The Acoustics of Multifamily Housing

For Architects, Builders, Developers & Occupants

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The Acoustics of Multifamily Housing
For Architects, Builders, Developers, and Occupants

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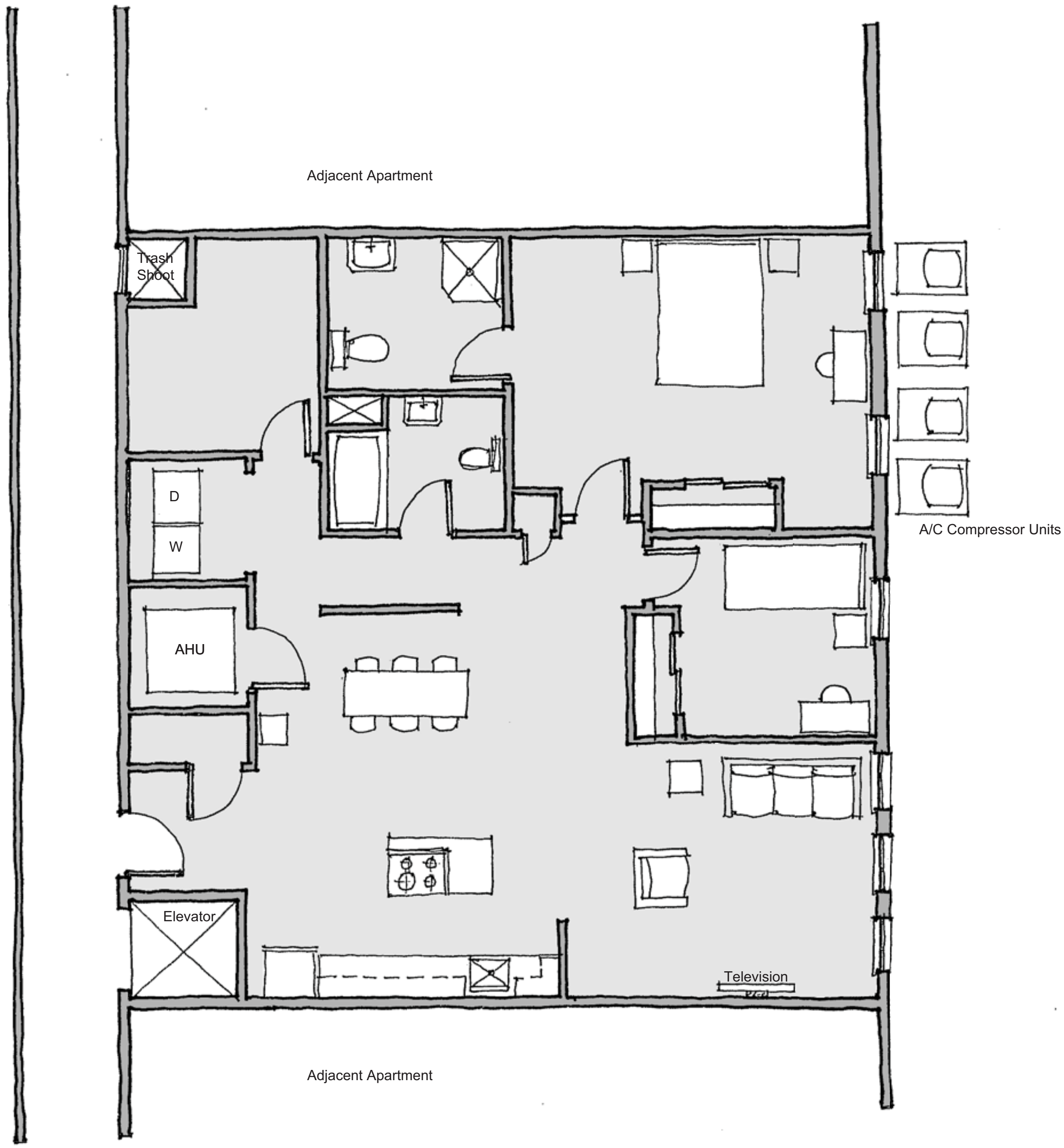
Noise and Privacy Quiz

From an acoustical point of view, how could this apartment be improved (answer in back of booklet)?



IMPACT NOISE: Footfall from above

Impact noise. This topic is touched on first because it is both particularly common and particularly difficult to mitigate in multifamily housing. Currently the field often defines floor-ceiling construction not through design or building codes, but rather through litigation. Impact noise, as a type of structure-borne sound, arises from impacts and vibrations transmitted directly to the building structure. These sounds can be loud and sporadic, therefore particularly annoying to building occupants, and unless they are accounted for in the initial design, structure-borne noise problems are especially difficult to correct.

Impact noises are radiated to structure through furniture movement, machinery, dropped items, rolling carts, kitchen activities, fitness activities, hammering, and slammed doors—but for purposes of this manual, impact noise discussion can be limited to footfall noise. When feet strike a floor, they can set the structure into vibration and structure-borne sound is radiated to both sides of a floor-ceiling assembly, often to a room below. Because structure-borne noise can travel quite far, footfall noise may be heard at great distances from the source.

Impact Noise

Different than airborne noise. The types of floor-ceiling assemblies that do well at keeping airborne noise out of a room below a source are not necessarily effective at keeping structure borne impact noise from radiating downward. (Airborne noises include people talking, or stereos playing.)

Possible in wood? In lightweight wood or steel frame construction, maintaining appropriate impact noise sound isolation may not be possible. Research and experience suggest that the low pitched thud associated with footfall in these types of buildings may simply not be practically mitigated to a level that many occupants would judge to be acceptable. Because annoyance in footfall is related to the audibility and not the magnitude of the noise, those developing, building, or designing multifamily housing should consider avoiding lightweight construction altogether in favor of a concrete building. If building in wood, one might consider establishing appropriate occupant footfall-noise expectations or adopting a townhouse regime where units are not stacked vertically. Know that in light wood construction, even if floors boast high Impact Insulation Class (IIC) ratings—ratings that if found in concrete construction would suggest proper performance—they may not be acceptable to a portion of reasonably-minded building occupants.

Impact Noise

Impact Insulation Class (IIC). This single-number rating provides a means for comparing the performance of floor-ceiling assemblies for the transmission of impact noise. The higher the Impact Insulation Class (sometimes written as Impact *Isolation* Class but still abbreviated as IIC), the better the assembly performs. A floor with no acoustic consideration in its design might earn an IIC of about 30, and most occupants would find that unacceptable; a floor that takes acoustics into careful consideration might achieve an IIC of 70 and most occupants would find that acceptable. Yet if a designer has taken some acoustic care in the design of a floor-ceiling, and achieves an (International Building Code minimum) IIC of 50 . . . well, some people will find that satisfactory and some will not.

Impact Noise

Achieving higher impact noise performance in design.

1. **Programming.** As with most problems related to noise control, locating noisy areas so that they are far from quiet areas is often the most successful, most cost-effective, and most architectural of the solutions available. To mitigate problems that might arise from impact noise, consideration should be given as to whether a parti that involves vertically stacking residential units is necessary at all.

2. **Damping at point of impact.** The most effective method to boost the performance of a floor-ceiling assembly is to prevent the impact sound energy from entering the building structure. This can be achieved by specifying carpet with a soft underlayment or rubber tile. Of course, even if carpet is specified occupants may later swap out that soft surface for a hard one sometime after taking ownership of a unit, *significantly* decreasing its impact noise performance.

