Facts for Steel Buildings

Sound Isolation and Noise Control

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SECTION 1
INTRODUCTION

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

This *Facts for Steel Buildings* summarizes basic facts about sound isolation and noise control in steel buildings. It is aimed at providing building owners and users with useful background information for design. More detailed information and specific design guidance may be found in AISC Design Guide 30, *Sound Isolation and Noise Control in Steel Buildings* (Markham and Ungar, 2015).

The goal of this *Facts for Steel Buildings* is to provide the design community with an understanding of sound isolation and noise control issues in buildings 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 considerations, such as structural efficiency, design flexibility, cost, schedule and environmental impacts. The information presented here is applicable to buildings of all structural types, but the focus regarding some details is on steel structures.

SECTION 2
SOME BASICS

2.1   How is sound or noise produced?

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. They 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). Noise is unwanted sound.

2.2   What are frequency and spectrum?

Frequency, measured in cycles per second (or Hertz, abbreviated as Hz), simply is 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 loudness of the tone. The period, T, the time taken by one cycle, is the reciprocal of the frequency.

Most pressure fluctuations associated with sound 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. For acoustical analysis, the frequency range of hearing is divided into standard octave bands—each octave band spans from a lower bound frequency to an upper bound frequency that is twice that of the lower bound. The standard octave bands are customarily referred to by their "center" frequencies: 16 Hz (the lowest octave band in the range of human hearing), 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz and so on up to 16,000 Hz (the highest octave band in the range of human hearing).

2.3   What is sound pressure level?

The sound pressure magnitudes encountered in most practical situations range between about 0.000000003 and 0.3 psi (0.00002 and 2,000 Pa).[*] It is standard practice to work with sound pressure in terms of the sound pressure level, *SPL*, a logarithmic measure expressed in decibels (dB). An *SPL* of 0 dB corresponds to a sound pressure of 2.9×10^{-9} psi (2×10^{-5} Pa), roughly the threshold of audibility. An *SPL*

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of 130 dB corresponds to a sound pressure of about 0.01 psi (69 Pa), roughly the threshold of pain.

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. Two essentially identical sources (e.g., two identical fans on a rooftop or two identical singers in a chorus), when added together, result in an increase in *SPL* between 3 dB and 6 dB, depending on how well their sounds overlap in time. An *SPL* of 6 dB corresponds to precise matching.

2.4   How does sound propagate?

A localized pressure disturbance generates propagating waves—much like a stone dropped into a pond causes ripples that propagate concentrically from the source—except that in an open volume of air (a volume without obstructions) the disturbances spread spherically, 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

$$\lambda = \frac{c}{f} = cT \qquad (2\text{-}1)$$

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

Propagating waves are affected only minimally by obstacles that are considerably smaller than a wavelength. Thus,

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* Both U.S. customary units and S.I. units are included in this paragraph for reference purposes. U.S. customary units are used throughout the remainder of this document.

for example, the transmission of noise at 50 Hz, the wavelength of which is about 20 ft, cannot be affected appreciably by a 3-ft-wide shield.

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 and windows) that may be set into vibration by sources that may be at some distance from the room. Such sources 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.)

2.5   What sounds do humans perceive?

Humans with normal hearing are able to perceive sound at frequencies from approximately 20 Hz to approximately 20,000 Hz; people with hearing loss tend not to hear sounds near the upper end of this range. 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. 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 the perceived loudness.

Several metrics exist that characterize complex sound spectra approximately in terms of a single number, 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 suitable sound level meter. 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. The NC value corresponding to a measured sound spectrum is determined by plotting the spectrum on a grid of standard NC curves. 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 describe complex sound spectra in terms of single numbers; various sounds that do not sound the same—i.e., sounds that have different frequency content—may 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 band or other spectral criteria should be used.

2.6   What is sound absorption?

Sound absorption is the removal of sound in a room or other enclosure resulting from the conversion of sound energy into heat. Sound is absorbed most significantly by porous materials (e.g., building insulation, acoustic ceiling tile, clothing, etc.), but can also be absorbed by panels (e.g., vibrating plywood or gypsum board panels) or by resonant cavities. Sound absorption has an important effect on the acoustical character of rooms—how reverberant or lively they sound. Absorption can reduce reverberation and thus can improve the intelligibility of speech in a lecture hall and control the build-up of activity noise in a restaurant or banquet hall.

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, but the sound field inside it will be highly reverberant because steel plates are highly reflective of sound, not sound absorptive. This document is primarily about sound isolation (blocking), and absorption can be very helpful as part of a sound isolation strategy; for example, absorption between layers of a partition or floor/ceiling assembly can improve the blocking provided by the assembly, and sound-absorbing finishes in the listener's room can reduce the reverberant build-up of sound in that space.

