, Leaks and Flanking

As illustrated in Section 7.1.2, gaps or leaks can significantly degrade sound isolation performance. It is critical to seal gaps effectively. ASTM C919 (ASTM, 2008a) provides a guide for the effective use of caulk and sealant in acoustical applications. Nonhardening sealant (such as silicone caulk and many firestop sealants) is generally preferred because it will not crack with building movement or with relative movement between resiliently decoupled structures as with spring-isolated ceilings.

In steel buildings with corrugated metal decks, it is particularly important to seal the top of the wall to the underside of the deck in locations where there is no ceiling or where the ceiling is acoustical tile or another material with a lesser *TL* than the wall material. Figure 7-1 details a good way to approach this when the wall is not parallel to the flutes: Fill the deck flutes with mineral wool, and then seal the top of the wall to the deck with a spray-applied, nonhardening sealant.

Gaps and leaks occur commonly at doors. Full-perimeter gaskets are typically necessary where a door is part of an acoustically sensitive wall. Full-perimeter gasketing must include overlapping astragals at double-doors (astragals seal the gap between doors), as well as means for providing a continuous seal at the bottom of the door. This bottom seal can take the form of a neoprene sweep that meets a raised ADA-compliant threshold, or an automatic drop seal can be mortised into or applied onto the bottom of the door.

Ungasketed doors are typically around STC 20 to 25, and gasketed doors may achieve STC 30 to 35. For better performance, one may use a specialty manufactured door assembly that bears an acoustical rating up to roughly STC 56. A rated assembly includes not just the door slab, but also the frame and the door seals, all of which are integral parts of an assembly provided by a single source. For critical spaces, entry vestibules are an effective way to address the transmission loss weakness of doors; when space allows for vestibules, they can be more effective and less expensive than acoustically rated door assemblies.

Flanking paths can compromise what is otherwise an effective building construction. Common flanking paths include adjacent wall, floor or ceiling assemblies that can transmit sound structurally, ductwork that can serve as a conduit for sound between spaces, and doors and windows, particularly undercut doors that allow for ventilation. Also consider doors and windows that may be adjacent to, rather than part of, the partition in question, but that nonetheless provide a path for sound to flank around the partition. Solutions to these issues may include gasketing for doors and windows; careful duct routing and internal sound absorbing duct liners; and the construction of inner wall, floor or ceiling surfaces that are decoupled from adjacent spaces.

At buildings with curtainwall façade constructions, the partition-mullion closure detail is an important potential flanking path. Mullions are typically thinner and lighter than the wall or floor/ceiling assembly that meets them. The mullion should be captured by the partition in a way that (1) provides an excellent seal between the partition and the mullion,

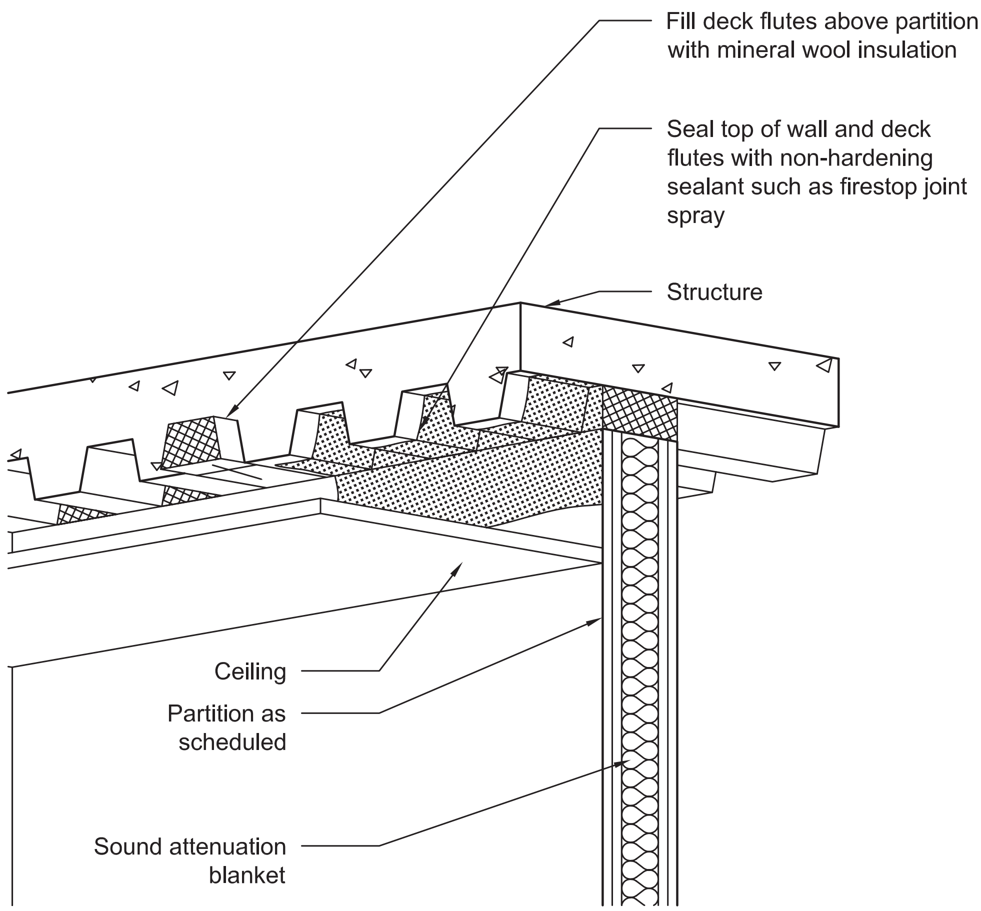


Fig. 7-1. Top-of-wall sealant at underside of fluted deck.

(2) permits movement of the façade independent of the partition to allow for thermal expansion and contraction, and (3) minimizes the area over which the lightweight mullion is the only building element separating two occupied spaces. Commercial products are available that extend an extruded metal cap (to match the existing mullion) from the end of the partition around the mullion with a compressible gasket on the window side.

In locations with very high sound isolation requirements (over STC 57), the mullion-partition closure detail will be insufficient. The mullion cap itself may not be robust enough; in addition, an exterior sound path can emerge as a significant flanking path when *TL* requirements are high. Sound that passes through the curtainwall can diffract around the partition and pass back into the building through the curtainwall. In such cases, spandrel panels can be used so that the partition is able to capture multiple mullions in series; alternatively, interior glazing (e.g., a storefront window) can be installed inside of the curtainwall to create a large dual-glazing system with a deep gap between the curtainwall and the interior glass. This latter approach can be complicated—details or systems to address moisture, condensation and cleanability must be addressed—but can be highly effective acoustically.

7.3.4 Matching Sound Transmission Through Constructions

If there are several potential sound paths between spaces (or several elements that make up a composite construction), it is important that they be designed in a balanced manner. The weakest path will compromise the acoustical performance. For example, if a door constitutes a significant weakness, the door must be upgraded so that its *TL* is in appropriate balance with that of the rest of the partition or façade. Otherwise, the composite *TL* (Section 7.1.2) will be controlled by the door, and any upgrades to the rest of the wall assembly will have no effect.

7.3.5 Absorption in the Receiver Space

Under certain circumstances, it may be appropriate to increase the acoustical absorption in the receiver space to improve the *NR* (see Equation 7-3.) Note that this strategy has a practical limit—often around 3 dB, and rarely more than 5 dB. If a sound isolation problem requires an improvement on the order of 10 dB or more, adding absorption to the receiver space cannot be the sole solution.

Chapter 8
Building Assemblies

8.1 ISOLATION OF AIRBORNE SOUND FOR HORIZONTAL ADJACENCIES AND FAÇADES

To determine what sound isolation is needed (or desired), refer to the noise criteria presented in Chapter 4 and to the sound isolation criteria in Chapter 5.

8.1.1 Metal Stud Walls

Table 8-1 presents sound isolation data for a range of single- and double-stud wall constructions. Trends discussed in Section 7.3 are observable in these results—specifically, the effects of insulation, stud gauge and spacing, number of layers of gypsum board (GWB), etc. Detailed spectral data for each assembly can be found in the sources referenced in the table. A word of caution: Studies have shown considerable variation in STC values for nominally identical assemblies tested in different labs at different times; in some cases, exceeding five STC points. When designing for regulated or critical applications, it is reasonable to design for at least three STC points above the criterion to account for this variation and for the vicissitudes of the construction process.

Note also that the data in Table 8-1 assumes normal weight gypsum board. Assemblies with low-density gypsum board will perform with one to four STC points lower than the corresponding STC value in Table 8-1, per data from U.S. Gypsum (USG, 2015).

Details and guidelines for specific applications are discussed in Table 8-1.

Data for wall assemblies featuring resilient elements is available from manufacturers of those assemblies. Examples of such assemblies are summarized in Table 8-2.

It can be observed from the table data that sandwiching a resilient element (channel or clip) between two layers of gypsum board (as in the third row of Table 8-2) severely limits the sound isolation of the partition, as compared to fixing the resilient element to the stud directly (as in the second and fourth rows).

Figures 8-1 and 8-2 show typical partition details suitable for a wide variety of applications. The single-stud wall shown in Figure 8-1 (approximately STC 52, depending on the details and the testing laboratory) is appropriate to separate classrooms from one another, to separate apartments or condominiums from common corridors, or to separate patient rooms from one another, for example. (See Chapter 5 for typical STC requirements of these adjacencies.) The double-stud wall in Figure 8-2 (up to STC 64) is suitable to separate luxury condominiums from one another, between a school gymnasium and a classroom, or around a courtroom. See Chapter 5 of this Guide for some typical criteria.

