Quiet Please

Strategies for toning down sound transmission in wood-framed floors and ceilings

by Russell DuPree

As the song goes, one man's ceiling is another man's floor, and when the upstairs neighbors put on their dancing shoes it can get noisy down below. As an acoustical engineer, I know from firsthand experience that sound transmission through building components—especially floor/ceiling assemblies—is tough to stop. It is usually easier to soundproof walls because the primary concern with them is to stop airborne sound. But with floors you have to control the impact, or structure-borne sound as well. These are noises such as footsteps, bouncing balls, and plumbing or mechanical equipment vibrating directly on the structure. Lightweight wood-frame buildings need to have structurally discontinuous assemblies to isolate rooms acoustically. This is pretty easy with walls, because you can simply run a double row of studs to break contact between adjacent walls. It's harder with ceilings, especially once the building is already complete. This article discusses the basic principles of airborne and impact sound transmission control and illustrates how to apply these principles to two basic types of wood-framed ceiling/floor combinations: one with exposed joists, and one without.

Acoustical terminology—Before we get into construction details and assembly advice, let's first define some acoustical terms and concepts. The ability of a wall or floor to reduce the airborne sound transmission of speech is usually expressed in terms of the *Sound Transmission Class* or STC. The chart below shows roughly how STC ratings correlate with various degrees of speech privacy.

For floor/ceiling assemblies an additional measuring system is used to rate the structure-borne noise generated by footfalls. This is called the *Impact Insulation Class,* or IIC. For both measurements, the larger the number, the better the performance.

There are a number of factors other than the STC or IIC ratings that enter into our judgments of acoustic privacy. They include the background sound level, the amount of sound-absorptive material in the room, a person's sensitivity to noise and the loudness of the noise source. But the sound insulating ability of the wall or floor, whether it be IIC or STC, is the single most important factor in predicting acoustic privacy.

Planning ahead is the first and most important step in avoiding acoustical disasters. This is especially true for controlling impact sound transmission. Don't locate a hard-surfaced floor over noise-sensitive areas or you'll run into trouble. As a rule, you should try to achieve an IIC rating of at least 50 for all floor/ceiling assemblies between dwelling units (top chart, p. 56) and at least 45 within a dwelling unit.

A little theory—The ideal wall or floor, from an acoustical point of view, would be made of a very massive and limp material—lead, for example, is perfect. Its high mass requires a lot of acoustic energy to move it, and its limpness prevents it from resonating like a sounding board. Unfortunately, it's cost-prohibitive to wrap rooms with lead, so we need to look at some alternatives.

In general, wood-framed dwellings do not have sufficient mass to reduce the transmission of noise to acceptable levels. This is especially true when the intruding noise has lots of low-frequency energy—amplified music and some types of mechanical equipment, for example. We hear the booming bass of the audio equipment, the low rumble of motors and blowers, and the incessant murmur of the TV next door.

If high-frequency sounds are transmitted from room to room, it is usually because there are sound leaks in the construction. These can be small gaps or cracks that are hidden from view but nonetheless allow a lot of sound to pass. Most of the acoustic energy in consonants (the part of speech that contributes most to intelligibility) is found in the higher part of the frequency spectrum between about 1,000 and 3,000 Hz. It is therefore essential that you seal thoroughly all cracks and gaps in sound-rated constructions, just as you would seal a boat so that it does not leak. As a rule of thumb, a 1-sq. in. hole in an STC 50 wall can degrade its performance to about STC 30.

Relationship of Sound Transmission Class to Speech Privacy	
STC 25	Normal speech intelligible
STC 30	Loud speech intelligible
STC 35	Loud speech blurred but intelligible
STC 40	Loud speech rarely intelligible but still audible
STC 45	Loud speech unintelligible and barely audible
STC 50	Loud speech almost inaudible
STC 55	Loud speech inaudible

The issue of sealing and caulking penetrations in sound-rated assemblies has major implications for many of the trades. Plumbers, for example, need to keep holes for pipes to a minimum so that they can be easily filled with acoustic sealant, and pipes need to be isolated from the structure with hangers designed to minimize contact with the building's frame. Likewise, the drywall installers, electricians and mechanical contractors need to exercise care when working in a sound-rated assembly.

