Understanding Noise And Vibration

Norman Varney

There are a variety of "room isolation" opinions offered regarding critical listening environments like home theatres, media rooms, and two-channel rooms. Between on-line forums, contractors, and manufacturers, it becomes very confusing. To make matters worse, typical building contractors and architects are not familiar with sound transmission information. How can you determine what means and methods are best for your environment? This article will help you understand some of the basics for controlling noise and vibration and provide some "benchmarking" tips for comparing the options.

It will be comforting to know that different isolation materials and methods can be quantified. You can cut through the misconceptions and hyperbole and develop a credible game plan for your room and your budget. You can find independent accredited test lab results on the Web sites of reputable acoustic manufacturers. These reports are based on established testing standards by organizations such as ASTM (American Society for Testing and Materials), ANSI (American National Standards Institute), ISO (International Organization for Standardization), etc. They will help you compare options and establish predictable goals for your room. Though your contractor may not know much about noise control, most solutions are pretty easy to construct. The methods do, however, require attention to detail. One hole left unsealed can destroy the noise control goal.

There are two reasons for noise control: one is to eliminate annoyance to and/or from another area(s), and the other is to have sound quality. Noise control must be in place before sound quality can be achieved. Lowering the noise floor improves the experience for the listeners by allowing them to become more fully immersed in the soundtrack, without distractions. This is a more relaxed and realistic experience. A lower noise floor means additional low-level details will be heard and additional clues in the scene will be comprehended. It also means more dynamic range, bringing more emotional influences to heighten the experience. Silence is a tool used frequently for impactive storytelling, and it is something coveted by most home theatres.

Fundamentals Of Noise Control

- Noise is a two-way street—if sound can get in, it can get out. You may only be concerned with one direction, but by addressing one, you address the other.
- Low frequencies are tough to control—they have lots of energy and long wavelengths.
- Sound follows the path(s) of least resistance.
- Once sound energy enters the structure, it spreads fast and is hard to stop.
- The noise control design is governed by the weakest link in the system.
- Sound leaks.

What Is Noise And Vibration?

Sound is initiated by something vibrating, which causes waves of changing air pressure to travel out, for the most part, in all directions. Noise is unwanted sound. For this article, noise will be any acoustical sound (we're not covering electrical noise here) that is not part of the originally recorded signal. Noise is transmitted as both airborne and structureborne sound. For example, a guitar string is plucked, causing the string to vibrate, and in turn pushes the air around it. This is airborne sound. When the sound waves travel and strike a wall, they become structureborne sound. Here, some of the sound energy is reflected and returned back into the room; some of it is absorbed by the wall; and some of it causes the structure to vibrate and transfer sound back into the room and to adjoining rooms. For playback systems, we are primarily interested in only the airborne sound generated by the loudspeakers—anything else is noise. I say primarily because we need some reverberant (reflected) sound in the room to keep it comfortable, psychoacoustically.

Controlling Structureborne Sound From Numerous Sources

Let's look at what else happens when sound enters the structure. We've discussed sound from within our listening space, but there may be noises generated outside our room that we don't want to distract or interfere with our listening experience. This may include footfalls, outside traffic, appliances, HVAC, plumbing, etc. There may also be reasons to keep sound from traveling out of our room that may distract others elsewhere. Remember, noise is a two-way street.

Noise control is a balancing act with sound quality. Imagine a concrete bunker; it does a good job of keeping sound out. It also does a good job of keeping sound in. All the sound waves are contained, even the low frequencies, which linger and muddy-up the sound. The concrete does little to absorb or transfer, compared to other materials and methods. This has to do with mass. Too much, and bass has nowhere to go. Too little, as in typical interior wood-framed walls, and there is little bass support, little tactile impact, and sound is heard and felt throughout the house. Mid and high frequencies are easily addressable with interior acoustic treatments, but not low frequencies. The partition must be able to flex some in order to absorb some low-frequency energy, yet it must have enough mass to support some of it for sound quality, as well as other means of controlling noise from becoming a disturbance.

Controlling structureborne noise and vibration calls for a systematic approach. There are many materials and methods to consider and their attributes must be weighed against your project's constraints for space, weight, décor, budget, time, local codes, etc. Noise can be controlled at the source, along the path, or at the receiver. This can be done by incorporating methods of blocking, absorbing, isolating and/or breaking the path of the sound energy. Typically, control measures are most effective at the source. But of course, this depends on which side of the street you're on!