Impact Noise

Achieving higher performance

3. **Damping between a hard finish surface and a structural surface.** This resilient underlayment can consist of a mesh, pad, board, or mat, layer. These are typically proprietary systems and are not equal in performance. Thick underlayments far outperform thinner underlayments, and those with thicknesses less than 3/8 inch (9 mm) should be avoided, especially in light wood construction. In concrete construction, a “floating floor” may be used to isolate a concrete pad from the structural floor below it. In this system, the upper floor hovers on spring or neoprene isolators. Know that most of the effective underlayments will add a not-insignificant thickness to the floor assembly, which can complicate the installation of cabinets and doors. When designing for an underlayment or floating floor, carefully detail to eliminate flanking paths at penetrations and walls.

Impact Noise

Achieving higher performance

4. **Damping between the structural floor and the ceiling below.** Generally, floor-ceiling assemblies with ceilings outperform those with exposed overhead structure. By decoupling the ceiling from the structure with spring hangers or resilient brackets, performance increases further. For concrete construction, maintain 4 inches (100mm) minimum air space between the ceiling and the structure (8 inches is better). For wood construction, resilient brackets with metal hat channels mounted with clips outperform resilient channel mounted directly to the structure in the field. This is because without proper jobsite supervision, the use of long screws may short circuit the resilient channel by penetrating the wood structure directly.

Impact Noise

Achieving higher performance

5. **Flanking.** The acoustical benefit of underlayments or resilient ceiling mounts can be compromised if the independence of resilient components is short-circuited. Special care is required in detailing and construction oversight to ensure that resiliently supported floors, floated floors, and resiliently hung ceilings make no rigid contact with the structure. When floors are isolated on an underlayment or floated, use a soft proprietary perimeter board at the edge of the floor in each room to keep structure-borne acoustic energy from transferring to the walls. Floor moldings should be attached to the walls, but make no mechanical contact with the resiliently mounted floor (use non-hardening caulk). Nor should spring and resiliently hung ceilings mechanically contact walls (again, use non-hardening caulk to make the seal). Be wary: pipes, conduit, ducts, and other services penetrating a damped floor-ceiling assembly will short circuit the resilient layer unless carefully detailed.

Impact Noise

Achieving higher performance

6. **Insulation in the cavity.** The use of sound absorbing fiberglass, cellulose, or mineral wool insulation in the cavity between the floor above and the ceiling below increases impact insulation performance.

7. **Stiffness and mass.** While “click-clack” sounds are associated with an inadequately resilient floor surface assembly, a “thud” sound is associated with insufficient stiffness. In wood construction, short joist spans, nominally those 14 feet (4.25 m) or less, outperform floors with longer joist spans in the field; floors with denser joist spacing, 16 inches (400 mm) on center or less, outperform floors with sparser joist spacing. Note that lab tests published for floor-ceiling assemblies do not currently account for the variability of joist spans. To achieve appropriate stiffness and mass in wood construction, a concrete or gypsum-concrete topping should be used.

Impact Noise

Shortcomings of the IIC rating.

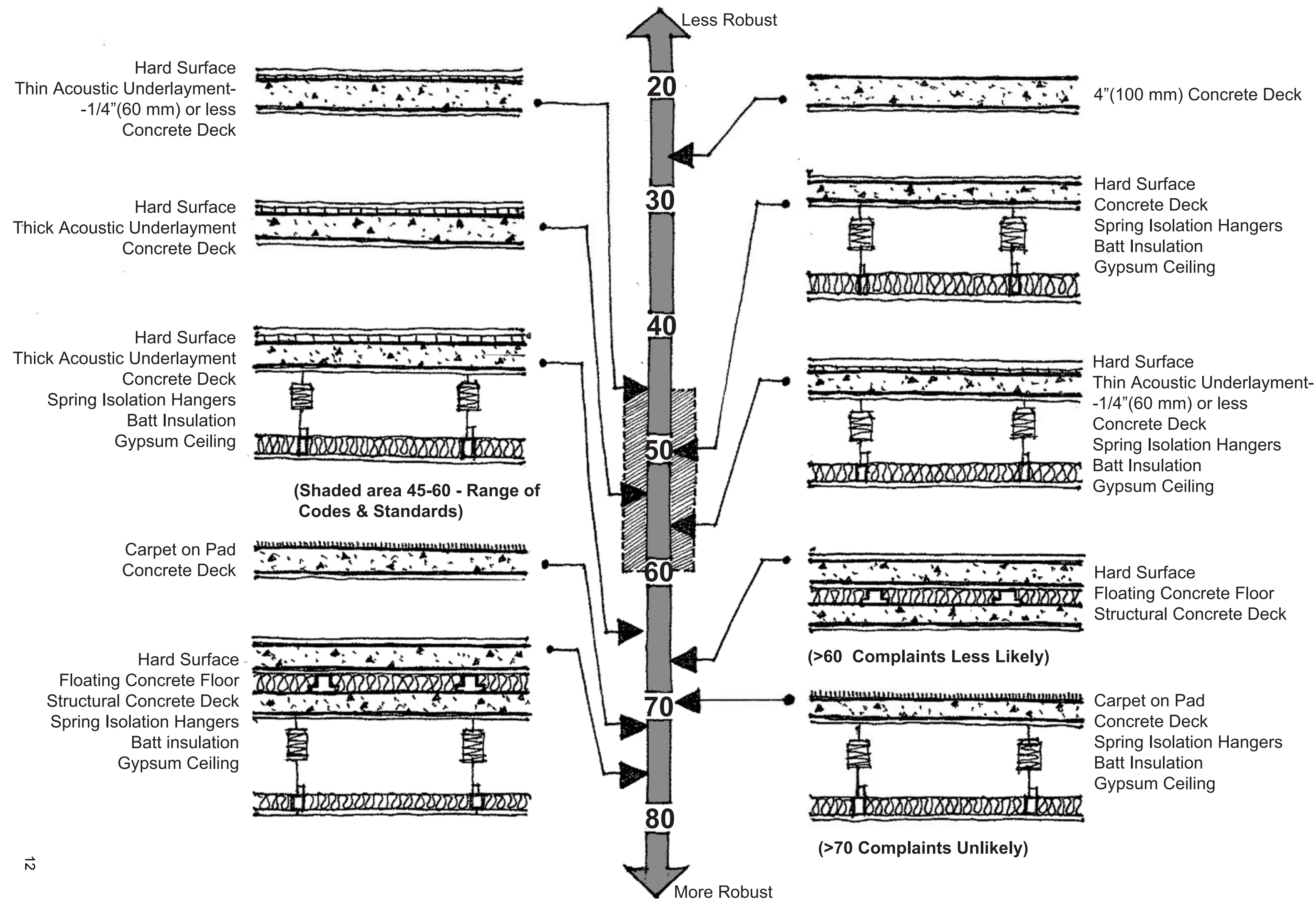
While the IIC rating is widely referenced, it does not always measure the likelihood of annoyance from footfall. First, assigning a single value as an acoustic metric oversimplifies the important role that frequency dependency plays in sound. Second, IIC ratings, especially those measured by product manufacturers, are tested in laboratory conditions, but in-the-field performance is known to vary from that which is measured in the lab. Third, IIC does not take into account the span of the floor in question. Fourth, floor-ceiling assemblies are fickle in their transmission of sound. A seemingly small change in the section detail may leverage large variations in sound isolation. It is therefore difficult to estimate an IIC rating, and since most floor-ceiling assemblies haven't been tested exactly as specified by architects, it may be difficult to know exactly how *your* assembly will perform. To date, manufactures have done an inadequate job of testing a sufficiently wide palate of assemblies. Finally, and most importantly, in its calculation structure the IIC metric doesn't properly account for the low frequency thud