Airborne sound control—One way you can control airborne sound transmission at low frequencies is to use the air space in a stud or joist cavity to your advantage. Air is a compressible material and can act like a kind of acoustic spring—the wider the air cavity the softer the spring, and the better the low-frequency noise reduction. The acoustic energy dissipates as it vibrates the ceiling, then the air space between the joists and then the subfloor. The trick, of course, is to create a structural discontinuity in the path that the sound takes from the ceiling to the subfloor.

The most common (and probably the most economical) method of creating this discontinuity is to use resilient channels along the bottom of the joists (top drawing facing page). These thin, webbed pieces of sheet metal (usually 25 ga.) are formed into a "Z" shape. The channel acts as a kind of flexible support onto which sheet materials can be mounted, minimizing the structural paths that sound can take between the drywall ceiling and the joists. The ceiling is then free to move up and down a little and allow air in the joist cavity to act as a cushioning spring.

Another technique is to use separate ceiling joists. This provides better isolation between the subfloor and the ceiling, and makes it easy to spot "short circuits" or instances of ceiling joists touching floor joists. It is also versatile because you can load the ceiling with as many layers of drywall as you want.

The down side is that the materials are more expensive and you may have to use extra long studs or extra top plates to maintain an 8-ft. ceiling height. Separate ceiling joists should definitely be considered, though, if you are trying to achieve STC ratings higher than 55 in wood-frame buildings.

Yet another technique for getting structural discontinuity into the assembly is to suspend a ceiling from wire hangers (bottom drawing). For this application use ⅞-in. hat channel (aka furring channel) to anchor a solid drywall ceiling. And if you want to go one step further to eliminate the vibration transmitted through the wires, small neoprene or fiberglass ceiling hangers that attach in the middle of the suspension wires are available from several companies, such as Peabody Noise Control (see sources of supply, p. 57).

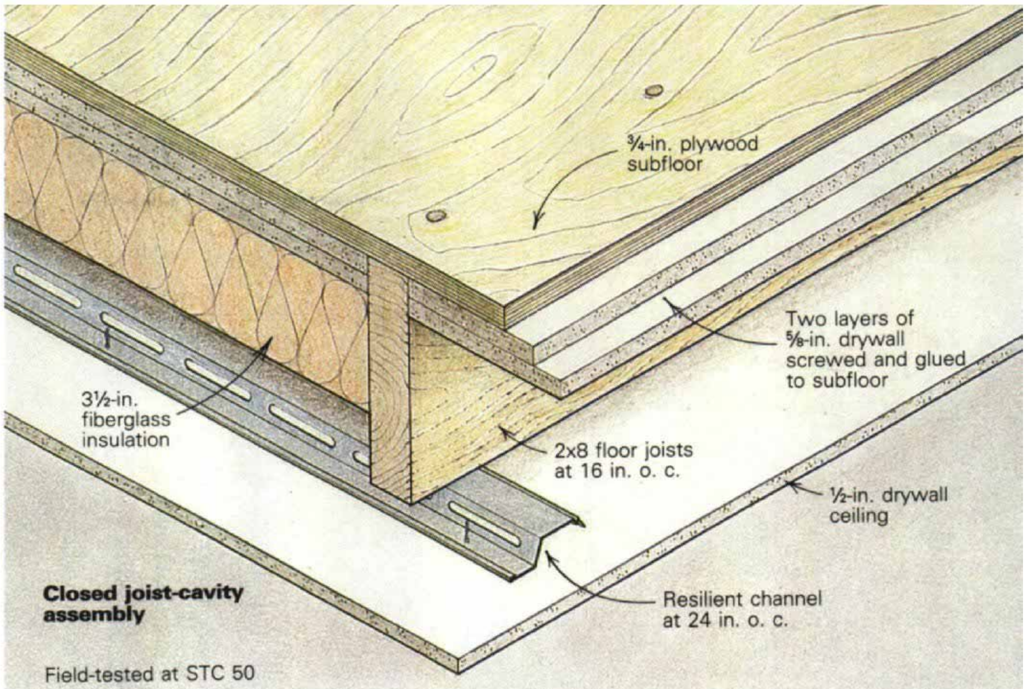
Exposed joist construction—A second approach to reducing low-frequency airborne sound transmission is mass loading. This is about the only way you can really cut noise transmission through a wood-framed exposed joist floor assembly. As a rule of thumb, it takes a doubling of the floor mass to achieve a substantial improvement in noise reduction for a given construction. For marginally good sound control (STC 40-45) from mass-loaded floors, you should try to achieve a dead load of at least 20 psf for the entire assembly. Obviously there can be structural problems with this method if the floor joists don't have the capacity to support the extra load.