The absorption coefficient is a dimensionless number between 0 and 1 that represents the fraction of the impinging sound that is absorbed by a material, with 0 representing total reflectivity (zero absorption) and 1 representing perfect absorption. The noise reduction coefficient (NRC) is the arithmetic average of the absorption coefficients in the 250-, 500-, 1,000- and 2,000-Hz octave bands and is suitable for evaluation of the absorptive properties of materials in the speech frequency range. The total quantity of absorption provided by a material is equal to its absorption coefficient multiplied by its surface area. The product, symbolized by the letter a, is in units of sabins.

The amount of time it takes for an impulsive sound in a room to decay 60 dB (corresponding to a decrease in the sound pressure by a factor of 1,000) is called its reverberation time. An empirical formula for reverberation time is:

$$RT = 0.049 \frac{V}{a} \qquad (2\text{-}2)$$

where

  RT = reverberation time, s
  V = room volume, ft^3
  a = total absorbtion, 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*—less than a half second. Classrooms have an *RT* of 0.6 to 0.7 seconds or less (depending on their size); fully occupied concert halls typically have an *RT* on the order of 2.0 seconds.

SECTION 3
SOURCES

3.1 How loud are speech and music?

The average speech spectrum peaks at mid-frequencies (500 to 1,000 Hz). These peaks for standard normal, raised, loud and shouting speech amount to roughly 54 dB, 61 dB, 67 dB and 75 dB, respectively, as measured 3 ft from the source (ASA, 2012). Large gatherings of people can, of course, produce much more noise 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. The noise in 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. However, for most design purposes, one may assume that the *SPL* 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. 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, the *SPL* can exceed 105 dBA.

The loudness of amplified sound is quite variable— typical television usage may be only slightly louder than typical speech, while the *SPL* in indoor pop music venues can exceed 110 dBA. Amplified music often contains significantly more low-frequency sound energy than unamplified music, and this low-frequency sound is more difficult to isolate. Designing sound isolation for amplified music venues, nightclubs and other loud spaces typically requires thorough sound level measurements of the specific facility; sometimes, physical attenuation means are impractical and the noise must be controlled by the imposition of mandated limits.

3.2 How significant are impact sounds?

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. The loudness of footfall and other impact sounds can vary widely. For example, sound levels due to footfall vary with walker weight and stride, shoe type, and floor/ceiling assembly details. Footfall of a typical walker wearing leather-sole shoes with rubber-tipped heels produces about 50 dBA in the room below a floor/ceiling assembly that just meets model building code requirements for impact sound isolation (Warnock, 1992).

In most cases, criteria for insulation from impact noise are based on building code requirements and other standard references, as summarized in Chapter 5 of AISC Design Guide 30. In cases of more extreme impact sources (e.g., fitness centers), measurements of impact sound levels at 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. Rain noise extends over a wide frequency range, with peak levels typically at frequencies between 250 and 500 Hz.

3.3 How are mechanical equipment noise levels obtained?

Noise from mechanical equipment often requires isolation. For most major building HVAC equipment, noise data can be obtained from manufacturers. Means for estimating sound levels from HVAC and plumbing sources can be found in Chapter 5 of AISC Design Guide 30. A discussion of mechanical equipment noise control follows in Section 7.

SECTION 4
PRIVACY

4.1 How is acoustical privacy created?

Acoustical privacy—the sense of being separate from and undisturbed by sound in adjacent areas—depends not only on the sound isolation created by intervening structures, but also on the background sound level in the listener's space. This is because continuous background sound masks otherwise intruding sound. 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.

4.2 What is electronic sound masking?

Electronic sound masking systems may be used in some circumstances to provide controlled background sound in order to improve privacy. Such commercially available systems comprise loudspeakers and controls configured to emit a continuous and uniform spectrum of sound tailored specifically 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, some closed offices, library reading rooms, and other spaces where privacy is desired and speech communication is not required over significant distances. These sound masking systems are sometimes referred to as white noise systems, but this is inaccurate.

White noise refers to a sound spectrum that has an equal amount of sound energy in each 1-Hz-wide frequency band; electronic sound masking systems produce rather different sound spectra.

4.3 How do privacy requirements vary?

Speech privacy requirements may range from freedom from distraction to confidentiality. In a large library reading room, freedom from distraction is a typical reasonable goal—nearby conversation may be audible and even intelligible if one attends to it, but not distracting to a person reading or working. In an executive office, in contrast, one typically expects confidentiality—speech in such spaces must not be intelligible in adjacent spaces and, if audible, only very faintly so.