Each situation is unique and must be carefully evaluated, and solutions prioritized. The following are general possible solutions to help alleviate or eliminate noise and vibration problems:

Suggestions for addressing noise control at the source are:

- Locate the source of vibration as far away from the receiver as possible
- Aim the noise source away from the receiving area
- Enclose the noise source using heavy construction and absorptive materials inside
- Provide isolation mounts between the source of vibration and the structure
- Add sound-absorbing materials to room surfaces
- Apply a resilient layer to any surface subject to impact
- Strengthen the structure at the points of vibration
- Reduce the power of the source of vibration

Suggestions for addressing noise control along the transmission path are:

- Isolate the source of vibration by providing (1) structural breaks or separations; (2) dynamic separation of components via resilient layer, flexible connections, etc.
- Seal all penetrations and openings along the airborne path
- Improve the sound insulation of the partitions
- Apply damping material where vibrations structurally transmit

Suggestions for addressing noise control near or at the receiver are:

- Move receiver as far away from source as possible
- Aim the receiver away from the source
- Add sound-absorbing materials to room surfaces
- Cover the radiating surfaces
- Reduce vibrations with damping material
- Sound masking
- Ear plugs

Flanking Noise

Flanking is the sound path involving elements other than the common partition, even though it may still be involved (see Figure 1). Once sound enters the structure, it propagates as vibration and radiates sound on both sides and for considerable distances. Sound travels easier and faster through denser elements. Flanking noise can be caused by sound originally airborne and then transferred structurally, like the loudspeaker's sound waves exciting a wall into vibration, which in turn plays like a loudspeaker itself on the other side. It can also be airborne sound transferred via the HVAC ductwork, like an acoustic intercom. It can pass through an unsealed penetration like back-to-back wall outlets or the gaps under the doors. It may also start structurally, as in the impact of footfalls, something dragged or dropped on the floor, or a door closing, or a vibration from an appliance sitting on the floor, etc.

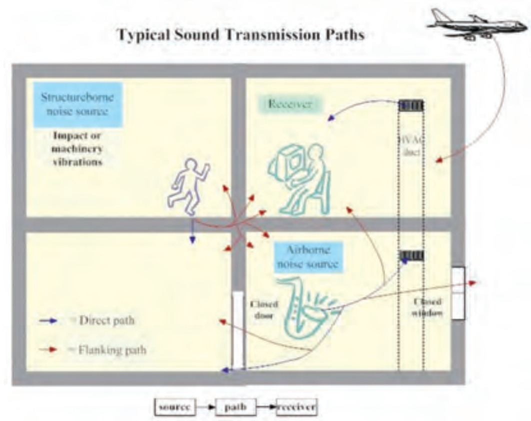

Figure 1

Determining Sound Transmission Loss

The ability of a material or partition system to block or attenuate sound from one area to another is measured by transmission loss (TL). The higher the TL, the better. It is measured in two adjoining reverberation chambers (see Figure 2) across a band of frequencies in decibel units of sound pressure. Typically, walls and floor/ceiling assemblies are tested, but doors and windows, of course, are also common partitions.

Once the TL measurements have been taken, they are tabulated and the assembly is given an STC rating. Current architectural acoustics literature refers to the term Sound Transmission Class (STC) all the time. By definition, STC is a form of rating airborne transmission loss (TL) in decibels for partitions derived from the TL data measured in 16 one-third octave bands from 125 Hz to 4 kHz. STC is a single-number rating system where the data collected is plotted against a reference contour curve. The contour is heavily weighted in the 500 to 2 kHz range, where speech intelligibility occurs. The higher the number, the better the isolation.

Because of its limits, an STC rating cannot tell you anything about lower bass frequency TL. This is not useful to rooms containing common music and/or LFE playback. STC misses the most pertinent information to home theatre isolation. However, sometimes manufacturers who quote STC have collected TL data below the STC cut-off, which when available upon request, is useful, at least the extent to which the data is reliable. To add to the frustration, with the single-number STC rating, the same number can yield different TL performance at different frequencies (see Figure 3). By the same token, you can have two STC ratings that vary significantly, yet are not perceivable. STC can be misleading but is all we have to work with at this point in time. The STC rating is a quick tool to compare different construction assemblies, but the designer should use the actual TL values at the frequencies of interest to determine the reduction of sound between two areas. By subtracting those values from the sound-pressure levels in the source room, the resultant noise levels can be predicted on the other side of the partition.