One good material for mass loading is ordinary sand. It is not only very massive per unit volume, it is also inexpensive, readily available and very limp. Working with sand is labor-intensive, but for small jobs it's a good choice because the best alternatives—drywall or lightweight concrete toppings—might not be feasible. Sheets of drywall don't work quite as well as sand, either, because drywall is pretty stiff.

While mass loading will cut down on sound transmission, you shouldn't use exposed joist floors between different dwelling units or between sound-sensitive rooms. Even with mass loading you can't achieve the degree of sound insulation that most people expect. Within your own house an STC rating of about 45 is generally acceptable between bedrooms or bathrooms and other rooms.

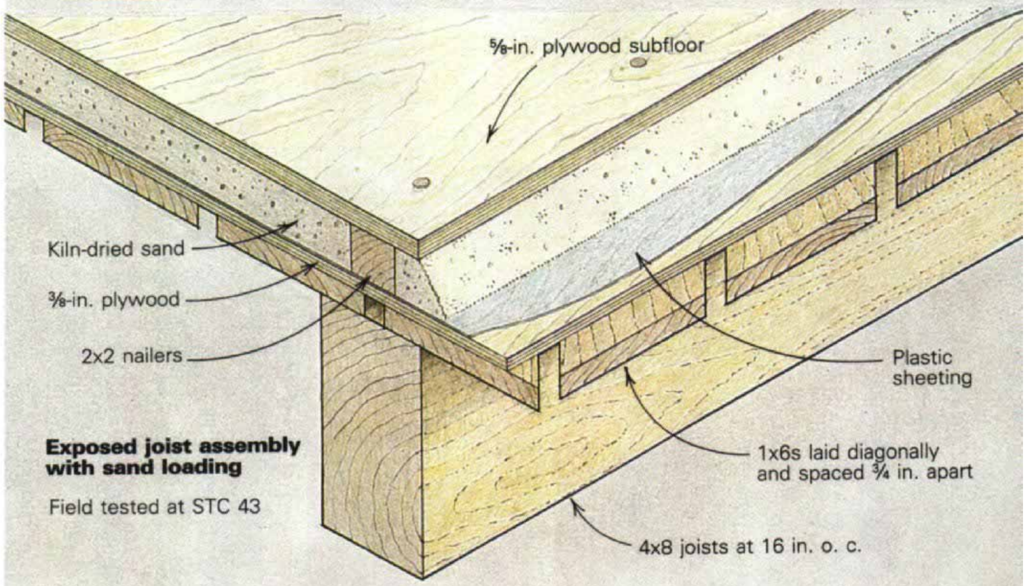
A case history—A few years ago my wife and I decided to build a mountain cabin with two other partners. Vacation houses are notorious for their lack of acoustic privacy because they are often occupied by many people at once. Naturally I wanted the house to have good sound insulation. The site gets a lot of snow in winter, so we designed a three-story house with living areas on the second floor and bedrooms above and below. We used an exposed-joist ceiling to separate the kitchen from the third-floor master bedroom.

The master-bedroom floor is supported by 4x8 joists at 16 in. o. c. (middle drawing).