Impact Noise

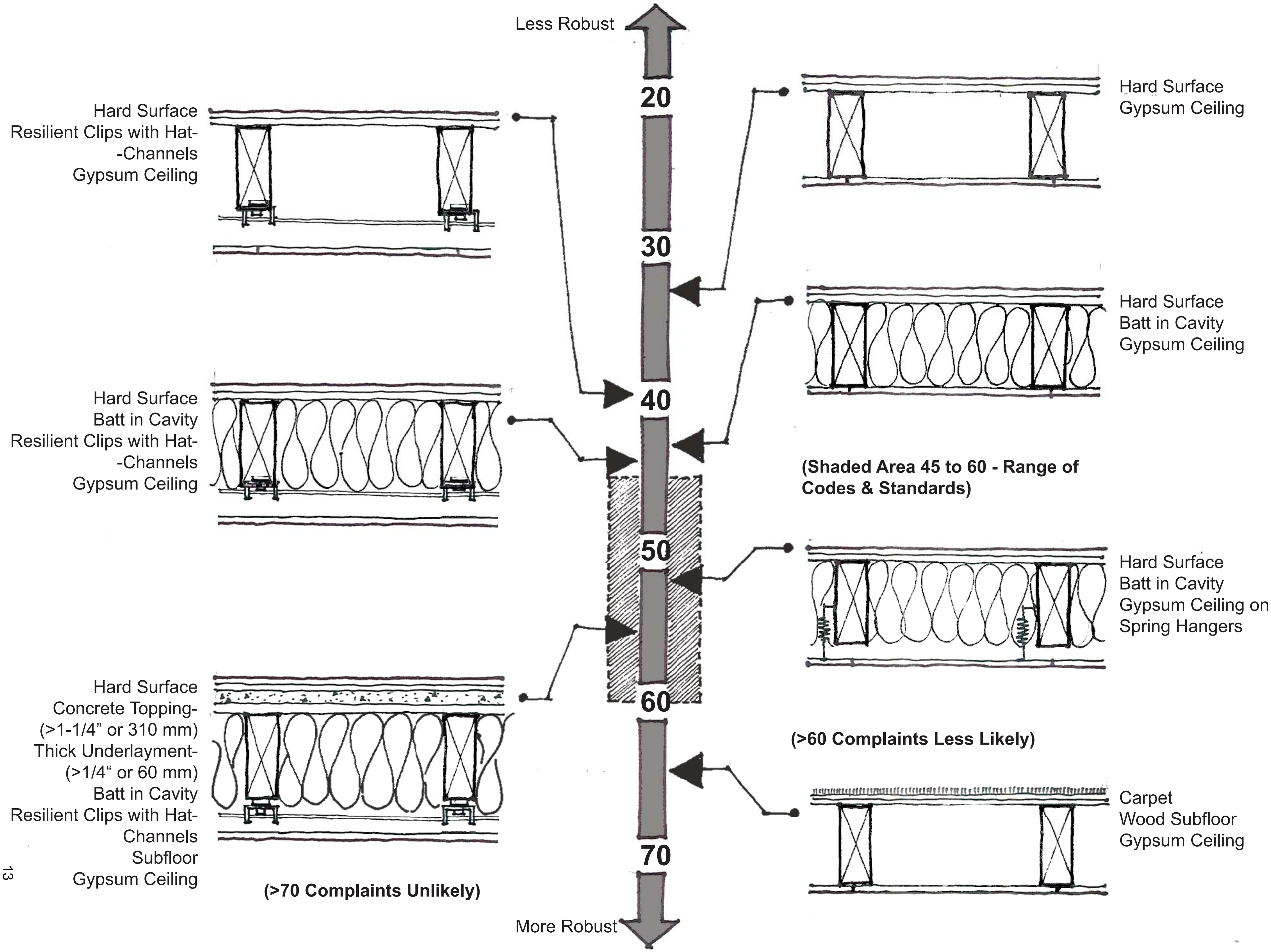
Shortcomings of IIC

associated with footfall in wood and light weight steel construction. Nonetheless, IIC is widely used and no better measurements have yet found broad acceptance (in the United States). It’s best to view IIC as a useful but flawed instrument.

Impact Insulation Class (IIC) for Concrete Construction



Impact Insulation Class (IIC) for Wood Construction



Impact Noise Checklist.

Early Design

1. Don't stack units vertically. Consider a townhouse configuration instead, if possible.

2. Don't program noisy spaces likely to generate footfall above quiet spaces.

3. Use concrete. Many researchers and practitioners believe there is no way to achieve acceptable impact noise isolation performance with wood or light steel construction.

4. Know that at present, minimum code performance is not aligned with widespread occupant satisfaction. Prepare occupants to maintain reasonable expectations.

Assembly Performance

1. Avoid excessive floor deflection in light wood construction. Although a floor joist system may be adequately designed in terms of structural and load requirements, it may deflect sufficiently under foot to cause squeaking or thud sound. This generally occurs when the joist is too shallow or the spacing between joists is too wide. For typical residential floor construction, the deflection of the floor should not exceed 1/8 inch under a uniform dead-load

Impact Noise

Checklist

Assembly Performance

distribution of 40 pounds per square foot. This amounts to approximately one-fourth of the conventional deflection limitations which are based on 1/360 of the floor span.

2. Remember that strong acoustical performance at airborne sound isolation (STC) or sound absorption (NRC) does not (necessarily) equate to good acoustical performance at impact noise isolation.

3. Educate your clients and occupants on the subject of impact noise.

4. Recognize that if you design soft walking surfaces, which do well mitigating impacts, they may be replaced at a later time by hard surfaces.

5. Where hard surfaces exist, use resilient underlayments or floating floors to isolate the finished floor from the structure.

6. Specify thick underlayments, a minimum of 3/8 inch (9 mm). This extra floor thickness may require special detailing at doorways and cabinets.

Impact Noise

Checklist

Assembly Performance

7. Design sound barrier gypsum ceilings under structural floors. Extend ceilings to cover the entire space, rather than only some rooms. Acoustical ceiling tile (ACT) ceilings offer scant impact noise protection.

8. Mount ceilings resiliently.

9. In concrete construction, maintain an airspace (with fiberglass insulation) of at least 4 inches (100mm) between the structural floor and the hung ceiling.

10. Detail and specify resilient brackets carefully and supervise their installation. When specifying resilient channel, use high quality stock, and not channel heavier than 25 gauge that is not really resilient, limit the length of screws attaching the ceiling to ensure they don’t engage the structure beyond the resilient channel, don’t install the channel between two layers of gypsum board, upside down, or with the solid part of the web at joists, and don’t excessively overlap the ends of the channel.

11. Design fiberglass batt insulation in the airspace between the structure and the ceiling.

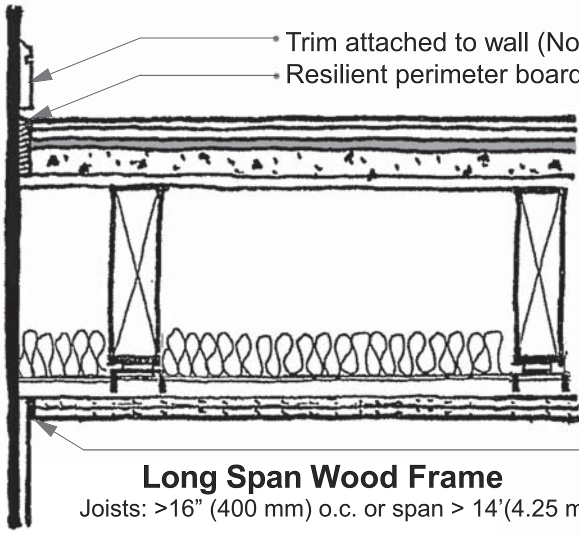
Flanking

1. Because flanking paths are the enemy of effective isolation, carefully detail the edge of the floor, the edge of the ceiling, and penetrations of the assembly so that resilient surfaces do not make mechanical contact. Use generous quantities of non-hardening caulk.