To better understand what STC ratings mean, let's correlate the STC of a partition to human perception:

STC 30 – loud speech is heard easily
STC 35 – loud speech is blurred, yet intelligible
STC 42 – loud speech is heard, but unintelligible
STC 45 – loud speech is only heard by straining
STC 48 – loud speech is barely audible
STC 50 – loud speech is inaudible
STC 61 – Bass and drums barely audible
STC 64 – LFE explosions barely audible

Now let's relate STC graphically with some common wall solutions (see figure 4).

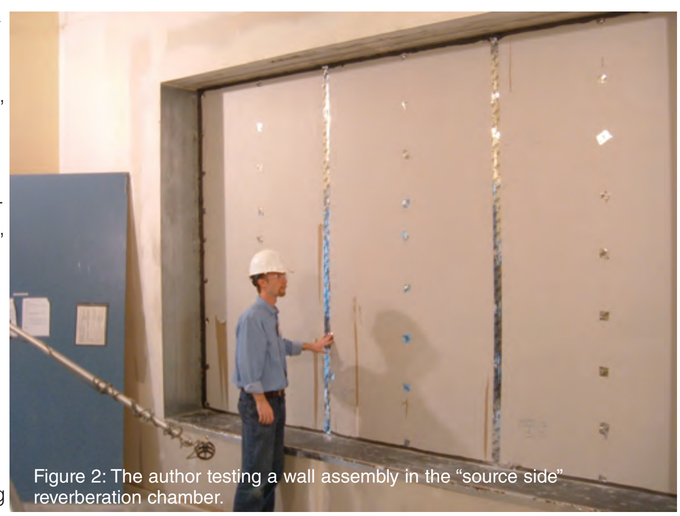

Figure 2: The author testing a wall assembly in the "source side" reverberation chamber.

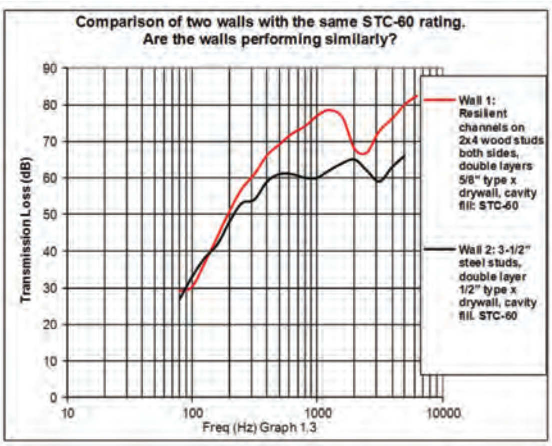

Figure 3

As can be seen above graphically, it is wise to shoot for a home theatre shell that will offer at least an STC 61. This level of noise control will offer little chance of annoyance inside or out.

STC rating "rules of thumb":

- An STC gain of 3 points is just perceptually quieter
- An STC gain of 6 is a very perceptual improvement
- An STC gain of 10 is perceived as reducing the noise-transmission level by 50 percent

Again, how is the sound transferred via a wall or floor?

When airborne sound waves impinge on a solid surface, it produces vibrations in that surface, which, even if it's three-feet thick concrete, it will vibrate as a structure and produce vibrations on the other side as a radiator of new airborne sound waves. Connecting framework can transfer sound from one end of the house to the other.

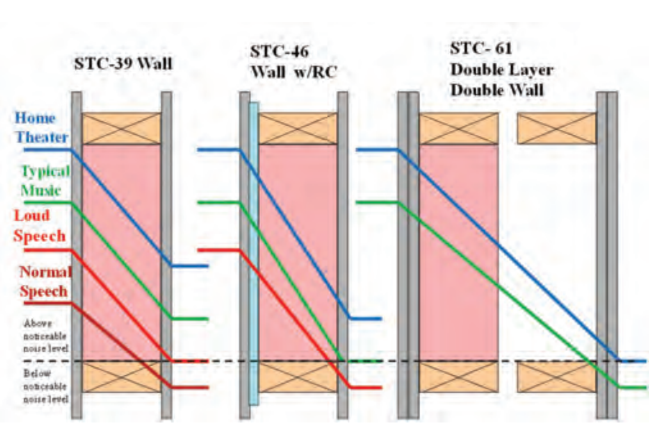

Figure 4

What about when the assembly is struck?