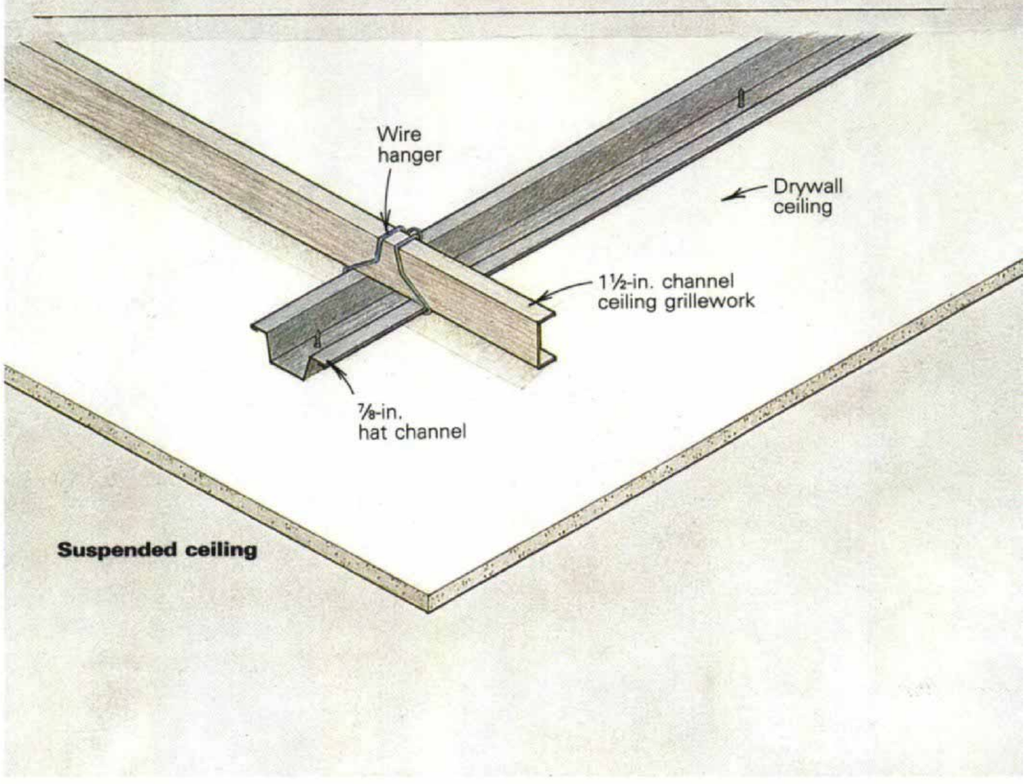
Closed joist-cavity assembly

Field-tested at STC 50



Exposed joist assembly with sand loading

Field tested at STC 43



Suspended ceiling

Drawings: Vince Babak

Minimum Sound Ratings of Floor/Ceiling Assemblies between Rooms in Multifamily Dwellings				
This chart gives minimum STC and IIC ratings. Note that it's most efficient to stack rooms with similar functions, and it's easier to temper structure-borne sound if the noisiest rooms are downstairs.				
Dwelling A		**Dwelling B**	**STC**	**IIC**
Bedroom	under	Bedroom	52	52
Bedroom	under	Living room	54	57
Bedroom	under	Kitchen	55	62
Bedroom	under	Family room	56	62
Bedroom	under	Corridor	52	62
Living room	under	Bedroom	54	52
Living room	under	Living room	52	52
Living room	under	Kitchen	52	57
Living room	under	Family room	54	60
Living room	under	Corridor	52	57
Kitchen	under	Bedroom	55	50
Kitchen	under	Living room	52	52
Kitchen	under	Kitchen	50	52
Kitchen	under	Bathroom	52	52
Kitchen	under	Family room	52	58
Kitchen	under	Corridor	48	52
Family room	under	Bedroom	56	48
Family room	under	Living room	54	50
Family room	under	Kitchen	52	52
Bathroom	under	Bathroom	50	50
Corridor	under	Corridor	48	48

Impact Insulation Class Ratings			
Type of material	**Exposed joist assembly with no sand loading**	**Exposed joist assembly with sand loading**	**Closed joist assembly with channels, batts, and extra drywall**
1. Bare subfloor	21	42	48
2. Ceramic tile on Wonder Board	32	46	54
3. Ceramic tile on Wonder Board on Ethafoam	40	58	57
4. Ceramic tile on Wonder Board on Enkasonic	36	53	54
5. Ceramic tile on Wonder Board on Ethafoam on Enkasonic	42	59	61
6. Parquet flooring on ⅜-in. particlebd.	33	49	54
7. Parquet flooring with foam backing on ⅜-in. particlebd.	34	53	55
8. Sheet vinyl on ⅜-in. particlebd.	30	47	50
9. Sheet vinyl on QuietCor on ⅜-in. particlebd.	30	52	51
10. 8-oz. outdoor-indoor carpet (no pad)	34	54	54
11. 23-oz. carpet on 40-oz. hairfelt pad	50	66	62
12. 23-oz. carpet on dense foam pad	61	79	72
13. 40-oz. carpet on 40 oz. hairfelt pad	55	70	66
14. 40-oz. carpet on dense foam pad	64	79	73

Rough-sawn 1x6s were nailed on top of the joists in a diagonal pattern and spaced about ¾ in. apart. Then we nailed ⅜-in. plywood over the 1x6s, followed by 4-mil plastic sheeting and 2x2 nailers centered over the joists. We filled the space between the nailers with kiln-dried sand and screeded it level. This we topped with a layer of ⅝-in. plywood glued and nailed to the 2x2s.