2. Know that recessed lights in a ceiling can compromise the performance of the assembly and require special detailing.

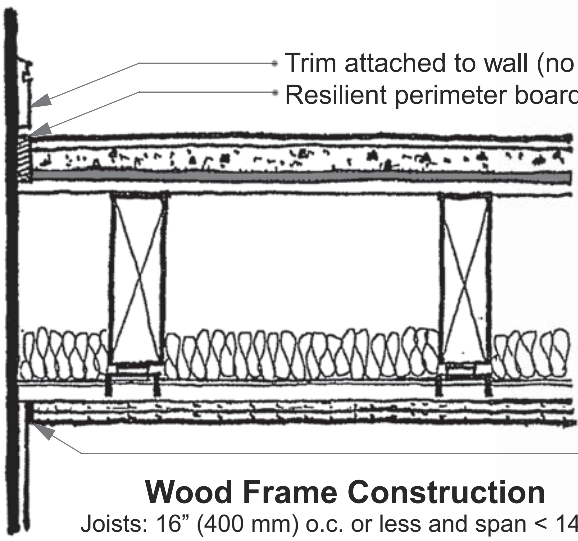
3. Detail the perimeter of the ceiling so that it doesn't make mechanical contact with the wall. Seal the ceiling perimeter with non-hardening caulk.

Recommended: Floor - Ceiling Assemblies



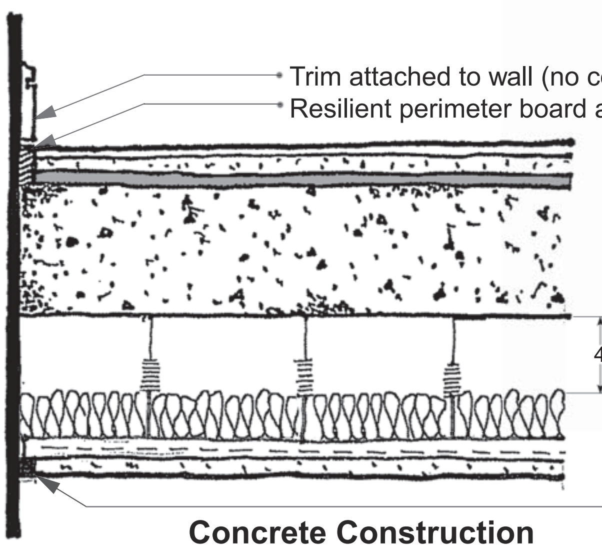
Long Span Wood Frame

Joists: >16” (400 mm) o.c. or span > 14’(4.25 m)



Wood Frame Construction

Joists: 16” (400 mm) o.c. or less and span < 14’(4.3 m)



Concrete Construction

*Resilient unlerlayment will improve performance but is not essential in concrete construction for most occupants

ACOUSTICAL PRIVACY

Airborne noise. Airborne sound transmission between rooms is generated by people talking or shouting, equipment running, and the sound amplification associated with stereos and television sets. Sound energy moves through the air to the wall assembly *and* floor-ceiling assembly, where it is radiated through the structure to the other side. Generally, occupants find louder noises and noises that start and stop or fluctuate to be particularly annoying but, as in the case of a dripping faucet, occupants may even be annoyed by mere audibility. Because people generally are annoyed by sounds that are (1) created by sources they are not involved with, (2) unpredictable, (3) perceived as unnecessary, and (4) generated by people toward whom they don't have a favorable attitude, airborne sound isolation *between residential units* can be particularly vexing.

Privacy

Low frequency sound. One can sometimes hear the bass beat of a car stereo for what seems like a two block radius, but can't make out the lyrics of the song on that car stereo until the car door is opened in close proximity. In this way low frequency sound energy travels far and easily moves through some building assemblies, particularly those that are light weight. In the context of multi-family housing, the low-pitched hum of mechanical equipment—and the amplified bass notes associated with stereos and TVs played too loudly—pass through many wall and floor-ceiling assemblies barely attenuated. Designers beware: Sound Transmission Class (STC) is an easy method of comparing the airborne acoustical isolation of building assemblies, and is effective at summarizing performance related to speech privacy, but is inadequate at summarizing performance associated with low frequency amplified music and mechanical equipment hum.

Flanking. Keeping sound out is like keeping water out. The overall performance of an assembly is more a function of its performance at the *weakest* point, not the average, therefore a small leak can render an assembly ineffective. This can only really be combated by thorough detailing and construction supervision, particularly where the floor meets the wall in wood construction.

Privacy

Electrical outlets facing opposite units should not occupy the same inter-stud wall cavity; niches for bookshelves or fire extinguishers should be well detailed; cabinets and medicine cabinets should not be designed back-to-back; conduit, pipes, ducts, and other penetrations should not move through sensitive assemblies, and when they do, the wall should be sealed at the penetration. Generous quantities of caulk should be used, particularly where drywall meets the subfloor. Designers beware: Sound Transmission Class (STC), while helpful in making comparisons, is only a description of the performance of the wall or floor ceiling assembly and does not account for sound flanking or installation quirks, better considered with whole-system-thinking.

Transmission Loss (TL). The airborne sound-insulating properties of a building element can be quantified by measuring its Transmission Loss (TL). The higher the TL values, the more robust the assembly is at attenuating the penetration of sound. Tested building elements will have Transmission Loss values at each of several frequency bands, from low-pitched tones to higher-pitched tones, and because airborne sound attenuation is only as good as the weakest link in the chain, a high value in one octave band will not necessarily make up for a low value in another.

Privacy

When accounting for low frequency noises associated with amplified music, transportation noise, and mechanical equipment rumble, special attention should be paid to select a building assembly with high 63Hz, 125Hz, and 250Hz octave band TL values.

Sound Transmission Class (STC). For easy comparison of building elements, Sound Transmission Class (STC) provides a *single number* rating. Like Transmission Loss, the higher the building assembly's STC rating, the more effective the assembly is at preventing the transmission of sound. But unlike Transmission Loss which links multiple values to a single assembly to account for performance variation between octave bands, Sound Transmission Class combines multiple values from across the frequency spectrum, weights them, and compiles one number to address all the octave bands. The casualty of this simplification is low frequency performance, which STC does not sufficiently relate.

Privacy

Achieving higher acoustical privacy in design. Building elements that are massive, airtight, and structurally discontinuous perform the best.

1. **Mass.** In general, the more dense the material, the more noise it will attenuate for a given thickness. For example, solid concrete is a better sound insulator than solid wood (of equal thickness), and a thicker concrete wall will attenuate sound more effectively than a thinner concrete wall. Multiple layers of thicker gypsum board on the outside of a wall outperform a single thinner layer. Doubling the weight of the wall by adding a layer to both outer surfaces can increase STC by more than 5 points.

2. **Airtight.** The best assemblies for maintaining acoustical privacy have surfaces with few or no interruptions and are sealed. A 1/16 inch (2mm) crack 16 inches (400mm) long will reduce a 9 foot long STC 50 wall to an STC 40 level. Try not to interrupt party walls or other acoustically sensitive walls with doors and systems such as electrical outlets, doorbells, fire alarms, intercoms, cabinets, phone jacks, conduit, ducts, grilles, and pipes.