For example, to illustrate the design process for a metal stud partition, consider an executive office: The wall with the entry door abuts an open plan office, and the other interior walls abut other office space. The door represents 20% of the area of the entry wall. A fully gasketed wood door will achieve about STC 30. For the sound isolation performance of the wall and door to be in appropriate balance (Section 7.3.4), the wall should be no greater than approximately STC 40 unless substantial door upgrades are contemplated. Per Table 8-1, a metal stud wall with one layer of ⅝-in.-thick gypsum board on each side and 3-in.-thick insulation in the cavity achieves STC 39 if 16 or 20 ga. studs are spaced 16 in. on center, roughly consistent with this goal. Equation 7-2 can be used to verify that the composite *TL* of this assembly is roughly 34 dB at mid-frequencies. Consider the room noise criteria and the source levels to confirm the appropriateness of this selection. The criterion is NC-30 in the private office and NC-40 in the open plan office (Table 4-1). Normal voice conversation is roughly 54 dB. The process used to determine the required sound isolation is summarized in Table 8-3.

The composite wall, therefore, meets the sound isolation requirement for the open plan office and leaves a modest margin of error in case the door gaskets are not well sealed. If well-sealed gaskets can be assured, the wall could be downgraded by deleting the batt insulation and the criterion will still be met.

If the wall to the adjacent office has a more stringent requirement, a confidential level of privacy from raised speech levels is desired, where raised voice conversation is 61 dB. The calculation then becomes as shown in Table 8-4.

From Table 8-1, a transmission loss requirement of 41 dB at mid-frequencies (roughly STC 41) would require either 25-ga. studs at 24 in. on center and batt insulation in the cavity, or a second layer of gypsum board added to the insulated 16-ga. stud wall selected for the open plan office. This is based on the assemblies given in Table 8-1 with STC values that are equal to 41 or greater from all data sources.

8.1.2 CMU Walls, Combination CMU/Metal Stud Walls, and Shaft Walls

In some areas, CMU walls are in widespread use for many of the applications considered in this Guide. Sound isolation data for several CMU walls are summarized in Table 8-5.

For locations where better *TL* is required, partitions that combine fully grouted CMU with either resiliently furred

Table 8-1. Sound Isolation Properties of Common Stud-Framed Walls							
	Wall Facing, GWB, Side 1	Wall Facing, GWB, Side 2		Stud			
Studs	Number of Layers, Thickness, in.	Number of Layers, Thickness, in.	Batt Insulation,[a] in.	Size, in., Gauge	Stud Spacing (o.c.), in.	STC	Data Sources
Single	1 layer, ⅝	1 layer, ⅝	None	3⅝, 25	24	38 to 42 38	1 2
Single	1 layer, ⅝	1 layer, ⅝	3	3⅝, 25	24	43 to 44	1, 3
Single	1 layer, ⅝	1 layer, ⅝	3.5	3⅝, 25	16	44 39 to 49[b]	3 2
Single	1 layer, ⅝	1 layer, ⅝	3	3⅝, 16 or 20	16 or 24	38 to 39	3
Single	2 layers, ⅝	1 layer, ⅝	3.5	3⅝, 25	24	47 to 49	1, 3
Single	2 layers, ⅝	1 layer, ⅝	3.5	3⅝, 16	16	42	3
Single	2 layers, ½ or ⅝	2 layers, ½ or ⅝	3 or 3.5	3⅝, 25	24	50 to 54 52 51 to 58	1 3 2
Single	2 layers, ½ or ⅝	2 layers, ½ or ⅝	3.5	3⅝, 25	16	49 52 to 56	3 2
Single	2 layers, ⅝	2 layers, ⅝	3.5	3⅝, 16 or 20	16	44, 45	3
Double	1 layer, ⅝	1 layer, ⅝	2.5 × 2	2½, 25	24	55	2
Double	2 layers, ⅝	2 layers, ⅝	2.5 × 2	2½, 25	24	64	2

1. California Office of Noise Control (DuPree, 1981).
2. National Research Council of Canada Institute for Research in Construction (IRC) Report IRC-IR-761 (Halliwell et al., 1998) and Report RR-343 (Kodur et al., 2013).
3. Bétit (2010).

[a] Per Report IRC-IR-761 (Halliwell et al., 1998); results in the same STC ranges with fiberglass batt, mineral fiber and cellulose insulation.

[b] A review of published laboratory test data indicates that some IRC tests (Halliwell et al., 1998) have produced higher STC results of nominally identical constructions than other tests (at IRC and elsewhere). These higher test results should not be used as the basis of design decisions. Some of these data are presented here to illustrate the wide range of published data.

gypsum board (shown in Figure 8-3) or separate stud partitions (Figure 8-4) may be used. The former is suitable where an upgrade of four to seven points beyond standard CMU walls is required. However, where GWB is added to a CMU wall on resilient furring (as in the last data point in Table 8-5, or as detailed in Figure 8-3), resonance of the mass-air-mass system will limit the isolation at low frequencies. When very high *TL* is required, particularly at low frequencies, a separate stud wall (see Figure 8-4) is far more effective. This detail is suitable around noisy mechanical equipment, some music spaces, and other sensitive adjacencies. STC values in the range of STC 70 to 75 are estimated for combination CMU/stud walls similar to that detailed in Figure 8-4.

These upgraded walls are also suitable around elevator shafts, mechanical shafts predicted to be noisy, around trash chutes and around other locations where CMU is used as a shaftwall assembly. In locations where C-H studs are used to construct shaftwalls near noise-sensitive locations such as bedrooms, executive offices or other spaces with a background sound criterion of NC-30 or less, use a separate row of studs spaced 1 in. from the shaftwall, with insulation in the stud cavity and one or more layers of GWB. A list of background sound criteria for various occupancies can be found in Table 4-1.

8.1.3 Façades

In most buildings, the sound isolation of the façade is controlled by the windows. Composite *TL* calculations (Section 7.1.2) are necessary to determine suitable criteria for

Table 8-2. Sound Isolation Properties of Single-Stud Walls with Resilient Elements							
Wall Facing, GWB, Fixed to Stud	Wall Facing on Resilient Furring, GWB			Stud			
Number of Layers, Thickness, in.	Number of Layers, Thickness, in.	Resilient Element	Batt Insulation, in.	Size, in., Gauge	Stud Spacing (o.c.), in.	STC	Data Sources
1 layer, ⅝	1 layer, ⅝	1-leg resilient channel with 1.5-in. screw flange	3.5	3⅝, 20 (or equiv.)	24	48	3
1 layer, ⅝	1 layer, ⅝	Resilient clip with hat channel	5.5	3⅝, 20 (or equiv.)	24	58	1
1 layer, ⅝	2 layers, ⅝ (with resilient clip between)	Resilient clip with hat channel between 2 layers GWB	3.5 + 1.5	3⅝, 20 (or equiv.)	24	53	1
1 layer, ⅝	2 layers, ⅝	Resilient clip with hat channel	5.5	3⅝, 20 (or equiv.)	24	60-61	1, 2
2 layers, ⅝	2 layers, ⅝	Resilient clip with hat channel	5.5	3⅝, 20 (or equiv.)	24	63	2

1. PAC-International laboratory test data (PAC-International, 2014).
2. Kinetics Noise Control laboratory test data (Kinetics Noise Control, 2014).
3. Clark Dietrich laboratory test data (Clark-Dietrich, 2014).

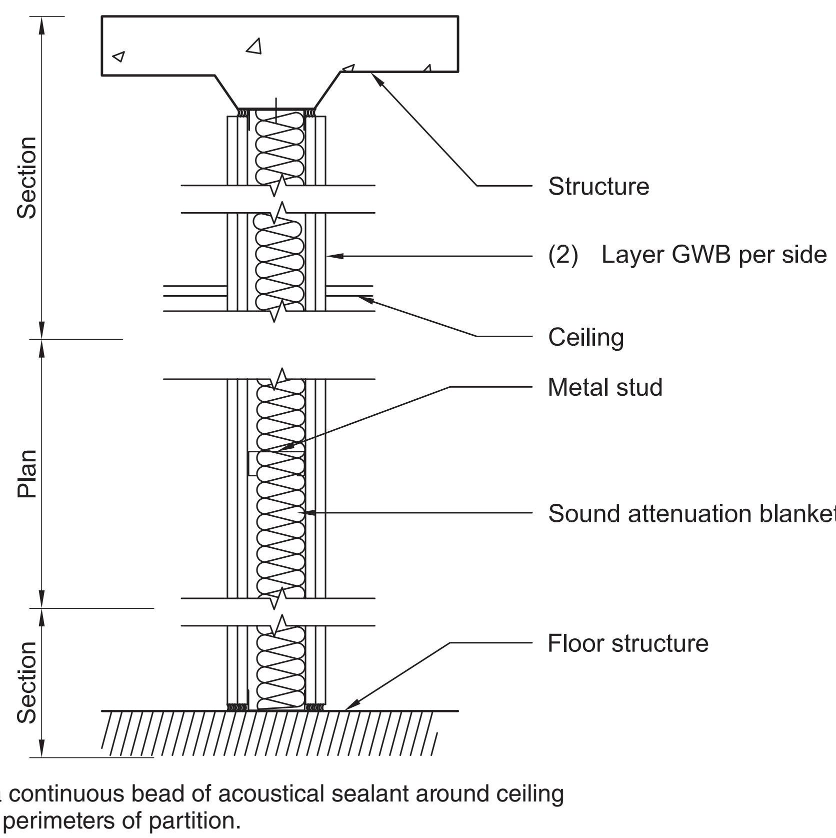


Fig. 8-1. Single-stud partition with four layers of gypsum board.