To assess the effect of the mass loading, I tested an exposed-joist floor assembly at a friend's house. His floor consisted of 2x6 T&G decking laid directly on double 2x10 joists spaced 32 in. o. c. The STC rating of this non-loaded construction was 34. Our sand-loaded floor, however, achieved an STC rating of 43—a nine-point improvement. Although STC 43 is not a satisfactory rating for critical separations, it is still a very cost-effective improvement and renders loud speech almost unintelligible between the floors.

Because sand-loading a floor dramatically reduces impact noise, it allows you to use flooring materials other than carpet and still achieve satisfactory impact sound insulation. I was curious about the noise reduction qualities of various flooring materials, so I tested the 14 different configurations of materials shown in the chart (lower left). These combinations are designed to compare four general classes of commonly used materials: ceramic tile, parquet, vinyl and carpet. Each class of material also shows at least one variation that improves the IIC rating. These variations consist of cushioning substrates or pads that are commercially available and are marketed at least partially for the purpose of reducing impact sound transmission. It is always wise, however, to check the manufacturer's recommendations against your particular design.

Closed joist construction—Between the first and second floors of our mountain cabin we wanted very good sound insulation because the first floor can be used as a separate "in-law" unit. Here we used a closed joist-cavity assembly (top drawing, previous page), with 2x8 joists, ¾-in. plywood and drywall hung on resilient channels. Incidentally, construction adhesive is good at preventing floor squeaks, but to be effective, it is very important to nail off the subfloor within about 15 to 20 minutes of spreading the adhesive. Spread only enough for one or two sheets at a time, and use ring shank nails. Space the sheets slightly apart before nailing to keep them from rubbing against one another. On the ceiling side we used resilient channels at 24 in. o. c. and attached them to the bottom of the joists with 1-in. drywall screws.

Be aware that there are different grades of resilient channel. I use USG RC-1 25 ga. channels because they are the most flexible I've seen. Some channels are made of heavier 20-ga. material and some have few, if any, voids in the web. The thinnest channels with the largest area of holes in the web (about 50%) will work the best acoustically.

Installing resilient channel—The workmen installing a resilient-channel ceiling must be made keenly aware that this job has to be done right or it's not worth doing at all. There are several areas where things can go wrong. First, never install resilient channels over sheet materials. For a significant improvement in the STC rating there needs to be at least a 3-in. air cavity behind the channel. If a resilient channel is sandwiched between two pieces of drywall, for example, there will be little noticeable improvement at the mid and low frequencies; you might as well have saved your money and left the channels out. This is one reason it's not easy to acoustically retrofit an existing floor-ceiling assembly. You can't just add channels and a layer of drywall over the existing ceiling and make much difference. And if you were thinking of adding fiberboard and another layer of drywall, forget it. That won't work either.

If you find yourself stuck with a situation where it is impossible to add resilient channels directly to the bottom of the joists, you will be better off just adding lots of drywall to the ceiling (try two or three layers of ½-in. material) or build up the floor above with the equivalent mass, using sand, drywall, lightweight concrete or some other dense material, assuming, of course, that the joists will support the extra load. Don't bother adding blown-in insulation to the joist cavity—it won't be worthwhile unless you've provided some structural discontinuity.

In resilient-channel construction, you also have to use the proper size screws. I recommend using 1-in. screws and ⅝-in. drywall. The idea here is that you want to eliminate the possibility that even one or two screws might penetrate the framing. It only takes a little structural connection between the ceiling and the joist for the ceiling to become an efficient sounding board. The depth of a resilient channel is about ½ in., so 1-in. screws would not penetrate a joist even if you were directly over one (be careful not to overdrive the screws). Also, most manufacturers recommend lapping the resilient channels at splices, applying them perpendicular to the joists, and avoiding cantilevers of more than about six inches. It is possible to attach two or even three layers of drywall to resilient channels, but if you do, I recommend 16-in. rather than 24-in. spacing. Even so, it is risky to build up layers of drywall on resilient channels because it becomes more likely that you will drive a screw into the framing.

Other details—It's also important to seal the edges of the drywall. Maintain a ½-in. to ¼-in. gap between the ceiling drywall and the intersecting wall drywall. Then fill the gap with foam backer rod and cover it completely with acoustical sealant. To conceal the joint, I prefer to use wood trim held ⅛ in. from the ceiling. This allows the edges of the ceiling to float freely and dissipate more acoustic energy.