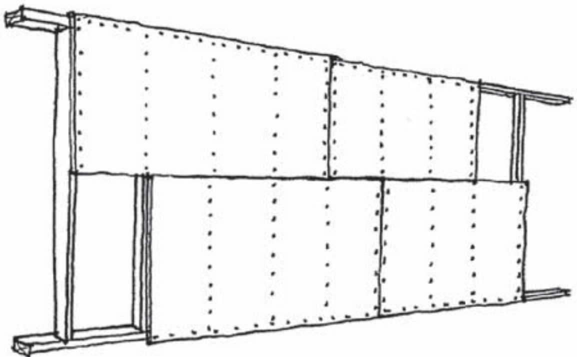
Achieving Privacy

3. **Structurally discontinuous.** A cavity wall outperforms a solid wall of equal weight. Maintaining a resilient connection between the wall structure and the panel(s) on one side of an assembly renders the assembly limp, increasing performance relative to rigid-mounted panels. A small room, like a closet, can be designed as a buffer zone, provided the small room extends the full length of the wall in question.

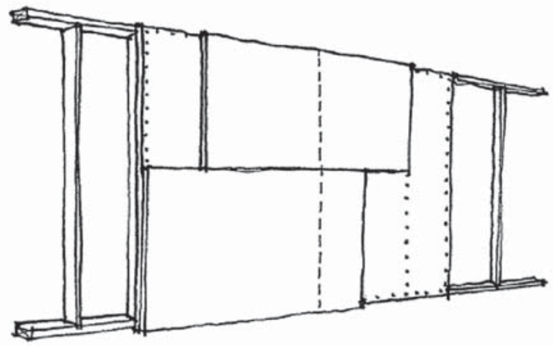
4. **Sound absorbing materials in the cavity.** In lightweight walls especially, fuzzy material such as fiberglass can improve the performance of a wall significantly, but sound absorbing insulation is not a substitute for mass and air-tightness. Indeed, the true benefit of a wall or ceiling cavity filled with sound absorbing materials can only be realized with structural discontinuity (item 3, above).

Principles of Sound Transmission Performance

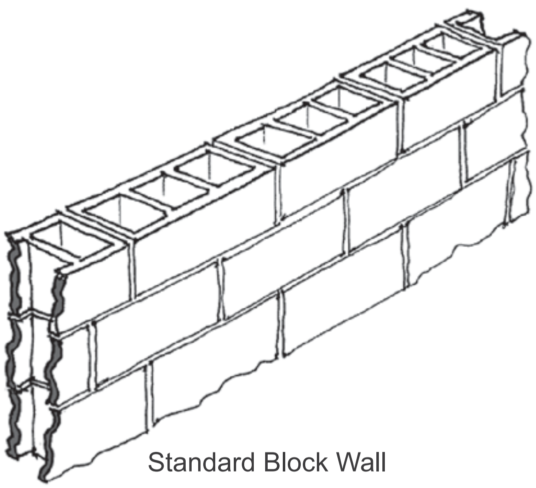
Baseline | **Better**



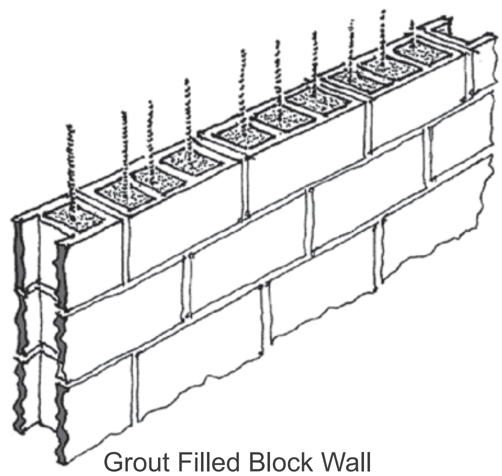
Single Layer Gypsum Board



Multilayer Gyp. Bd. with Staggered Panel Joints

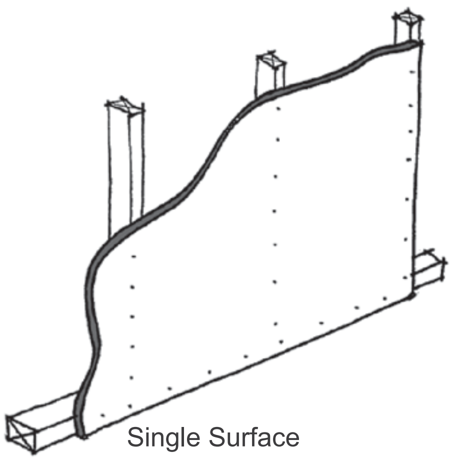


Standard Block Wall

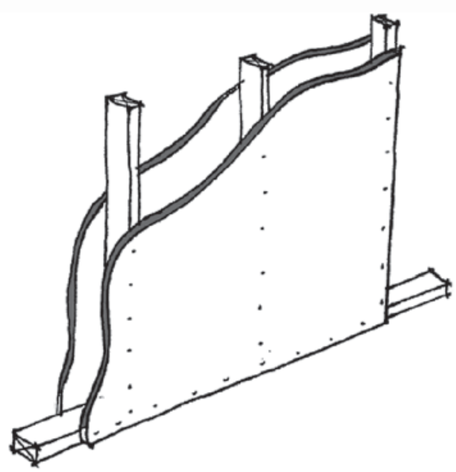


Grout Filled Block Wall

Increased Mass



Single Surface

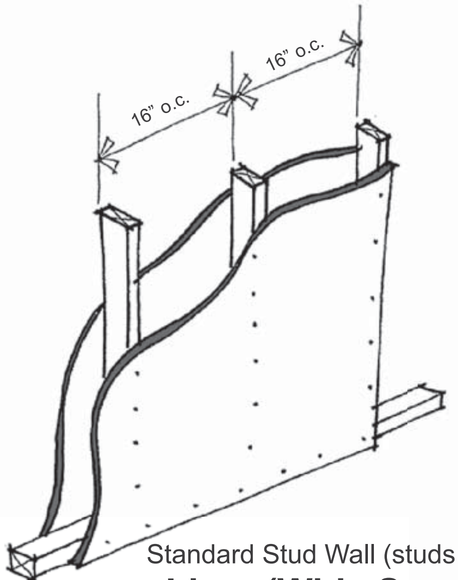


Two Surfaces with Cavity

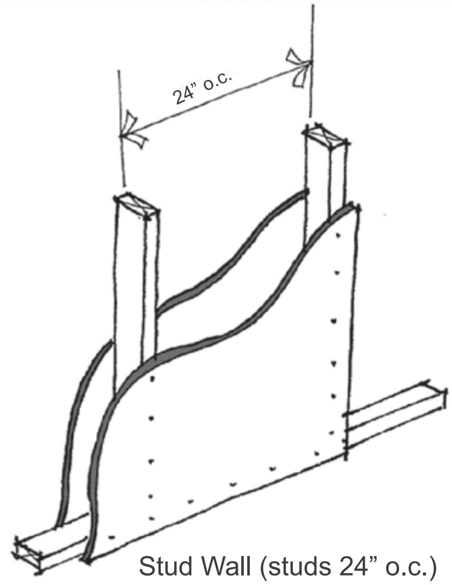
Use of Airspace

Principles of Sound Transmission Performance

Baseline	Better

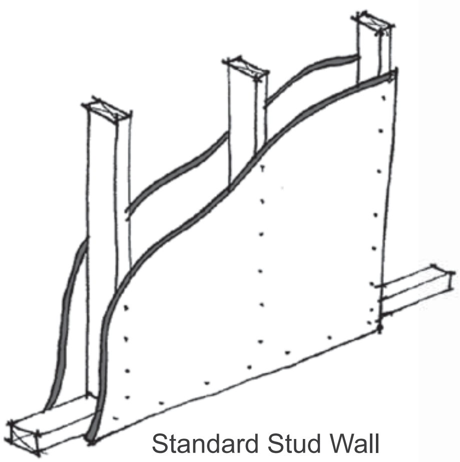


Standard Stud Wall (studs 16” o.c.)