Speech privacy in closed rooms can be achieved by providing intervening structures that are highly sound isolating or by providing structures with limited (but nonzero) sound isolation performance and added background sound. In open-plan offices, 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). Guidelines for designing sound isolating constructions are presented in Chapter 7 of AISC Design Guide 30.

SECTION 5
AIRBORNE SOUND TRANSMISSION

5.1 What is sound transmission class (STC)?

The transmission loss (TL) of a construction is the difference, in dB, between sound impinging on the construction and the sound transmitted by it. TL is a function of frequency and is determined from idealized laboratory measurements.

Sound transmission class (STC) is a single-number characterization of the TL of a construction, based only on TL data from 125 Hz to 4,000 Hz. STC does not fully characterize the TL of a construction; it 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, STC does not differentiate between assemblies that are acoustically weak in one frequency range only (but otherwise may be quite robust) and those that are weak throughout the spectrum. Furthermore, because STC is measured in a laboratory under highly controlled conditions, it does not account for the variations and weaknesses that inevitably are introduced in actual installations. Despite these limitations, STC is in widespread use. STC is a useful metric to characterize the capacity of common well-constructed assemblies to block typical sound, such as speech. Measures, such as apparent sound transmission class (ASTC), noise isolation class (NIC), and normalized noise isolation class (NNIC), are designed for field measurement; typically, a measurement in the field will be on the order of 5 points less than the corresponding laboratory STC value. Outdoor-indoor transmission class (OITC) is a more realistic measure of real-world sound transmission isolation of building façades.

5.2 How can a sound-isolating assembly be improved?

The sound isolation properties of a building's construction can be improved by increasing its mass, decreasing its stiffness, adding damping or introducing decoupling of mass layers.

Heavy assemblies block sound better than lighter ones. Building assemblies block high-frequency sound far more readily than low-frequency sound. This is why it's the bass part of your neighbor's stereo that you can hear through your party wall and not the vocal track. Mass of building constructions can be increased relatively easily, if that is 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.

Double-partition arrangements can provide considerably more transmission loss than single panels of much greater weight. One can improve isolation performance of double-stud walls by filling the space between the panels partially with a sound-absorptive material, such as fiberglass batts. Similarly, the sound isolation performance of floor/ceiling assemblies can be improved by (1) increasing the depth of the ceiling plenum, (2) suspending the ceiling resiliently so as to de-couple the floor from the ceiling, and (3) placing sound absorbing insulation in the ceiling plenum.

Damping—the capability of a structure to dissipate energy—reduces the severity of vibrations and sound transmission at resonances. Therefore, components with greater damping tend to provide greater transmission loss. For example, the intermediate layers in laminated glass assemblies contribute considerable damping, resulting in laminated glass providing greater transmission loss than monolithic glass panes of the same thickness.

5.3 How is it that common assemblies in steel buildings can block as much sound as comparatively heavier concrete constructions?

A very common floor-ceiling assembly in a steel building is comprised of a composite concrete/metal deck with a ceiling suspended below. This assembly features two separate mass layers (the deck and the ceiling), analogous to a double-partition arrangement as previously discussed. The separate mass layers in this assembly will block more sound than a monolithic assembly of equal weight. In many cases, sound-absorbing insulation is added to the ceiling plenum, increasing the transmission loss of the assembly. For example, a 6¼-in.-thick composite deck comprised of lightweight concrete on 3-in. metal deck, with a ½-in.-thick lightweight gypsum wall board ceiling suspended 2½ in. below the deck on wire hangers, and insulation in the ceiling cavity, with a total weight of approximately 55 psf, has an STC rating of STC 55. Conversely, a 6-in.-thick cast-in-place concrete slab weighs much more (approximately 75 psf), but has the same STC rating: STC 55.

5.4 What are typical airborne sound isolation requirements?

Model national building codes (e.g., IBC) (ICC, 2015) require at least STC 50 (or 45 if field tested) between adjacent dwelling units and between dwelling units and public spaces. Classrooms must be separated from one another by STC 50 constructions in order to meet applicable ANSI standards (which have been adopted by some green building standards and others); greater STC performance is required for classrooms adjacent to mechanical rooms, music spaces, gymnasiums, toilet rooms, etc. The Facilities Guidelines Institute's *Guidelines for Design and Construction of Health Care Facilities* document (FGI, 2010) includes sound isolation requirements that range from STC 50 (e.g., between patient rooms) to STC 60 (e.g., between an MRI room and a patient or exam room). More stringent sound isolation criteria may apply to luxury condominiums, courtrooms, worship spaces and other facilities.