Penetrations of the drywall ceiling should be kept to a minimum. Don't use large recessed light fixtures. One or two small recessed fixtures are okay if you enclose them in taped drywall boxes (check with the manufacturer to make sure the light fixtures are rated for enclosed spaces). Seal all penetrations for electrical boxes, plumbing stubouts and ductwork with acoustical sealant or other nonhardening sealant such as silicone or butyl rubber. Tremco and USG both make good acoustical sealants (see sources of supply, below).

Because the floor/ceiling construction between the first and second floors of our house had to provide very good sound insulation, we had to add more mass to the assembly, even though we installed resilient channels on the ceiling. We could have poured a gypsum or lightweight concrete topping on the subfloor, but these materials were not available in our area and would have been too expensive anyway for such a small job. So we screwed and glued two layers of ⅝-in. drywall to the underside of the plywood subfloor between the joists. This is preferable to adding more layers of drywall to the resilient channels and running the risk of making the ceiling too stiff or shorting out the channels with drywall screws.

One final element in this floor/ceiling construction was the addition of 3½-in. thick fiberglass insulation to the joist cavity. Many people think that sound-absorptive materials like fiberglass, rockwool or cellulose are a panacea for all acoustical problems. But these materials are only good at absorbing sound in a joist cavity when there is structural discontinuity built into the system. Then they will cut out some of the mid to high frequencies, and improve the STC rating by several points. The thicker the insulation, the more effective it is at low frequencies, but a 3-in. thickness is usually adequate. It does not matter much whether you use fiberglass, rock wool or spray-on cellulose fiber, but don't use rigid foams because they will transmit sound.

Field measurements of our closed joist-cavity assembly showed it had an STC rating of 50. This is generally considered adequate for separations in market-rate multifamily housing units. Without the resilient channel, insulation and extra drywall between the joists, the STC rating would have been about 37.

Sound-sealing doors—The weak elements in residential sound control are often doors. An acoustically isolated room must have a heavy door with good seals—including the threshold. In most cases, solid-core wood or 18-ga. insulated steel-slab doors are adequate. These typically have STC ratings of about 26-30 with high-quality gaskets. Hollow-core doors perform very poorly, with typical STC ratings of about 18.

The head and jambs of a door are relatively easy to seal. Neoprene gaskets, either adhesive or screw-on, are best. Extruded plastic and spring brass types of weatherstripping do not provide the quality seal that soft neoprene rubber does. Sealing the threshold, however, is more difficult. "Sweep"-type door bottoms will not work nearly as well as compression types. You should consider using neoprene automatic door bottoms such as those from Pemko or Zero (see sources of supply, left) for rooms where noise control is a major concern. These companies also offer other gasketed types of thresholds that you may want to consider. □

Russell DuPree is a noise-control engineer with the Department of Health Services in Berkeley, California. Charts adapted from a HUD guide, "A Guide to Airborne, Impact and Structure-borne Noise Control in Multifamily Dwellings."

Sources of supply

Akzo Industrial Systems Co.
P. O. Box 7249
Asheville, N. C. 28802
704-258-5050
—Enkasonic, a sound-control matting made of extruded-nylon filaments

Dow Corning Corp.
4291 Communications Dr.
Norcross, Ga. 30093
404-923-3818
—Ethafoam, a pliable, closed-cell foam sound-control matting

Peabody Noise Control, Inc.
6300 Irelan Pl.
Dublin. Ohio 43017
614-889-0480
—isolation hangers, foams, elastomeric pads, vibration dampers

Pemko
4226 Transport St.
P. O. Box 3780
Ventura, Calif. 3006
805-642-2600
—sound-tempering thresholds and acoustic gaskets

Tarkett
P. O. Box 264
Parsippany, N. J. 07054
800-225-6500
—QuietCor, a thick, sound-deadening vinyl underlayment

Tremco Manufacturing Co.
10701 Shaker Blvd.
Cleveland, Ohio 44104
216-292-3000
—acoustic sealants

U. S. Gypsum
101 S. Wacker Dr.
Chicago, Il. 60606
312-321-4344
—resilient channels, acoustic sealants

Zero Weatherstripping Co., Inc.
415 Concord Ave.
Bronx. N. Y 10455
212-585-3230
—sound-tempering thresholds and acoustic gaskets