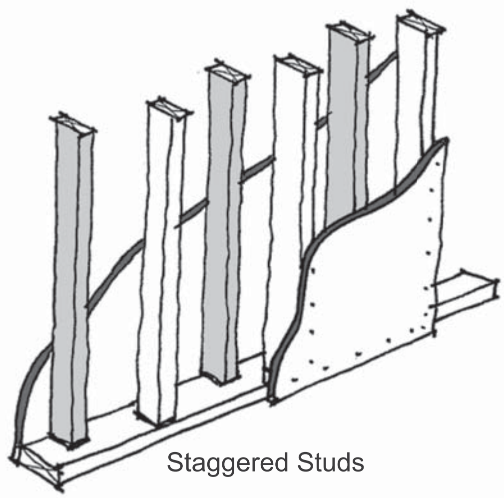


Stud Wall (studs 24” o.c.)

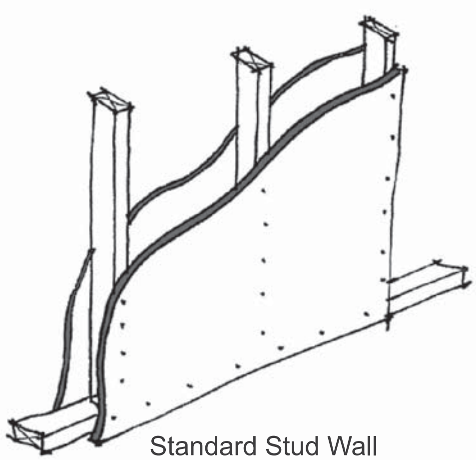
Limp (Wide Spacing Between Studs)



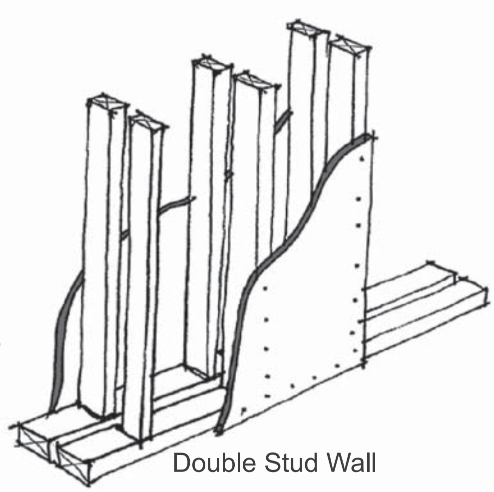
Standard Stud Wall



Staggered Studs



Standard Stud Wall

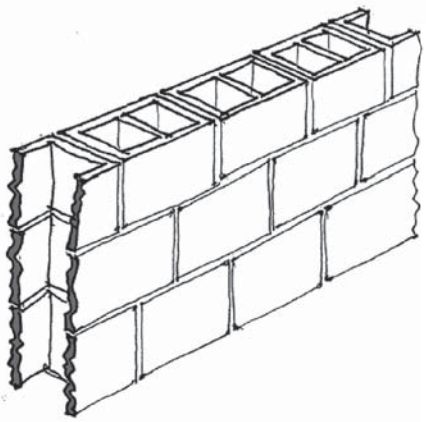


Double Stud Wall

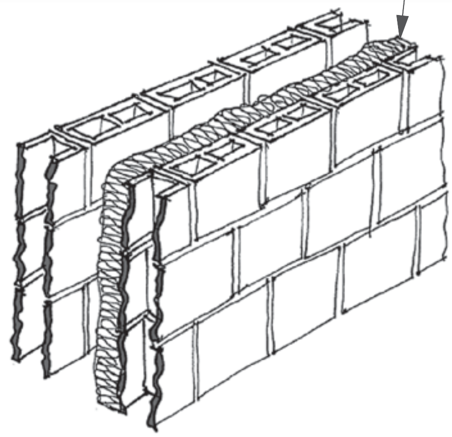
Structural Discontinuity

Principles of Sound Transmission Performance

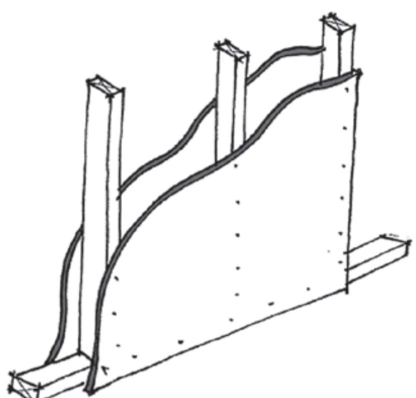
Baseline | Better



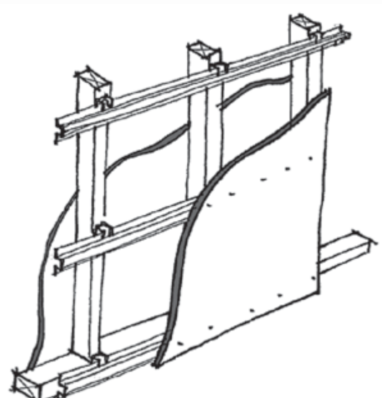
One Wythe of CMU



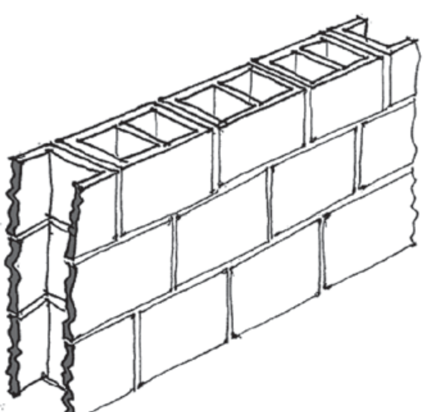
Two Wythes of CMU with Cavity



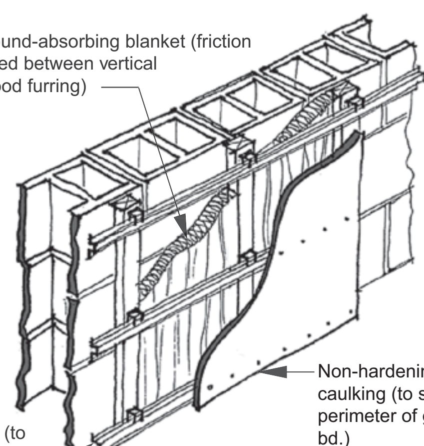
Standard Stud Wall



With Resilient Brackets



CMU Wall

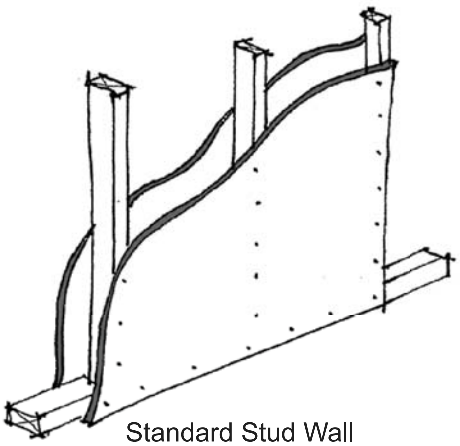


CMU Wall with Furring, Resilient Clips and Gyp. Bd.