Table 8-3. Example Calculations of Sound Isolation Requirement (500 Hz)		
	Executive Office	**Open Plan Office**
Steady-state criterion from Table 4-1	30 dB	40 dB
Plus transient criterion for office work from Table 4-2	–5 dB	5 dB
Equals criterion for intruding sound level	25 dB	45 dB
Source level	54 dB	54 dB
Minus criterion for intruding sound level	25 dB	45 dB
Equals minimum sound isolation requirement	29 dB	9 dB

Table 8-4. Example Calculations of Sound Isolation Requirement—Higher Level of Privacy (500 Hz)	
	Executive Office
Steady-state criterion from Table 4-1	30 dB
Plus transient criterion for confidential speech from Table 4-2	–10 dB
Equals criterion for intruding sound level	20 dB
Source level	61 dB
Minus criterion for intruding sound level	20 dB
Equals minimum sound isolation requirement	41 dB

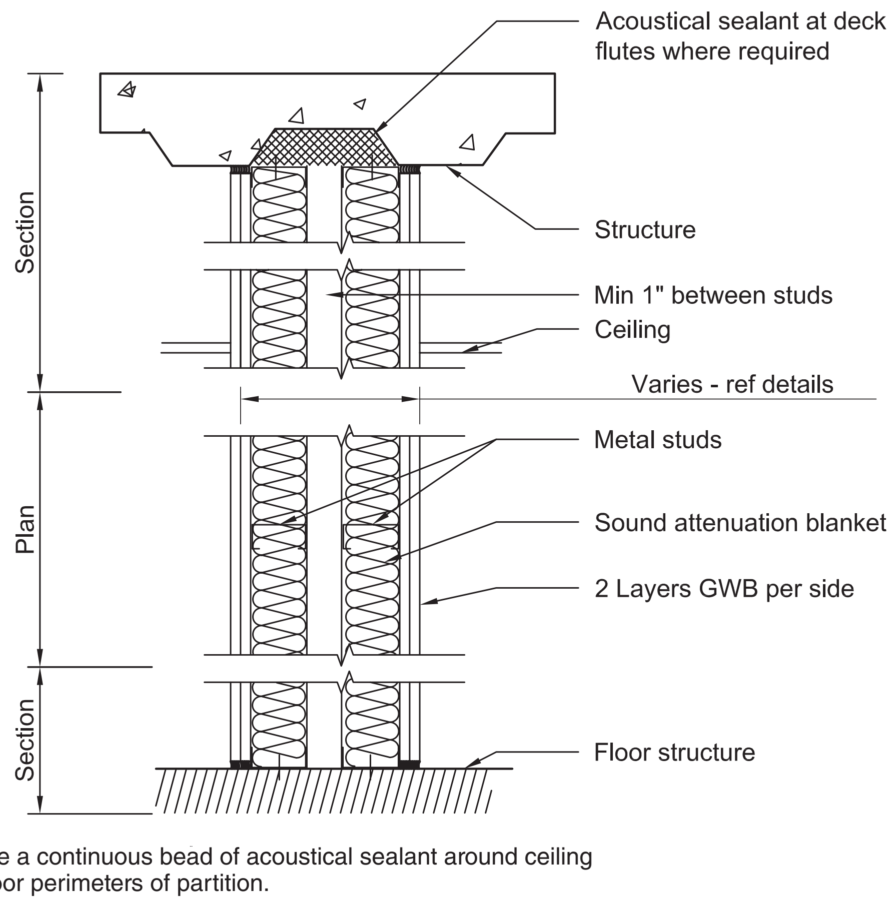


Fig. 8-2. Double-stud partition with four layers of gypsum board.

Table 8-5. Sound Isolation Properties of CMU Walls[a]				
CMU Type	**Fill**	**Sealant**	**Additional Layers**	**STC**
8-in. × 8-in. × 16-in. 3-cell lightweight CMU (28 lb/block)	None	None	None	45
8-in. × 8-in. × 16-in. 3-cell lightweight CMU (28 lb/block)	None	Primer-sealer and finish coat each side	None	46
8-in. × 8-in. × 16-in. 3-cell lightweight CMU (28 lb/block)	Fully grouted (with #5 rebar)	None	None	48
8-in. × 8-in. × 16-in. 3-cell lightweight CMU (28 lb/block)	Fully grouted (with #5 rebar)	2 coats latex paint each side	None	55
8-in. × 8-in. × 18-in. 3-cell lightweight CMU (34 lb/block)	None	None	None	49
8-in. × 8-in. × 18-in. 3-cell lightweight CMU (34 lb/block)	Expanded mineral loose-fill insulation	None	None	51
8-in. × 8-in. × 18-in. 3-cell lightweight CMU (34 lb/block)	None	None	1 layer, ⅝-in. GWB on resilient channels, each side	56

[a] From California Office of Noise Control (DuPree,1981).

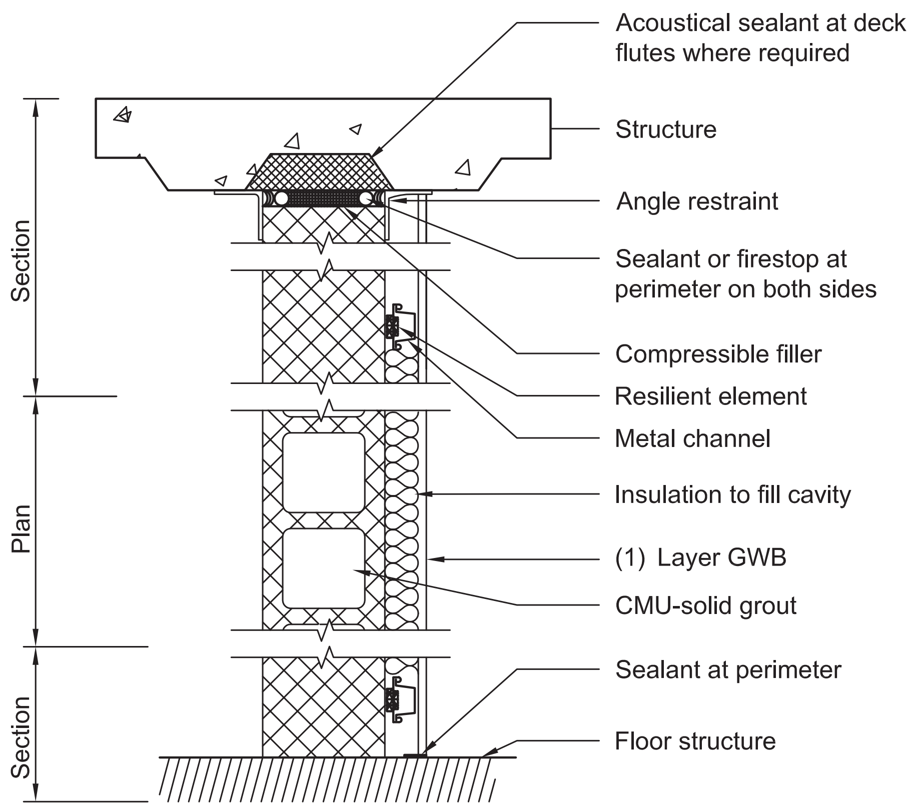


Fig. 8-3. CMU with resiliently furred gypsum board.

walls and windows individually. In locations with significant levels of exterior noise, interior storm windows or other double window constructions with a deep airgap between lites may be necessary. *TL* data for window constructions used in all building types is available from a variety of window and glazing manufacturers (e.g., Viracon, St. Cloud Window, Saflex, and many others).

In most cases, standard exterior wall constructions that feature batt or open-cell foam insulation (not closed-cell foam) will outperform the glazing constructions sufficiently such that no further upgrades to the wall will be necessary. However, in some locations with high *TL* requirements, additional layers of sheathing (exterior) or gypsum board (interior) are necessary to improve the *TL*. In rare cases, resiliently furred or double-wall constructions may be required.

In buildings with curtainwalls or storefront glazing, the glass represents the vast majority of the façade. Specialty sound-isolating curtainwalls with built-in air gaps of significant dimension between separate lites are available for highly sensitive applications. For more typical applications, it is important to keep in mind several guidelines when specifying the curtainwall system:

- The frame should have a surface weight that is at least as great as the glass buildup; otherwise, the frame itself will represent a weakness in the composite *TL* of the window system.
- Larger tube sections of frames can be packed with insulation, which can help address *TL* concerns when lightweight framing elements are unavoidable.
- Sealants must be highly reliable, continuous and airtight.
- Lamination can be a significant benefit, as discussed in Section 7.3.1.
- As discussed in Section 7.3.2, the wider the gap between separate lites, the better the low-frequency *TL* will be.