Impact sound is caused by a floor or wall assembly set into vibration by direct mechanical contact. The energy can also be transmitted throughout the structure and re-radiate in connected spaces. In your home, common examples are: footfalls on a tile or wood floor, rollers from an infant's "walker," a food processor on a kitchen island, etc. In each of these cases, the offending vibration is primarily transferred into the floor and then down to the ceiling below.

Like STC, IIC is an important rating factor in reducing noise transfer. Impact Insulation Class (IIC) measures impact noise, otherwise known as structureborne vibration. The IIC classification process is like the STC, using a tapping machine in place of loudspeakers, to measure TL in 16 one-third octave band frequencies from 100-3,150 Hz. Again, the single-number classification is plagued with the same problems as the STC mentioned previously.

Noise Criteria (NC) is yet another set of spectral curves used to obtain a single-number rating, this time describing the "noisiness" of environments for a variety of uses. NC is commonly used to rate the relative loudness of ventilation systems. NC has been in use for a long time, but because noise-induced annoyance is not directly proportional to loudness, a better system of evaluation was devised by ANSI in 1981, called Room Criteria (RC). Along with the relative loudness level number, this rating includes a letter to describe the sound's spectral character. For example; N for neutral, R for rumbly, and H for hissy. In addition, RC adds two lower-frequency octave bands; 16 and 31.5 Hz. STC, IIC, and NC (and others) are tools designed to be used to assess noise as it would affect speech intelligibility, not for the wide bandwidth and dynamic range of home theatres.

Figure 6 will give you an idea of non-home theatre sources of vibration, along with their typically associated frequency spectra.

Design Considerations

Care should be taken when designing the shell to ensure that the ceiling, the floor, and the walls are compatible with each other. For example, specifying a wall assembly with an STC 60 with a ceiling assembly of IIC 45 would not make sense.

Penetrations for lighting, HVAC registers, etc. can greatly compromise the performance. How much will depend on the original assembly TL values, the number and size of penetrations, and how the penetrations are addressed acoustically. A tiny sound leak can quickly reduce the STC value by 10 to 15 points.

Area percentage of openings for doors and windows with their STC values should be calculated with the partition assembly to determine the composite STC, which can then be used to predict interior noise levels.

There are four primary ways to reduce structural noise transfer in your home theatre:

1. Air

Air gaps inside wall and ceiling assemblies act as noise insulators. The deeper the air cavity, the more energy is isolated. This is why you typically see thicker walls in theatre designs, though, there are other means. Examples are: a 2x6 stud wall isolates more noise than a 2 x 4-inch wall; a staggered-stud wall, using a 2 x 8-inch stud plate, isolates more than a 2 x 6-inch wall; and better still would be a double-stud wall. For reference, an improvement from an STC 34 for the 2 x 4, to an STC 47 for the double-stud wall. Resilient channels (RC) or isolation clips also increase the air cavity, which depending on the assembly, can offer a gain of 5 to 14 STC points.

Adding standard fiberglass insulation to the air cavity provides additional absorption benefits. Depending on the partition, fiberglass insulation can add 2 to 10 STC points. There are other more expensive types of insulation, like cotton or wool that can be considered as well.

2. Mass

As a general rule, every doubling of the weight of the assembly will increase the sound transmission loss by 5 to 6 dB. In home theatre wall and ceiling assemblies, increased mass is often achieved by adding layers of conventional drywall or mass-loaded vinyl (MLV). While such improvements are measurable, they are often not substantial.

Remember this benchmark for comparisons: A standard, non-insulated interior wall with 2 x 4 studs, 16 inches on center will deliver an approximate STC of 34.

Adding a layer of drywall on the "source" side of a wall will provide a 3 to 5 point increase in STC, and a second layer on the "receive" side will add another 3 to 5 STC points. This is helpful but not acceptable for a noise-controlled home theatre (see Figure 4).

MLV is often viewed as the "be all and end all" for effective isolation, but independent lab tests indicate that it is not. When MLV (1mm thick, ~1# / square feet) is added to a standard insulated 2 x 4-inch wall, STC values are only in the 43 to 47 range. This holds true in two scenarios: 1) the MLV is attached "limply" to the studs before the drywall is installed, and 2) the MLV is "sandwiched" between two layers of drywall.

Constrained-layer damping between layers of drywall is an additional isolation method that provides several benefits: The added mass (without added stiffness) from the viscoelastic "damping" compound reduces sound transmission as well as cavity resonances. The damping action allows the treated surfaces some freedom to move (good for low-frequency absorption), while reducing the vibration amplitude and duration of the movement. The result is a shell that starts and stops along with the soundtrack, fast and articulate.