Where a sound isolation criterion is not prescribed, one may derive it by subtracting the background sound criterion for the room from the expected source level. See AISC Design Guide 30 for additional criteria and for further guidance on deriving appropriate sound isolation criteria in the absence of explicit requirements.

5.5 What are STC values for some standard assemblies?

Single-stud walls with insulation in the cavity and a single layer of gypsum board on each side typically have STC ratings in the range of STC 40 to STC 45. With two layers of gypsum board on each side, the STC is increased to roughly STC 50. Double-stud partitions can be STC 55 (one layer each side) to STC 65 (two layers each side).

Resilient clips can improve the isolation of single-stud walls. Per manufacturer's data, single-stud walls can achieve STC values in excess of STC 60 with two layers of gypsum board installed on resilient clips fastened to metal studs.

For walls requiring very high transmission loss, stud walls can be combined with fully grouted CMU walls.

The transmission loss of floor/ceiling assemblies depends largely on the mass of the floor, as well as the mass of the ceiling, the depth of the ceiling plenum, and the method of suspending the ceiling. Most floor/ceiling assemblies in steel-framed buildings range from STC 55 to STC 65.

See AISC Design Guide 30 for a more comprehensive summary of STC values for a range of assemblies and for guidelines for suitable application.

5.6 How do gaps, cracks, leaks and flanking paths affect the transmission loss of building assemblies?

Gaps and the like can degrade sound isolation performance significantly. It is critical to seal gaps effectively. In steel buildings with corrugated steel 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 of acoustical tile or of some other material with lesser TL than the wall material. Gaps and leaks occur commonly at doors. Full-perimeter gaskets are typically necessary where a door is part of an acoustically sensitive wall.

If there are several potential sound paths between spaces (or several elements that make up a composite construction, such as a wall that contains a door and/or a window), it is important that they be designed to be balanced from the standpoint of sound transmission. The weakest path will determine 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 transmission loss will be controlled by the door, and any upgrades to the rest of the wall assembly will have no effect on the transmission loss.

5.7 How does acoustical absorption affect sound isolation?

Noise reduction is the difference in sound pressure level on one side of a structure (such as a wall or ceiling) in a "source room" and the resulting sound level on the other side of the structure, in the "receiver space." Under certain circumstances, it may be useful to increase the acoustical absorption in the receiver space in order to improve the noise reduction. This approach 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; upgrades to the TL or reductions in the source level will likely be necessary. Similarly, sound-absorbing finishes in the source room can provide only modest improvements (typically no more than 2 to 5 dB) in reducing the reverberant build-up of noise within the source room. However, absorptive finish materials may be appropriate and effective for improving the perceived acoustical quality of a given room, irrespective of the modest sound isolation benefits.

SECTION 6
IMPACT SOUND TRANSMISSION

6.1 What is impact insulation class (IIC)?

The impact insulation class (IIC) rating is similar to the STC rating, except that it represents isolation from an impact source—typically footfalls, but also rolling carts, etc.—rather than from an airborne sound source. In the United States, IIC testing is done with a standardized tapping machine outfitted with calibrated steel hammers. Like STC, IIC is a laboratory metric only. Field measurements of impact sound typically are characterized by the apparent impact insulation class (AIIC) and sometimes by the normalized impact sound rating (NISR). It is typical for the AIIC measurement results to be 1 to 5 points less than the corresponding laboratory measured IIC.

Multifamily dwellings are required to achieve IIC 50 between dwelling units under most building code requirements. Criteria for footfall isolation in other buildings follow a similar pattern to those of airborne isolation; see AISC Design Guide 30 for additional information.

6.2 How can the IIC rating of a floor/ceiling assembly be improved?

Two basic tools are most helpful in isolating footfall sound: (1) ceilings that are decoupled from the floor structure above, and (2) floors that "float" above the structure on resilient underlayments. If floors are placed on resilient underlayments and ceilings are suspended with resilient hangers or clips, the IIC of most floor/ceiling assemblies in steel buildings will be between IIC 50 and IIC 65. AISC Design Guide 30 contains IIC data for a range of floor/ceiling assemblies.

The finish floor surface affects mid- and high-frequency impact sound transmission, especially as compared to bare concrete. Floor finishes adhered directly to the subfloor transmit more impact sound than "floating" assemblies. Finishes 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 with various hard floor finishes (wood, vinyl, tile, laminate, etc.) will typically fall within a roughly 5-point range.