In the best case, the window or curtainwall system under consideration will be tested as an entire system. However when published *TL* data are for unframed glass only without accounting for the frame or seals, adherence to these guidelines will ensure that *TL* of the entire assembly will approach that of the unframed glass in isolation.

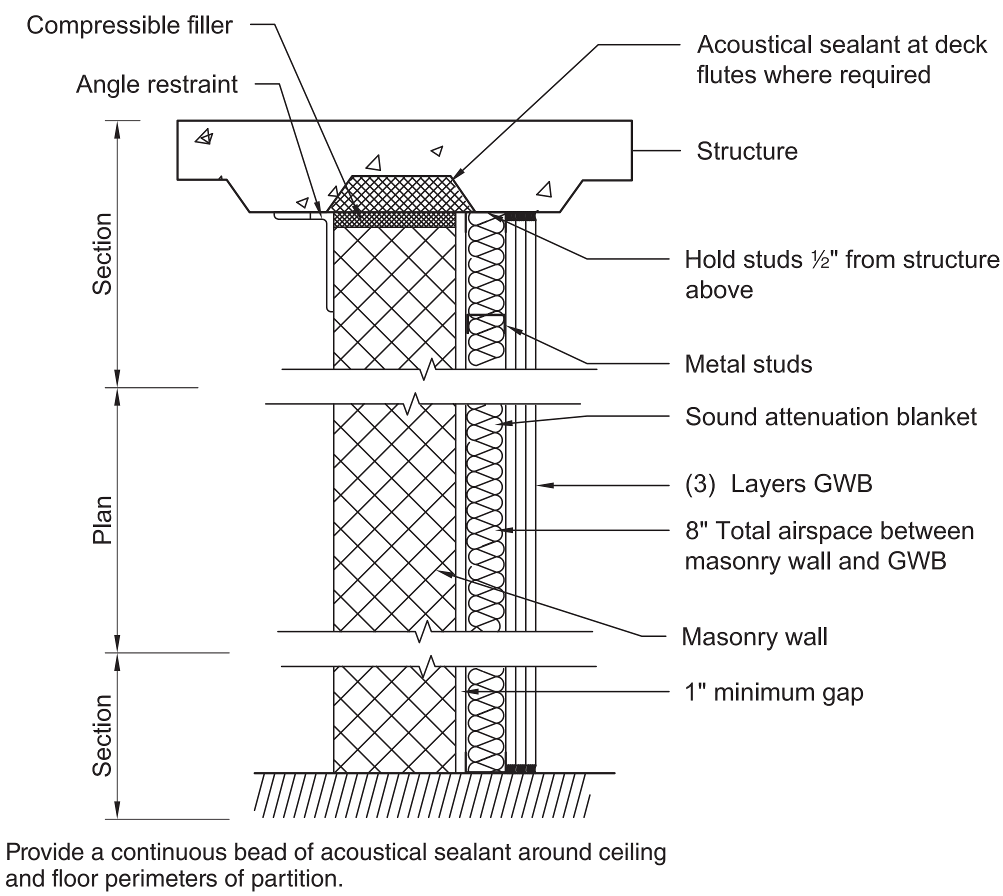


Fig. 8-4. CMU combined with separate metal stud wall.

Table 8-6. Sound Isolation of Floor/Ceiling Assemblies					
Floor/Slab/Deck	Insulation	Ceiling Suspension	Ceiling	STC	Data Source
10-in. hollow core concrete panels, 64 psf	–	–	–	50	1
6-in. concrete slab, 75 psf	–	–	–	55	1
8-in. concrete slab, 95 psf	–	–	–	58	1
6-mil vinyl floor on 1⁄10-in. resilient underlayment on 6¼-in. total-thickness lightweight concrete on 3-in. 18-ga. galvanized composite metal floor deck	3-in. mineral fiber board	3-in. 16-ga. wire hangers	1 layer, ½-in. lightweight GWB	55	2
¾-in. hardwood floor on 1-in. resilient sleeper system on 6¼-in. total-thickness lightweight concrete on 3-in. 16-ga. galvanized composite metal floor deck	3-in. glass fiber batt	Resilient clip with 4-in.-deep angle, steel stud framing	2 layers, ⅝-in. GWB	FSTC* 69	3
3½-in. normal-weight concrete over Type 0.6C, 26-ga. steel deck (0.562 in.-deep), on 10K1 open-web steel joist, 24 in. o.c.	None	Resilient clips 48 in. o.c. with 25-ga. hat channel, 24 in. o.c.	1 layer, ⅝-in. GWB	60	3
5-in. concrete slab, 42 psf, on metal deck	None	16-in.-deep wire hangers	Mineral fiber ACT in T-grid	60	4

1. California Office of Noise Control (DuPree, 1981).
2. NGC Testing Services (NGC, 2014a).
3. PAC-International laboratory test data (PAC International, 2014).
4. Long (2014).

* STC value was obtained in field test rather than in the lab.

8.2 ISOLATION OF AIRBORNE SOUND FOR VERTICAL ADJACENCIES

The design elements described in Section 7.3—mass, separation, insulation between mass layers, damping, sealant of gaps, and avoidance of flanking paths—apply not only to wall systems but also to floor/ceiling and roof/ceiling assemblies. In steel buildings, these assemblies typically include a ceiling that is separate from the floor deck. This creates an opportunity to introduce a combination of mass, separation and insulation that can be highly effective at isolating airborne sound.

Note that impact noise (Sections 8.3 and 8.4) and mechanical impact noise (Chapter 9) also need to be considered where they occur.

8.2.1 Floor/Ceiling Assemblies

Table 8-6 summarizes the STC values of various floor/ceiling assemblies used in steel buildings. (Some typical concrete slab constructions are also shown for reference.) Table 8-7 summarizes similar data for roof/ceiling assemblies.

8.2.2 Suspended Ceilings and Floating Floors

Suspended ceilings can increase the *TL* of a floor/ceiling assembly significantly, particularly at low frequencies, if they are supported by flexible elements. Data on concrete slabs show clearly that ceilings on spring hangers with nominally 1-in. static deflection under load provide substantially better sound isolation performance than ceilings on resilient clips or other neoprene hangers whose deflection is typically less than 0.20 in. Similar data for steel construction are not as prevalent, but more flexible hangers are particularly needed to decouple the ceiling from the relatively flexible deck.

The effect of decoupled layers may also be obtained by supporting a floor with a comparatively high mass per unit area resiliently above the structural slab. Such a floating floor can increase the airborne sound isolation considerably if the floor is massive enough (at least 0.1 times the mass of the deck) and the support is sufficiently flexible. The supports can be spring, rubber or compressed fiberglass mounts.

In combination, floating floors and resilient ceilings can be extremely effective. A 4-in.-thick floating concrete floor on a 6-in.-thick concrete deck or a composite steel deck of

Table 8-7. Sound Isolation of Roof/Ceiling Assemblies							
Roof Buildup	Structure	Insulation	Ceiling Suspension	Ceiling	STC	OITC	Data Source
0.036-in.-thick corrugated galvanized steel deck	–	–	–	–	23	–	2
Membrane, ½-in. roof cover board, 3-in. rigid foam insulation, ⅝-in.-thermal barrier underlayment board, 22-ga. steel deck	Nominal 10-in. open-web steel joists	3.5-in. glass fiber batt	Drywall furring channel	½-in. GWB	56	42	1
Membrane, 2 layers ¼-in. roof cover board, 3-in. rigid foam insulation, ⅝-in. thermal barrier underlayment board, 22-ga. steel deck	Nominal 10-in. open-web steel joists	3.5-in. glass fiber batt	Resilient sound isolating clip	⅝-in. GWB	58	43	1
Membrane, ⅝-in. roof cover board, 3-in. rigid foam insulation, ⅝-in. thermal barrier underlayment board, 22-ga. steel deck	Nominal 10-in. open-web steel joists	3.5-in. glass fiber batt	None	None	44	33	1
Membrane, ⅝-in. roof cover board, 3-in. rigid foam insulation, ⅝-in. thermal barrier underlayment board, 22-ga. steel deck	Nominal 10-in. open-web steel joists	3.5-in. glass fiber batt	Resilient sound isolating clip	⅝-in. GWB	59	46	1
Membrane, ⅝-in. roof cover board, 3-in. rigid foam insulation, ⅝-in. thermal barrier underlayment board, 22-ga. steel deck	Nominal 10-in. open-web steel joists	3.5-in. glass fiber batt	Resilient sound isolating clip	2 layers, ⅝-in. GWB	61	49	1

1. Stewart (2011).
2. Mehta et al. (1999), Appendix J.

similar mass and stiffness with a gypsum board ceiling suspended below on spring hangers has been measured to provide as much as STC 94 (Brunette, 2007).

Resilient ceilings and floating floors are very helpful in isolating impact sound as well, as discussed in Section 8.3.

Details of floor/ceiling assemblies and further guidelines on their use can be found in Section 8.4.

8.2.3 Roof/Ceiling Sound Isolation Data

Roof structures play an important role in isolating noise from aircraft flyover and other exterior noise. Table 8-7 summarizes airborne sound isolation data for several steel roof assemblies with suspended ceilings.