There are many different materials and methods deployed to reach STC levels beginning in the high 40's. Manufacturers of these products publish independent lab tests of various build-ups and their relative STC ratings. Be aware that many tests are done with the unconventional stud spacing of 24-inch on center spacing, which provides better TL than 16-inch on center. Most residential walls are framed with 16-inch on center spacing. Some tests use light-gauge metal studs, which are more resilient than wood, and depending on the assembly, can reduce the transmission by about 8 STC points.

3. Absorption

There are two types of absorption (converting sound energy to heat) encountered by the room; in the air, and at the boundary. Air, in small rooms, is pretty insignificant. However, as mentioned above, air between dividing surfaces can be very significant. Boundary absorption is due to the movement of surface materials. Both have to do with sound wave resistance. In addition, by adding interior absorptive materials to both the source and receive rooms, a reduction in the average noise level and the reverberant sound field is gained in the receive room, even with no changes to the partition. This addition is most beneficial on the source side. How much of an improvement depends on the noise, the room size, and the type and quantity of interior absorption materials, but typically up to 6 dBA.

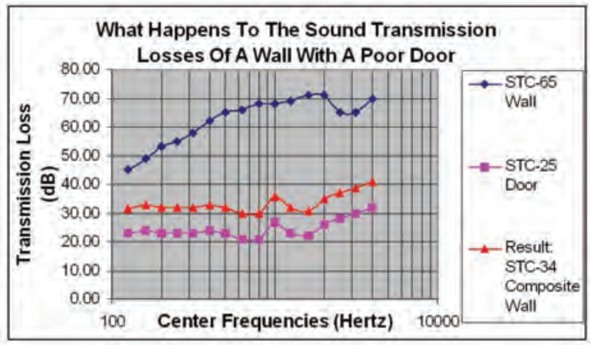

Figure 5: Note that the partition is heavily affected by the weakest part of the system (see Figure 5), which is typically a door or window. Note also how a small leak affects the assembly's performance. A 1 percent leak area can never exceed STC 20, no matter how good the partition's potential.

4. Decoupling

Let's take a step back to remember that the reason sound energy migrates (to rooms next door, as well as above or below) is because the drywall (or subfloor) is fastened to studs, ceiling joists, and floor supports with screws and nails. These screws and nails are mechanically connecting all of the room surfaces to the structural elements of your home, and therefore, provide a path for energy to enter or leave your critical listening environment.

The most effective method to stop this vibration pathway is to eliminate it. And it's not as hard as it may seem. In many moderately priced multi-family apartments or condominiums, a standard building product called resilient channel (RC) is used. Don't confuse this product with "furring channel" or "hat channel." With RC, the drywall screws no longer hit the studs (or ceiling joists), which lessens the amount of energy that transfers from the surface of the drywall to the structure. In other words, the drywall is "decoupled" from the stud or joist.

RC, when installed correctly, can deliver STC ratings in the upper 40's. However, this system is very easy to "short out," a condition where some drywall screws wind up hitting the stud.

Within the last 10 years, specialty "drywall isolation clips" have been developed that provide a higher level of installation assurance and an overall higher level of "decoupling" of the drywall and studs. These clips are typically installed in grids where the drywall is attached to drywall furring channel (or "hat channel"). Clip spacing may vary but is typically every 48 inches horizontally (every 3rd stud) and 24 inches vertically.

Drywall isolation clips often offer the "biggest bang for your buck." Published tests from a variety of clip manufacturers' demonstrate that by simply adding clips only to the "source" side of a wall, STC ratings of 55 and higher are achieved. Think about this. A standard STC 34 described earlier (2 x 4-inch, 16 inches on center, one layer of drywall each side) could become an STC of 55 by simply including insulation and isolation clips. That is dramatic! And, interestingly, transmission loss in the frequencies below 125 Hz is noticeably higher than any other application we've discussed in this article. This is because the mass is decoupled and allowed to move—more low frequency absorption and less vibration transferred.

To see this for yourself, some manufacturer's tests provide data that show the transmission loss (TL, i.e. the reduction, in decibels) at specific frequencies below 125 Hz. For example, you may be considering two isolation methods that have very comparable STC ratings. But, at 80 Hz, you find a TL of 36 for one assembly and 23 for another. This means that one option tested 13 decibels better than the other at 80 Hz, even though the STC ratings were comparable. At 80 Hz it sounds less than half as loud as the other assembly. Guess what that means when you're watching "Master and Commander" in your home theatre?