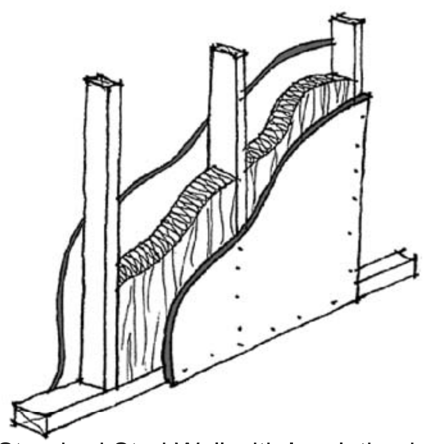
Structural Discontinuity

Principles of Sound Transmission Performance

Baseline	Better

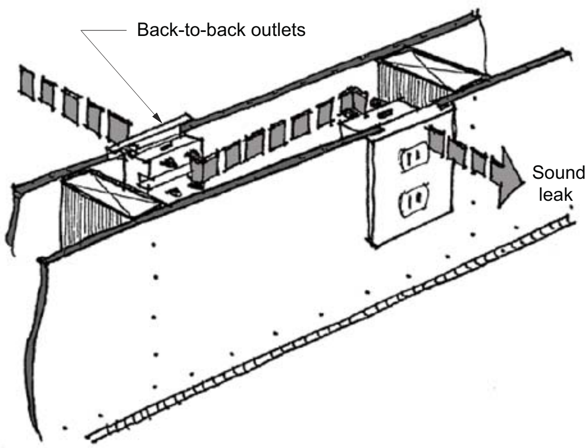


Standard Stud Wall

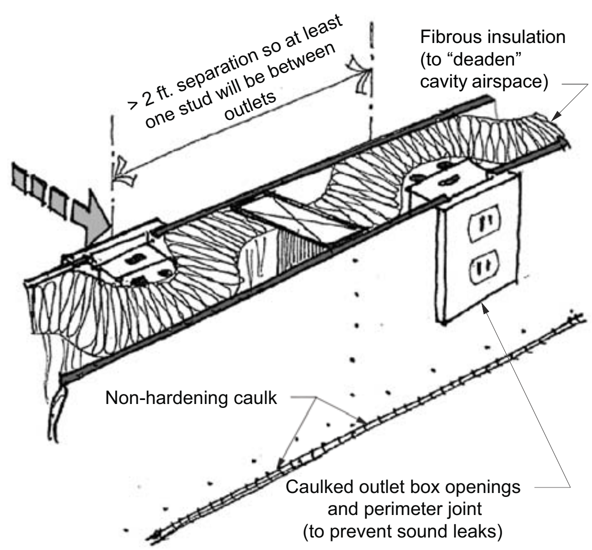


Standard Stud Wall with Insulation in the Cavity

Absorption in the Airspace



Stud Wall with Outlets in the Same Cavity



Stud Wall with Outlets in Separate Cavites

Airtight

Privacy Checklist

Early Design

1. Program and space-plan with acoustics in mind. Keep the quiet spaces and noisy spaces far away from one another, not only in plan, but in section as well. This is by far the most effective, least costly, and most architectural of the solutions available.

2. Recognize that some rooms are simply too noisy to be adjacent to noise-sensitive spaces, period.

3. Design rooms that are not noise sensitive as buffer zones between noisy spaces and quiet spaces. For instance, one might place a row of closets, utility rooms, vestibules, and bicycle storage rooms between units. Experience suggests that the room two-doors-down is much quieter than the adjacent room.

4. Recognize that within a dwelling, an open plan will not afford acoustic privacy. For instance, if the watching-television space and dining space are in plain sight of one another, no acoustical treatment will provide for meaningful aural separation between the two.

Privacy Checklist

Assembly Performance

1. Do not confuse sound absorption with sound transmission loss. A material's sound absorption or an assembly's impact noise performance has little—and often no—effect on its sound transmission properties. Noise Reduction Coefficient (NRC), and Impact Isolation Class (IIC) are independent of sound Transmission Loss (TL) and Sound Transmission Class (STC). Acoustical ceiling tile typically has no meaningful effect on the transmission of sound between occupied rooms.

2. Be conservative and specify an assembly that well-exceeds the minimum required. Sound Transmission Class (STC) regularly varies +/- 2 points from measurement to measurement. Some vary more. Know that some manufacturers, when publishing results from acoustic tests, will put forth the highest score ever achieved rather than a typical score.

Privacy Checklist

Assembly Performance

3. If measuring as-built assembly performance in the field, know that field test values usually come in below those measured in the laboratory. This is because*, in situ*, construction irregularities and flanking paths compromise the robustness of the more controlled samples tested as panels in the lab. Nominally, one may assess a penalty of five points when translating to field measurements if there is the clear recognition that in some cases, the penalty may be more than ten points.

4. Know that sound more easily passes between units if exterior windows of adjacent units are located near one another.

5. Specify massive, airtight, and structurally discontinuous assemblies for walls *and* floor-ceilings.

6. Two layers of gypsum board on one or both sides of a wall outperforms one layer. Three layers outperforms two. When layering, stagger the gypsum board seams so they do not align. Attach layers of gypsum board together with visco-elastic adhesives rather than rigid curing adhesives or screws.

Privacy Checklist

Assembly Performance

7. In concrete block construction, know that the densities of available products vary, and that heavier block outperforms lighter block. To increase performance, fill cells with sand or mortar. Staggering wood studs so that each stud only makes contact with one wall surface is more effective than normative stud wall construction where each stud makes contact with both surfaces. A double stud wall with separate sole plates separated by one inch (25mm) is better still, and recommended practice for party walls in multifamily light wood frame construction. In double stud construction, only affix gypsum board to the *outside* of the stud assembly, keeping the cavity between the exposed surfaces free of sheathing surfaces.

8. If structural considerations allow it, increase the spacing between studs from the normative 16 inches (400mm) to 24 inches (600mm). The same is true for the spacing of resilient channel. Note that this approach is not recommended for joists in floor-ceiling assemblies as it is associated with an increase in impact noise.

Privacy Checklist

Assembly Performance

9. Use resilient connections to attach a ceiling, or one surface of a wall, to the structure. Flanking issues can arise when improperly long screws are used that short circuit the resilient connection by biting directly into the stud or joist. Unless proper supervision will be present during installation to ensure that either short screws are used or that panel attachments are only made to the resilient channel *between* the structural members, specify a resilient channel system with clips. Cabinets or baseboard trim attached directly to the studs can short circuit the isolation provided by the resilient connections.

10. Know that lighter-weight steel studs are limper, and therefore more effective, than heavier-weight steel studs, and more effective than wood studs.

11. Coupling a gypsum board wall to a concrete block wall with furring increases performance of the block wall. Insulation between the furring and resilient clips to attach the gypsum wall surface is better. A double block wall with a fiberglass insulation filled cavity between withes is better, still.

Privacy Checklist

Avoid Flanking

1. Use generous quantities of non-hardening caulk to ensure a tight seal (1) where wall board meets the floor, (2) where ceilings meet walls, and (3) at penetrations from ducts, electrical outlets, pipes, etc.. To seal larger holes, use firestop putty.

2. Electrical outlets, phone jacks, cable wall jacks, pipe and duct penetrations, etc. should not occupy the same inter-stud wall cavity. When possible, do not locate these flanking opportunities in party walls.