8.3 IMPACT SOUND INSULATION

8.3.1 Metrics

Impact sound (described in Section 6.2) results primarily from footfalls. Floor impacts can also be generated by rolling carts, particularly on grouted tile or other discontinuous floor surfaces, and by other sources. The impact insulation class (IIC) rating is very similar to the STC rating except that it represents isolation from an impact source rather than an airborne source. In the United States, IIC testing is done with a standardized tapping machine outfitted with calibrated steel hammers; see ASTM E492 (ASTM, 2009d) for the standard methodology for laboratory measurement of IIC ratings. Note that IIC is a laboratory metric only. Field measurement of impact sound, standardized in ASTM E1007 (ASTM, 2013), typically is characterized by the apparent impact insulation class (AIIC) and sometimes by the normalized impact sound rating (NISR). In the field it is typical for the AIIC measurement result to be one to five points less than the corresponding IIC measured in a laboratory.

In Europe, ISO 717 Part 2 (ISO, 2006) standardizes the weighted normalized impact sound pressure level, $L_{n,w}$, measured in a laboratory and its counterparts in the field. In other parts of the world, impact sources other than tapping

Table 8-8. Impact Isolation of Floor/Ceiling Assemblies						
Finish Floor	**Slab/Deck**	**Batt Insulation**	**Ceiling Suspension**	**Ceiling**	**IIC**	**Data Source**
None	8-in. hollow core concrete panels, 57 psf	–	–	–	28	1
None	6-in. concrete slab, 75 psf	–	–	–	34	1
6-mil vinyl floor on 1⁄10-in. resilient underlayment	6¼-in. total-thickness lightweight concrete on 3-in. 18-ga. galvanized composite metal floor deck	3-in. mineral fiber	3-in. 16-ga. wire hangers	1 layer, ½-in. lightweight GWB	55	2
¾-in. hardwood floor on 1-in. resilient sleeper system	6¼-in. total-thickness lightweight concrete on 3-in. 16-ga. galvanized composite metal floor deck	3-in. glass fiber batt	Resilient clip with 4-in. deep angle, steel stud framing	2 layers, ⅝-in. GWB	FIIC* 65	3
None	3½-in. normal-weight concrete over Type 0.6C, 26-ga. steel deck (0.562-in. deep) on 10K1 open-web steel joist, 24-in. o.c.	None	Resilient clips 48-in. o.c. with 25-ga. hat channel, 24-in. o.c.	1 layer, ⅝-in. GWB	35	3
a. Glue-down wood b. Vinyl c. Quarry tile d. Floating laminate	1½-in. gypsum concrete on 0.4-in. entangled mesh underlayment on Hambro D-500 composite floor with 2½-in. concrete deck on steel joists	None	Resilient channels	1 layer, ½-in. GWB	51 53 54 55	4

1. California Office of Noise Control (DuPree, 1981).
2. NGC Testing Services report 7014187 (NGC, 2014b).
3. PAC-International laboratory test data (PAC-International, 2014).
4. Maxxon laboratory test data (Maxxon, 2014).
* STC value was obtained in field test rather than in the lab.

machines are used. Japan has standardized the use of a heavy ball, which when dropped from a standard height, imparts more low-frequency energy into the floor system than does the standard American and European tapping machine.

8.3.2 Test Data and Guidelines

Table 8-8 summarizes impact sound isolation data for a range of floor/ceiling assemblies. Details of floor assemblies and guidelines are discussed in the following.

The finish floor surface significantly affects mid- and high-frequency impact sound transmission, especially when compared with bare concrete. Floor finishes adhered directly to the subfloor transmit more impact sound than floating assemblies. Those with substantial surface hardness (tile, stone) transmit more high-frequency sound than softer finishes such as certain vinyl products. For a given assembly, the IIC will typically fall within a roughly five-point range with various hard floor finishes (wood, vinyl, tile, laminate, etc.), as evidenced by the last row of Table 8-8.

The impact insulation class for carpet floors is not shown in Table 8-8. For most assemblies using concrete, carpet floors will yield impact isolation results at or above IIC 70, even without a ceiling. However, carpet alone does not always isolate low-frequency impact sounds very well—especially below 100 Hz, the bottom range of the IIC contour. For good low-frequency isolation, ceilings on spring hangers and/or floor underlayments at least ¼ in. thick or thicker are necessary.

Details in Figures 8-5 through 8-9 show a number of typical floor/ceiling assemblies appropriate to a variety of applications in steel buildings. Also note the following regarding floor/ceiling assemblies:

1. Resilient floor underlayments are very effective for improving footfall noise isolation of floating floor assemblies such as engineered wood, laminate, and vinyl floor products. This improvement extends to lower frequencies for thicker underlayments.

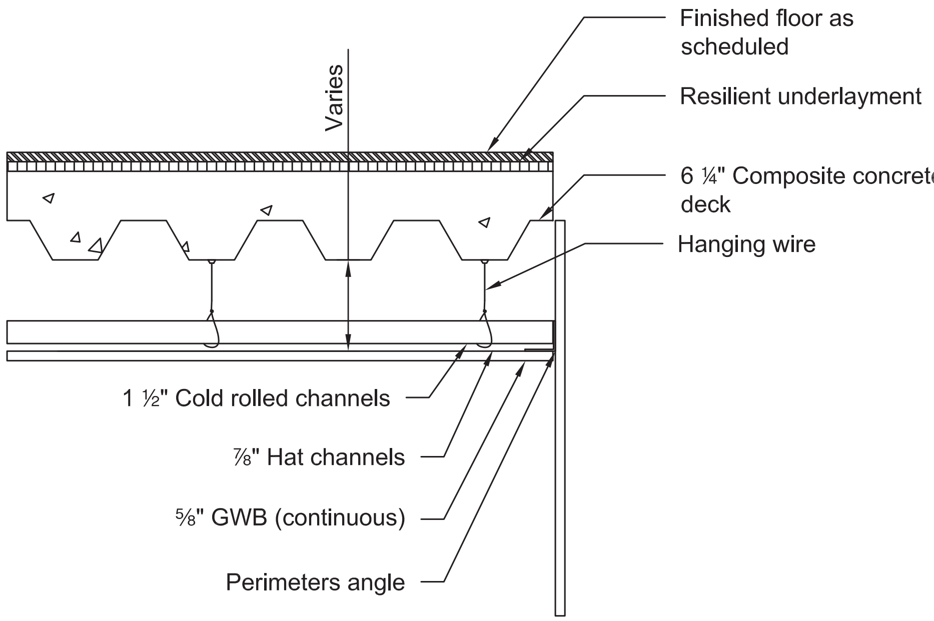


Fig. 8-5. Composite metal/concrete deck with wire-hung ceiling and floors on a resilient underlayment.

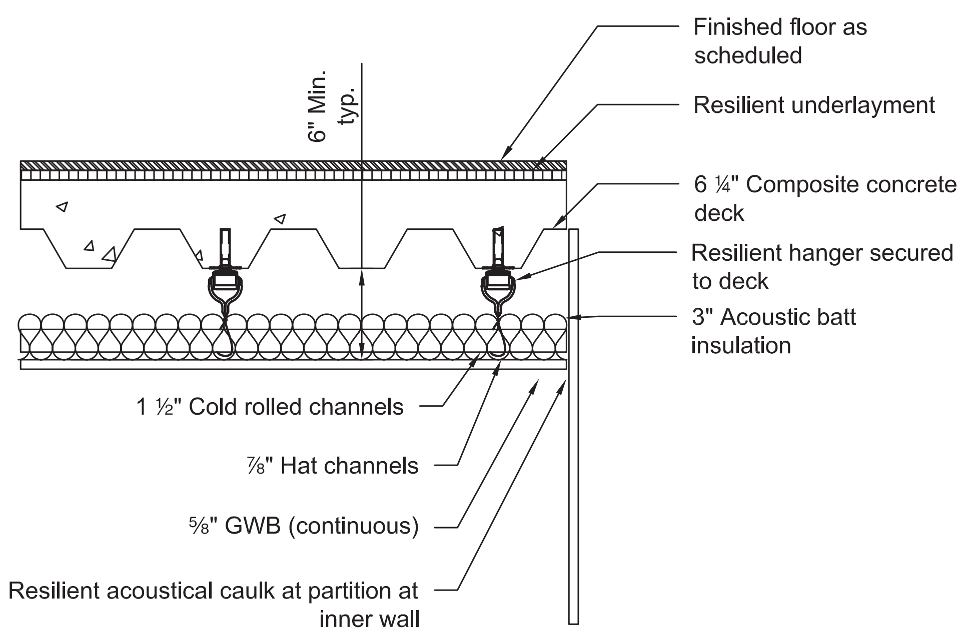


Fig. 8-6. Composite metal/concrete deck with neoprene ceiling hanger and floors on a resilient underlayment.