Design And Construction Tips

By now you have probably gathered that the acoustical performance can be greatly affected by design and construction details. Here are a few tips to help achieve your goals:

1. Sealing

An air seal around the perimeter of each wall, floor, ceiling, door/window opening or penetration should be made to keep vibra-

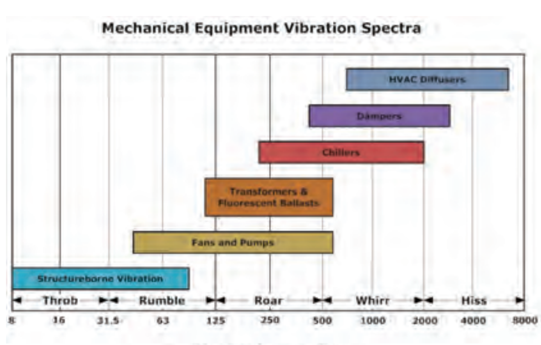

Figure 6

tions from being transferred to adjoining surfaces. This decoupling is then filled with a resilient material such as foam or rubber, and then an air-tight seal is made with a resilient caulking compound. This allows the surface to move without moving the others. Floating floors consist of raft build-ups, and floating ceilings utilize hangers. Like the walls, they are cut short to avoid contact with the adjoining surface, and the void is filled with foam and/or acoustic caulking.

2. Doors

Doors are usually the weak area of the wall, in particular, the perimeter and threshold of the door. Remember that the door rating should match the wall. Solid wood doors with perimeter seals typically offer an approximate STC of 30. Heavier noise-rated doors systems are available and can offer much better isolation, and they quickly become heavy and expensive. Sliding doors should be avoided when noise is an issue. Doors across from other doors should also be avoided.

3. Windows

Windows normally have the worst TL values of the shell. Use of thick insulated glass and double glazing helps. Other means of reducing noise through windows are: increase the air gap between panes, good seals, locate them as far away from the noise source as possible, reduce the window coverage area, and avoid placing windows across from one another.

4. Electrical

Avoid locating electrical switches and outlets back-to-back. Make sure wall and ceiling cavities for fixtures and boxes are filled with insulation and sealed airtight with acoustic caulk and/or wrapped with acoustic putty.

5. Plumbing

There are several acoustical design considerations regarding plumbing. For example: adding swing arms so that expansion and contraction can occur without binding, isolate piping from surrounding structures with resilient mounts, provide air chambers at each outlet to eliminate "hammering," consider over-sized pipes and reduced water pressure, and as always, avoid back-to-back fixtures and use acoustical caulk around all penetrations.

6. HVAC Ducts

Ducts easily transmit sound from one register to the other. Sound can also break in or break out along the duct work. Consider thick metal ducts with acoustic duct lining to attenuate fan and motor noise, etc. Sometimes duct wrap, or even lagging, is required to reduce sidewall transmission. Flexible boot connections are great low-frequency decouplers, as are hangers. A dedicated HVAC line is recommended for maximum control of isolation, airflow velocity (turbulent air noise), and comfort. Of course quiet, well-balanced motors and fans will reduce noise carried through the ducts.

7. Mechanical Equipment

Whenever possible, locate transformers, furnaces, HVAC units, pumps, etc., as far away as possible from the receiving space. In addition, you may need to enclose them, use vibration isolators, seal penetrations, etc. to contain and/or absorb noise.

In summary, the most effective way to decide on the isolation design for your room is to consider the costs and the benefits. The good news is that you now understand what to look for and that you can find credible STC and IIC ratings from reputable manufacturers of isolation materials and systems. Compare those results to your desired goals and the estimated costs for materials and construction, and you're on your way to estimating your room's transmissibility, noise floor, and dynamic range! Here are the noise control steps:

Basic Noise Solution Strategy

Step 1. Evaluate the noise environment under existing or expected conditions.

Step 2. Determine the acceptable noise level or criterion at the receiver location.

Step 3. Prioritize each noise path contribution in regards to the goal.

Step 4. Establish physical, budgetary, décor, local code, and resource constraints.

Step 5. Evaluate various design/material solutions to meet the objectives.

Noise control is best considered at the design stage, not during construction. By following the steps above, the full potential of your investment can be realized, to the enjoyment of those within its walls and to those who are not. **WSR**

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