For most structures that include concrete, carpet floors will yield impact isolation at or above IIC 70, even without a ceiling. For this reason, many leases for apartments require carpet over a high percentage of the floor surface. However, carpet alone does not always isolate low-frequency impact sounds well (below 100 Hz, the bottom range of the IIC metric). For good low-frequency isolation, ceilings on spring hangers and/or thick resilient floor underlayments (¼ in. or thicker) are necessary.

6.3 How does the impact isolation performance of a typical floor/ceiling assembly in steel-framed buildings compare with that in concrete buildings?

Typical constructions in steel-frame buildings can provide impact isolation performance that is equal to or better than that of typical constructions in buildings framed with concrete. For example, a 6¼-in.-thick lightweight concrete/steel deck with a gypsum wall board (GWB) ceiling suspended 2½ in. below the deck on wire hangers and insulation in the ceiling cavity and a vinyl plank floor on a 0.1-in.-thick resilient underlayment has an IIC rating of approximately IIC 55. A 6-in.-thick cast-in-place concrete slab has an IIC rating of approximately IIC 50 with the same floor and underlayment assembly.

SECTION 7
MECHANICAL EQUIPMENT NOISE

7.1 How is mechanical equipment noise transmitted?

Noise transmission from mechanical and electrical equipment can be airborne (radiated from the equipment casing, for example) or structure-borne: noise can radiate 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. In addition to noise generated by 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.

7.2 How is community noise regulated?

Criteria for exterior noise 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 are not to exceed 10 dB above the ambient sound level during hours of normal equipment operation.

3. Absolute limits—for example, sound levels are 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.

7.3 How is the sound isolation criterion for blocking airborne mechanical equipment noise established?

Source levels of mechanical equipment are described in Chapter 6 of AISC Design Guide 30. 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: the roof/ceiling assemblies and the wall assemblies as previously discussed in Section 6.

7.4 How is airborne noise from rooftop mechanical equipment controlled?

The most effective means for controlling rooftop equipment noise often consists of selection of quiet equipment. Many types of 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 operated at slower speeds, or reciprocating machines can be replaced by rotating ones. Equipment may also be relocated or reoriented so that the noisiest side of the equipment faces away from the nearest and most noise-sensitive locations. Noisy rooftop mechanical equipment should not be located directly above spaces with a noise goal of NC-20 or lower; wherever possible, the equipment should be clustered over spaces with noise goals of NC-35 and higher.

If equipment cannot be relocated and its noise levels cannot be reduced, upgrades to the roof/ceiling assembly are needed. For control of community noise, equipment enclosures and noise barriers may be added.

7.5 How is structure-borne noise from rooftop mechanical equipment controlled?

Vibrating rooftop equipment should be vibration-isolated from the building structure to reduce structure-borne noise transmission. For the isolation to be most 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, as described further in AISC Design Guide 30.

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

7.6 How is noise from mechanical equipment rooms isolated?

Because it typically is difficult to install a continuous ceiling in a mechanical equipment room—and such ceilings often are severely compromised acoustically by equipment hangers—mechanical equipment rooms should not be located directly below noise-sensitive spaces. Where it is necessary to locate a mechanical room below a noise-sensitive space, a sound barrier ceiling can be installed from beam to beam, exposing the bottom flange of the beam; supports spanning from beam to beam below the sound barrier ceiling can be installed 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. The noise-sensitive spaces should be provided with resiliently hung ceilings.

As with rooftop equipment, equipment in mechanical rooms must also be vibration-isolated. 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. Guidelines for vibration isolation appear in AISC Design Guide 30.

GLOSSARY

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

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.

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.

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., doubling up through 16,000 Hz.

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

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. Speed of sound varies somewhat with temperature, humidity and pressure, but may be considered as constant for building noise analyses.

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.

ABBREVIATIONS

AI	articulation index		**Hz**	Hertz
AIIC	apparent impact insulation class		**IBC**	International Building Code
ANSI	American National Standards Institute		**IIC**	impact insulation class
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers		**NC**	noise criteria
			NIC	noise isolation class
ASTC	apparent sound transmission class		**NNIC**	normalized noise isolation class
CAC	ceiling attenuation class		**NR**	noise reduction
CMU	concrete masonry units		**NRC**	noise reduction coefficient
dB	decibel		**OITC**	outdoor–indoor transmission class
FGI	Facilities Guidelines Institute		**PI**	privacy index
GSA	U.S. General Services Agency		**STC**	sound transmission class
HUD	U.S. Department of Housing and Urban Development		**TL**	transmission loss
HVAC	heating, ventilation and air-conditioning			

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