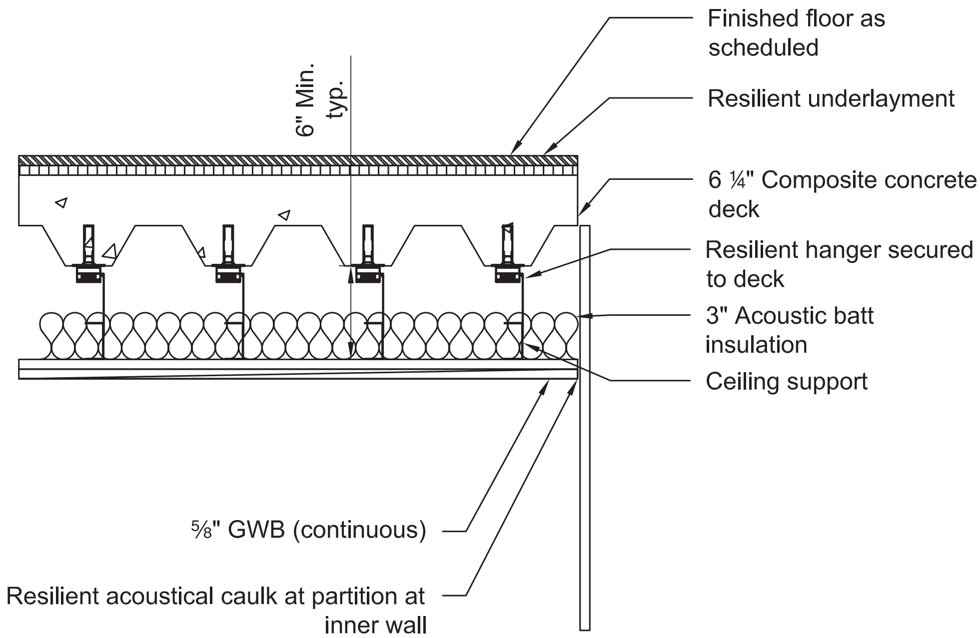


Fig. 8-7. Composite metal/concrete deck with resilient clip and floors on a resilient underlayment.

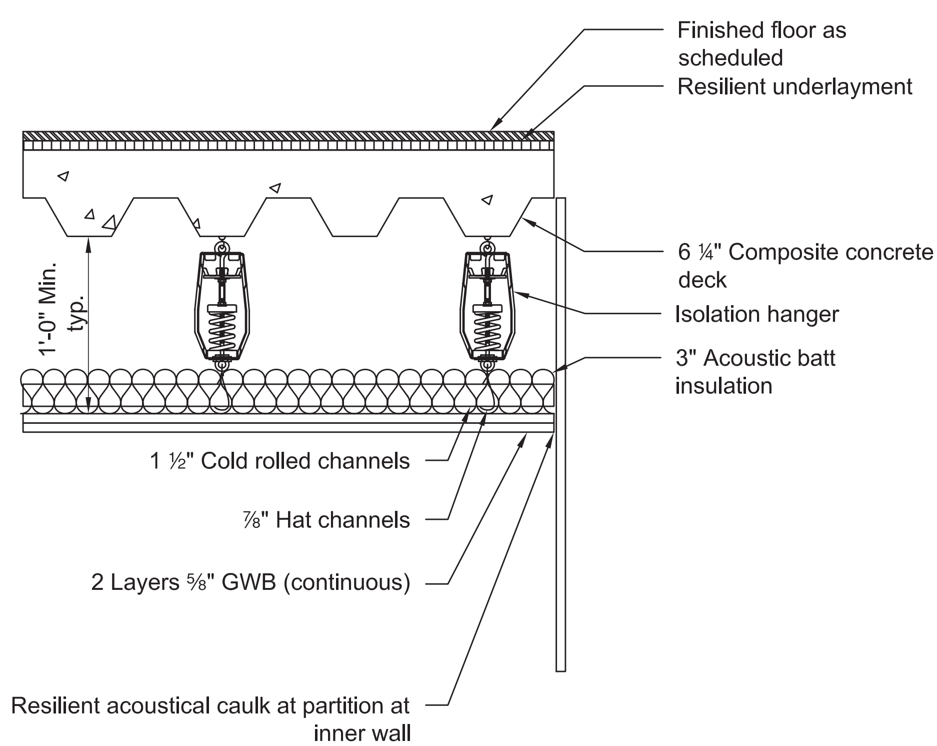


Fig. 8-8. Composite metal/concrete deck with spring ceiling hangers and floors on a resilient underlayment.

2. Resilient underlayment products include recycled rubber mats, entangled wire mesh products typically used under gypsum concrete, foam, felt, fiberglass, and cork. For nail-down wood flooring, resilient floor systems with built-in wood nailers are available.
3. Data in Tables 8-6, 8-7 and 8-8 indicate the benefit of ceilings and insulation in the ceiling cavity. The deeper the separation between the ceiling and the deck, the better the isolation, particularly at lower frequencies. Where noise below 125 Hz is a concern, a minimum ceiling depth of 12 in. should be implemented.
4. Airborne and impact isolation benefits from resilient ceilings, as described in Section 8.2.2.

8.4 FLOOR/CEILING ASSEMBLIES

The floor/ceiling assembly depicted in Figure 8-5 is typical for stacked corridors in multi-family residential buildings and for a variety of commercial and health care applications with airborne and impact noise isolation requirements. A variant of this detail, with mineral fiber acoustic ceiling tile (ACT) instead of a gypsum board ceiling, is typical of many commercial and educational buildings. It provides roughly STC 60 (per the last row in Table 8-6) and impact isolation between IIC 50 and IIC 60, depending on the thickness of the underlayment and the type of floor finish.

The floor/ceiling assembly shown in Figure 8-6 represents an upgrade from the assembly of Figure 8-5. Insulation is added in the ceiling cavity, and wire hangers are replaced by neoprene-resilient hangers. This detail is suitable for stacked residences in a multi-family building and will achieve an STC rating in the high 60s and an IIC rating in the low to mid 60s, depending on the depth of the ceiling plenum, the thickness of the insulation, the type of resilient hanger and the thickness of the floor underlayment.

The assembly depicted in Figure 8-7 is similar to that of Figure 8-6 but with an alternate means of resilient ceiling support. The assembly has been further upgraded with the addition of a second layer of gypsum board on the ceiling. This assembly corresponds to the fifth row of Table 8-6 (FSTC 69) and the fourth row of Table 8-8 (FIIC 65).

The assembly in Figure 8-8 is suitable for transfer floors in high-end residential buildings, where the floor plans above and below the assembly are different and where more active spaces, such as living rooms or kitchens, may stack above more noise-sensitive spaces such as bedrooms, or where residences are located above retail or restaurant spaces.

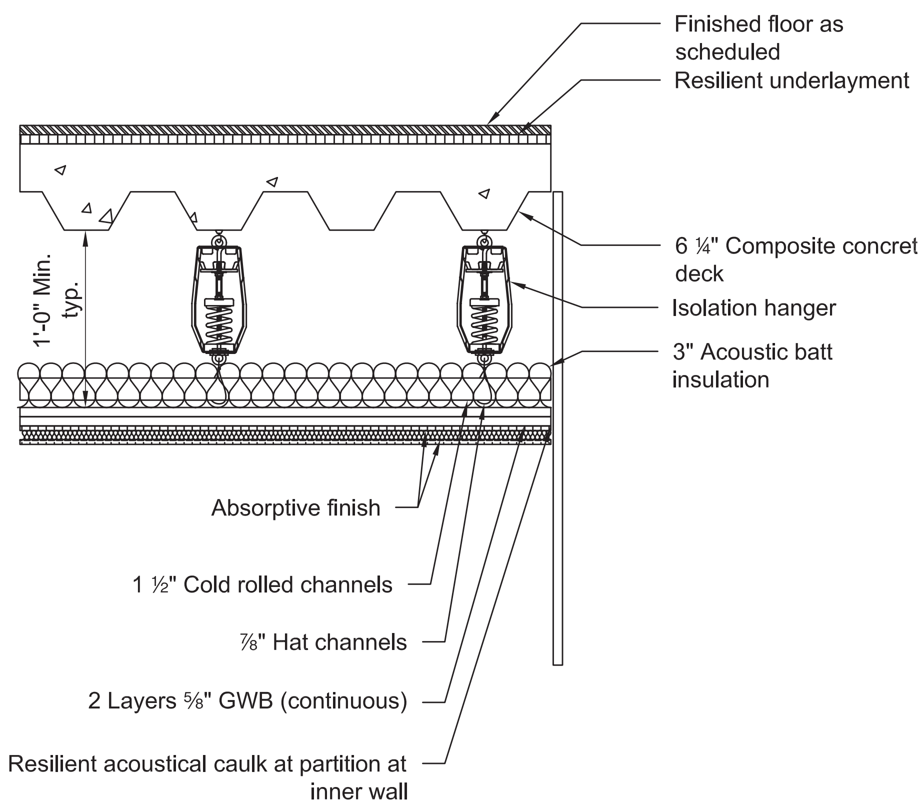


Fig. 8-9. Composite metal/concrete deck with spring ceiling hangers, sound-absorptive ceiling finish and floors on a resilient underlayment.

Figure 8-9 shows a minor variant of Figure 8-8 with a sound-absorbing finish surface applied to the underside of the gypsum board. (More about sound-absorbing finishes appears in Section 3.7.) This detail is suitable for spaces with very high sound isolation requirements, such as trial jury suites in courtrooms or in high-end residential buildings for isolating amenity spaces with the potential for high activity (e.g., media rooms) from residences above.

Figure 8-10 shows a further upgrade to the assembly in Figure 8-8: a resiliently supported floating floor. This detail is suitable for mechanical penthouses over noise-sensitive spaces (e.g., luxury residences, executive offices, music rooms, etc.). It is also suitable for isolating other high-noise or high-impact sources, such as dance rehearsal spaces located over noise-sensitive facilities as one may find in an academic or professional performing arts building. The STC and IIC of the floor/ceiling assembly in Figure 8-10 is estimated to be in the range of STC 75 to 80 and IIC 70 to 75.

