Facts for Steel Buildings number 4

Sound Isolation and Noise Control

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TABLE OF CONTENTS

TRANSMISSION
assembly be improved?
TRANSMISSION 12

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.

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 distribu--

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 mea-

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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 6 -in.-thick composite deck comprised of lightweight concrete on 3-in. metal deck, with a -in.-thick lightweight gypsum wall board ceiling suspended 2 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

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 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 cir-

ABBREVIATIONS

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 units
dB	decibel
FGI	Facilities Guidelines Institute
GSA	U.S. General Services Agency
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
NC	noise criteria
NIC	noise isolation class
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

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