8.5 ACOUSTICAL DECK

Acoustical deck is the generic name for structural deck that provides a significant level of sound absorption. Such decks are in common use in gymnasiums and other large spaces that do not have suspended ceilings but require sound absorbing treatment. Acoustical deck typically consists of a combination of perforated and unperforated metal, with insulation (usually glass fiber) located behind the perforated portions. Depending on the profile of the corrugations and the perforation pattern, an acoustical deck can provide a noise reduction coefficient of NRC 0.50 to NRC 0.90 or greater. (In many projects, including many public school projects, NRC 0.70 is a common design goal.) The most sound-absorbing of the decks have perforations on the bottom horizontal face of the deck, with a corrugation pattern that maximizes the area with perforations. Decks with perforations on the vertical portions of the corrugations are less efficient acoustically. Most acoustical deck products are most sound absorptive at 500 Hz and above, with more modest sound absorption at 250 Hz and little sound absorption below 125 Hz. (See Section 3.7 for an introduction to sound absorption and room acoustics.)

Partitions that meet the underside of an acoustical deck must be carefully sealed to the deck, as illustrated in Figure 7-1, but in a manner that avoids flanking around the sealant via the perforations in the metal. Where sound isolation across a partition is critical, the partition should interrupt the acoustical deck so that the deck is not continuous across it. For more modest applications, expanding foam sealant can be carefully sprayed into the insulation directly above the head of the partition.

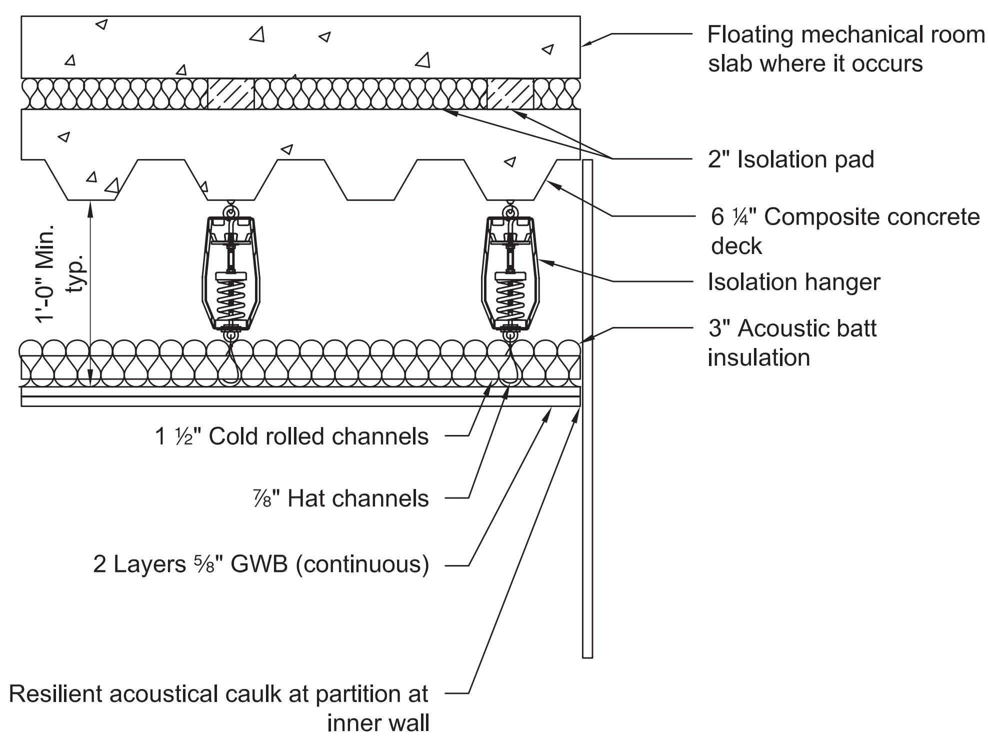


Fig. 8-10. Composite metal/concrete deck with spring ceiling hangers and resiliently floating concrete floor.

Chapter 9
Equipment Noise Isolation

9.1 INTRODUCTION

Noise levels from mechanical equipment are discussed in Section 6.3 of this Guide. This chapter addresses means to isolate that noise.

Noise transmission from mechanical and electrical equipment can be airborne, radiated from the equipment casing, or structure-borne, radiated from vibrating structures that are set into motion by equipment in contact with structural elements. Airborne noise can be transmitted via duct systems as well as through building constructions, as discussed in Chapter 7. In addition to noise generated by the equipment itself, noise can also result from fluid flow (e.g., air through ducts, water through pipes).

Mechanical systems can create significant noise, not only inside buildings, but also outdoors nearby and at neighboring properties. Many building projects feature barriers, enclosures, or mechanical noise control treatments on exterior equipment to comply with community noise requirements. Relatively comprehensive guidelines for the control of building mechanical equipment noise may be found in the *ASHRAE Handbook: Heating, Ventilation, and Air-Conditioning Applications* (ASHRAE, 2011). This chapter briefly summarizes some key principles as they relate to the control of equipment noise in steel buildings.

9.2 NOISE CRITERIA

9.2.1 Hearing Damage Limits

The Occupational Safety and Health Administration (OSHA) limits the daily noise exposure of workers in Standard 1910.95 (OSHA, 2004). The limits are summarized in Table G-16 of that standard and are reproduced in Table 9-1.

Daily exposures are summed (sound levels weighted by duration of exposure) to determine an overall sound level exposure. Further, exposure to impulsive or impact noise is limited to under 140 dB peak sound pressure level. Noise dosimeters worn by employees can be used to determine total daily noise exposure to check for compliance with OSHA standards. Industrial machinery and manufacturing equipment may be loud enough to put building occupants at risk relative to OSHA standards. Noise levels from typical building mechanical equipment are far from exceeding the limits in Table 9-1 in the vast majority of cases, but noise in mechanical rooms or factory spaces may be significant.

Typical indoor noise criteria are summarized in Table 4-1 of this Guide.

9.2.2 Community Sound

Criteria for exterior sound levels generated by building equipment are typically set by local or state community noise regulations. Requirements vary widely and broadly take on one or more of the following forms:

1. Subjective limits—for example, sound levels that are annoying or bothersome are prohibited.
2. Relative limits—for example, sound levels not to exceed 10 dB above the ambient sound level during hours of normal equipment operation.
3. Absolute limits—for example, sound levels not to exceed 50 dBA at night in residential zones.

Subjective limits are very difficult to evaluate, and sometimes require measurements of precedent sound levels to confirm compliance. To demonstrate compliance with relative criteria, it is necessary to measure ambient sound levels at the building site when the equipment in question is not in operation. Typically, the 90th percentile sound levels—the sound levels that are exceeded 90% of the time—are used to establish ambient levels. Determination of compliance with absolute criteria is typically more straightforward and may not require sound level measurements without the equipment operating.

9.3 ROOFTOP MECHANICAL EQUIPMENT NOISE CONTROL

9.3.1 Airborne Sound Through Roof and Wall Structures

Source levels of mechanical equipment are described in Section 6.3.2, and room sound level criteria are discussed in Chapter 4. In a given situation, the difference between the two determines the sound isolation requirements of the intervening structures; here, the roof/ceiling assemblies and the wall assemblies discussed in Chapters 7 and 8 of this Guide.

If an initial design results in excessive noise, remedial measures are necessary. The most effective means in many cases involves selection of quieter equipment. Often, mechanical equipment can be purchased with low noise options—equipment casings can be insulated and made heavier, and particularly noisy components (such as compressors) can be wrapped in loaded-vinyl sound isolation blankets. Equipment types can also be selected that are inherently quieter—for example, fans can be upsized and

Table 9-1. Permissible Noise Exposures, OSHA 1910.95	
Duration per Day, Hours	Sound Level, dBA
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

operated at slower speeds, or reciprocating machines can be replaced by rotating ones. Equipment may also be relocated. Noisy rooftop mechanical equipment should not be located directly above spaces with a noise goal of NC-20 or lower under any circumstances; wherever possible, the equipment should be clustered over spaces with noise goals of NC-35 and higher.

Once the aforementioned steps have been implemented as far as practicable, sound isolation enclosures or noise barriers, as well as building assemblies described in Chapter 8, should be considered to address noise propagating to neighboring properties. Outdoor sound attenuation due to rooftop barriers can be found in the *ASHRAE Handbook*; a more thorough analysis of barrier attenuation can be found in Long (2014) and other noise control textbooks. Exterior noise propagation can also be predicted using software applications such as those discussed in Section 6.1.2.

9.3.2 Structure-Borne Noise

Vibrating rooftop equipment should be vibration-isolated from the building structure to minimize structure-borne noise transmission. For the isolation to be efficient, the static deflection of the equipment isolation should be at least 10 times the deflection of the structure due to the load of the equipment. Stiffening of the roof deck structure with added steel, or locating the equipment on steel dunnage above the roof is often useful. Vibration isolation systems should be selected based on the operational characteristics of the equipment and the sensitivity of the spaces below it. Some suggestions for selection of vibration isolation curbs and mounts are as follows:

1. Noisy rooftop equipment should not be located directly above spaces with noise goals of NC-20 or lower.
2. Rooftop air handling equipment with compressor/condenser sections should be vibration-isolated, typically with springs under the assembly achieving a minimum static deflection under load of 1.5 in. If the operating speed of the equipment is below 305 RPM, softer springs (greater minimum static deflection) may be required.
3. Air handling equipment without compressor/condenser sections generally requires internal isolation; fans within the equipment typically should be on spring isolators selected to achieve a minimum static deflection of 1.5 in. under load.
4. Cooling towers on roofs of sound-sensitive buildings typically should be on spring mounts on dunnage supported from the major building structure. The deflection requirements for the springs depend on the operational speed of the equipment. Equipment controlled by a variable frequency drive, sometimes operates at very low speeds, requiring very soft springs for effective isolation. If this is impractical, springs may be omitted and neoprene isolators used to isolate audible noise, in which case, low-frequency vibrations will be imparted on the building structure, probably at low magnitudes for equipment operating slowly.
5. Emergency generators typically require spring isolators when located over noise-sensitive spaces. Usually, spring isolators are located between the dunnage or other structural support and a noise isolating enclosure, often selected for a minimum static deflection of 1.5 in. under load, depending on the size of the generator and the sensitivity of the space below.
6. Other equipment (exhaust fans over 1 HP, other fans, condensing units, etc.) also typically requires vibration isolation based on the size and operational parameters of the equipment.

Piping, ducts, conduit and other connections to vibration-isolated equipment should be made with flexible connectors. In many cases, piping will also require vibration isolation from the building structure. Flexible connectors alone are often insufficient because fluid in the pipes can transmit vibration past the flexible connector.

9.4 MECHANICAL EQUIPMENT ROOMS

9.4.1 Sound Isolation

Noise levels in mechanical equipment rooms can be calculated using Equation 6-3 and the equipment noise data provided by equipment manufacturers and in Section 6.3.2 of this Guide. The room criteria (Chapter 4) determine the required isolation performance of building assemblies (Chapter 8).

Because it is typically difficult to install a continuous ceiling in a mechanical equipment room—and such ceilings often are severely compromised by penetrations for equipment hangers—mechanical equipment rooms should not be located directly below noise-sensitive spaces. Where necessary, a sound barrier ceiling can be installed between the beams from web-to-web, exposing the bottom flange of the steel structure; supports can be installed from the flanges below the sound barrier ceiling to support hung mechanical equipment, with resilient hangers as needed. Where ceilings in mechanical rooms are not feasible, floating concrete floors can be installed in sensitive spaces above these rooms. Both options can be costly and difficult to implement correctly.

Where mechanical equipment rooms are located above noise-sensitive spaces, the mechanical rooms can be provided with floating floor assemblies where necessary, similar to the detail in Figure 8-10.

9.4.2 Vibration Isolation

Like rooftop equipment, equipment in mechanical rooms must also be vibration-isolated. Similar guidelines (Section 9.3.2) apply, with some additional recommendations:

1. Base-mounted pumps generally should be placed on concrete inertia bases, which are supported on spring isolators selected for a minimum static deflection under load of 1.5 in.
2. In-line pumps typically require spring hangers or mounts selected for a minimum static deflection under load of 0.75 in. The piping associated with these pumps must also be isolated throughout the mechanical equipment room.
3. Boilers and other miscellaneous equipment that generate modest vibration levels can be mounted on neoprene mounts selected to achieve 0.10 to 0.30 in. of deflection under load.
4. Electrical transformers should be mounted on neoprene mounts, typically selected to achieve 0.20 in. of deflection under load.

Other vibration-producing equipment in the building—such as motorized garage door openers, trash compactors, vehicle lifts, etc.—should be isolated from the building structure, as well, to avoid transmission of structure-borne noise.

Glossary of Terms

Absorption coefficient: The portion of sound that is absorbed by a material at a given frequency, expressed as a number between 0 and 1.

Articulation index (AI): Single-number metric that characterizes ease of speech communication.

A-weighted decibel (dBA): Single-number representation of sound pressure spectrum that accounts for variation of human hearing sensitivity with frequency.

Ceiling attenuation class (CAC): Laboratory measure of how much sound a suspended ceiling tile blocks.

Coefficient of transmision: The fraction of sound pressure transmitted through a structure at a given frequency.

Damping: The capacity of a structure to dissipate energy.

Decibel (dB): Ten times the logarithm of the ratio of a value to a reference value. Decibels are used to express sound pressure level, sound power level, and sound intensity level.

Diffuse sound field: A sound field (as in a room) where many reflected sound waves cause the sound (as averaged over a small volume of the room) to be evenly distributed throughout the room, essentially independent of distance from the source.

Flanking path: The path of sound transmission that circumvents the most direct path. Flanking can be via air or structures.

Frequency: Number of times per second that sound pressure cycles from positive to negative values and back again. Equivalently, the number of times that a full wavelength passes in 1 second. Measured in Hertz (cycles per second). Frequency of a sound is related to perceived pitch.

Impact insulation class (IIC): Laboratory measure of how much impact sound a structure blocks.

Masking: Obscuring perception of one sound by another.

Noise criteria (NC): Single-number rating of sound level in a room.

Noise isolation class (NIC): An in-situ measure of how much airborne sound a structure blocks.

Noise reduction: The difference in sound pressure level between a source on one side of a structure (such as a wall or ceiling) and the resulting sound level on the other side of the structure.

Noise reduction coefficient (NRC): Average of absorption coefficients in the 250-Hz, 500-Hz, 1,000-Hz, and 2,000-Hz octave bands.

Octave band: Band that spans from one frequency to twice that frequency. Standard octave bands are customarily named by their "center" frequencies—the rounded-off geometric average of the upper and lower bounds. The center frequencies of standard octave bands in the audible spectrum are 16 Hz, 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, etc., up through 16,000 Hz.

Period: The time between arrivals of successive sound pressure maxima; equal to the reciprocal of frequency.

Pitch: The frequency of a tone.

Privacy index (PI): Single-number metric that characterizes speech privacy; equal to 1 minus the articulation index, expressed as a percentage.

Pure tone: Sound pressure that varies sinusoidally with time at a single frequency.

Reverberation time: the amount of time it takes for an impulsive sound in a room to decay 60 dB.

Sabin: Unit of measurement of sound absorption. One sabin is equal to the sound absorption that 1 ft^2 of an open window contributes.

Sinusoidal: Continual and smooth variation between a maximum and minimum, with each change between a maximum and minimum taking the same amount of time.

Sound: Vibration propagation through an elastic medium, typically air.

Sound pressure: Small pressure fluctuations above and below atmospheric pressure caused by propagating vibration of the air.

Sound pressure level: A logarithmic measure of sound pressure expressed in decibels.

Sound transmission class (STC): Laboratory measure of how much airborne sound a structure blocks.

Spectrum: Distribution of magnitude versus frequency of a specified quantity.

Speed of sound: Approximately 1,120 ft/s or 340 m/s in air. The speed of sound varies somewhat with temperature, humidity and pressure, but may be considered as constant for building noise analyses.

Third-octave band: Similar to octave bands but where successive bands (and their bounds) differ by a factor of $\sqrt{2}$ rather than by a factor of 2.

Transmission loss: A measure of how much sound a structure blocks at a given frequency; typically expressed in decibels.

Wavelength: Distance a wave travels during the time it takes for successive maxima to reach a fixed point; equal to the product of speed and period.

SYMBOLS

L_A A-weighted sound level at 100 ft from the track, dBA

L_{dn} project day-night noise level, dBA

$L_{n,w}$ weighted normalized impact sound pressure level, dBA

NR noise reduction, the difference between sound levels on the source side and those on the receiver side of an intervening construction, dB

PWL sound power level, dB

Q directivity factor

R room constant, ft^2

R_w weighted sound reduction index

RT reverberation time, s

S surface area of the intervening construction common to both the source and receiver sides, ft^2

S_n surface area of the *n*th component, ft^2

S_{total} total surface area of the intervening construction common to both the source and receiver sides, ft^2

SPL sound pressure level, dB

T period, s

TL transmission loss, dB

V room volume, ft^3

V train speed, mph

a total absorption, sabins

a_2 total acoustic absorption in the receiver space, sabins

c sound speed, ft/s

d distance from the source, ft

f frequency, Hz

p sound pressure level, psi

p_{ref} reference value of pressure, psi

α absorption coefficient

$\overline{\alpha}$ average absorption coefficient, equal to a divided by the total room surface

λ wavelength, ft

τ coefficient of transmission

τ_{comp} transmission coefficient of the overall composite construction

τ_n transmission coefficient of the *n*th component

ABBREVIATIONS

ACT acoustic ceiling tile

AI articulation index

AIIC apparent impact insulation class

ANSI American National Standards Institute

ASHRAE American Society of Heating, Refrigerating and Air Conditioning Engineers

ASTC apparent sound transmission class

CAC ceiling attenuation class

CMU concrete masonry unit

dB decibel

dBA A-weighted decibel

FGI Facilities Guidelines Institute

FHWA Federal Highway Administration

FSTC field sound transmission class

GSA U.S. General Services Agency

GWB gypsum wall board

HUD U.S. Department of Housing and Urban Development

HVAC heating, ventilation and air-conditioning

Hz Hertz

IBC International Building Code

IIC impact insulation class

INM integrated noise control

NC noise criteria

NIC noise isolation class

NISR normalized impact sound rating

NNIC normalized noise isolation class

NR noise reduction

NRC noise reduction coefficient

OITC outdoor-indoor transmission class

PI privacy index

STC sound transmission class

TL transmission loss

TNM traffic noise model

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