3. Use plastic vapor-barrier electrical outlet boxes: they outperform metal electrical outlet boxes in acoustic tests.

Privacy Checklist

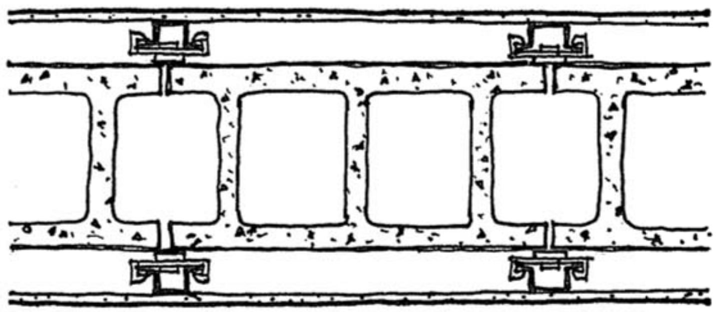
Avoid Flanking

4. Niches for bookshelves or fire extinguishers should be well considered, kitchen cabinets and medicine cabinets should not be designed on party walls.

5. Conduit, pipes, ducts, and other penetrations should not move through sensitive assemblies, and when they do the wall should be sealed at the penetrations. This may require use of sleeves, grout, caulk, and packing.

6. Run walls *all the way* to the underside of the slab—do not terminate the wall short of the slab simply because it has gone through a hung ceiling and will appear proper when viewed from within the room.

Recommended: Party Wall

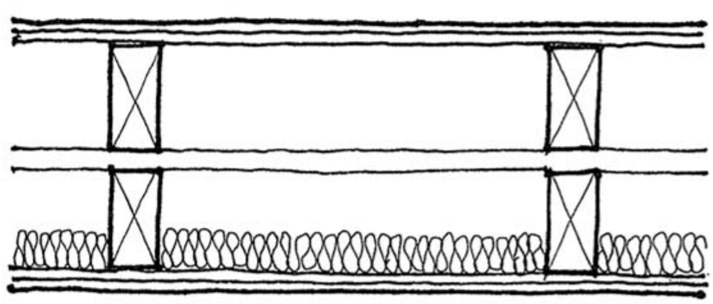


Block Construction

STC 56
5/8” (16mm) gypsum board, screwed to channels
Resilient clips with hat channel
8 x 8 x 16” 3-cell lightweight concrete masonry units (34 lbs/block)
Resilient clips with hat channel
5/8” gypsum board, screwed to channel

Concrete Construction

STC 58
8” (200mm) thick flat concrete panel (95 psf)



Wood Construction

STC 62
5/8” (16mm) gypsum board, screwed 12” (300mm) o.c. (2 Layers)
Double row of 2 x 4 studs, spaced 16” (400mm) o.c. on separate plates spaced 1” (25mm) apart
1 1/2” (40 mm) thick sound attenuation blanket
5/8” gypsum board, screwed 12” o.c. (2 layers)

Privacy Checklist

Avoid Flanking

7. Conduct preliminary tests of the sound insulating effectiveness of a wall or floor-ceiling prior to painting and final completion. Visually inspect for cracks or gaps in surfaces. Your ears are excellent acoustic instruments: run a noisy device such as a vacuum cleaner or power tool in a closed room and listen in the adjacent room for locations where the noise is leaking through. A physician's stethoscope can help with this too.

8. Locate building control joints where needed. The proper use of control joints to account for differential expansion and contraction will minimize the future cracking of walls and therefore minimize the potential for sound flanking through cracks. Because control joints offer vibration isolation as well, locate rotating and reciprocal-motion equipment such as pumps, compressors, chillers, cooling towers, exhaust fans, air handlers, washers, and dryers on a separate building segment—separated from dwelling unit segments with a building control joint.

Privacy Checklist

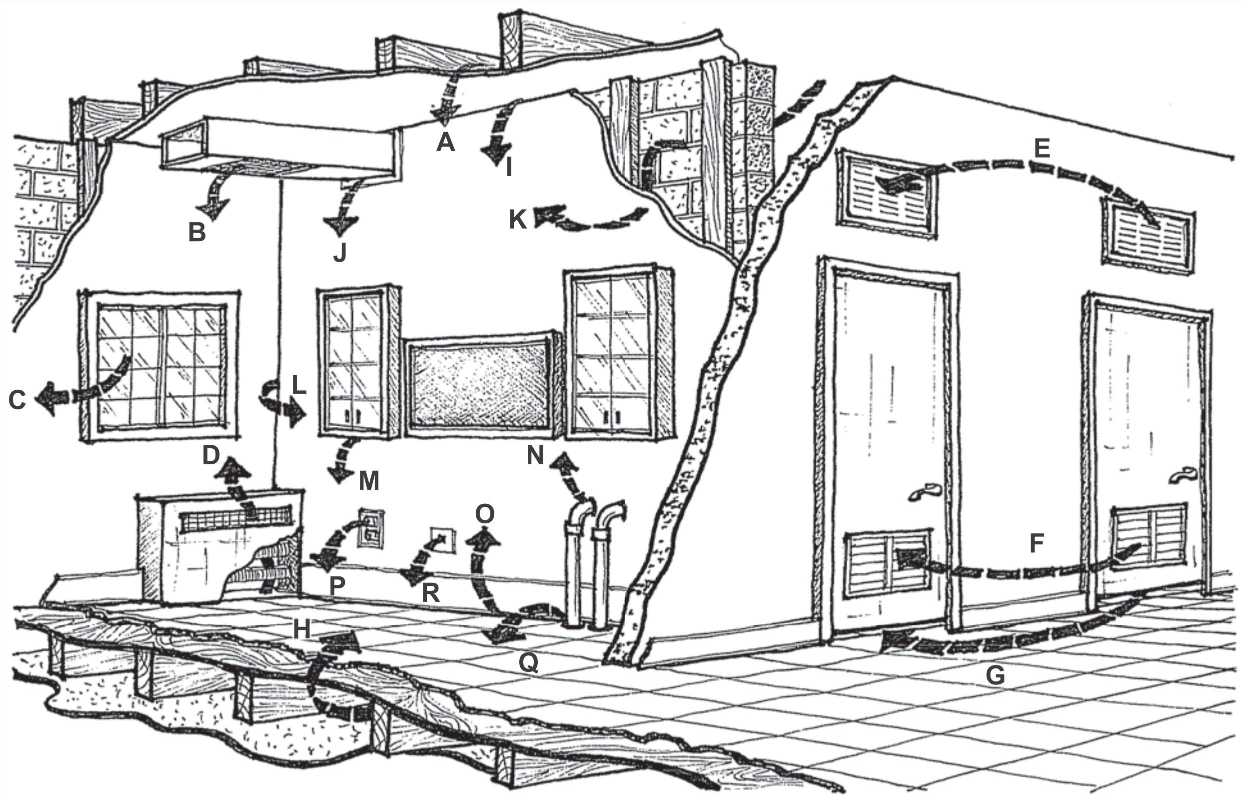
Avoid Flanking

9. Where critical adjacencies exist between noisy and quiet spaces and there *must* be a door connecting the two, design a vestibule between two doors instead. Solid wood doors and hollow metal doors outperform hollow wood doors. Gasketed doors outperform those without gaskets. Louvered doors provide almost no acoustical separation. High-performing, proprietary, acoustical doors are available, but generally very expensive.

10. Ensure that sound attenuating blanket insulation at least two inches (50mm) thick is specified for cavities in assemblies designed to keep out noise. Supervise installation to ensure the insulation doesn't sag and isn't compressed.

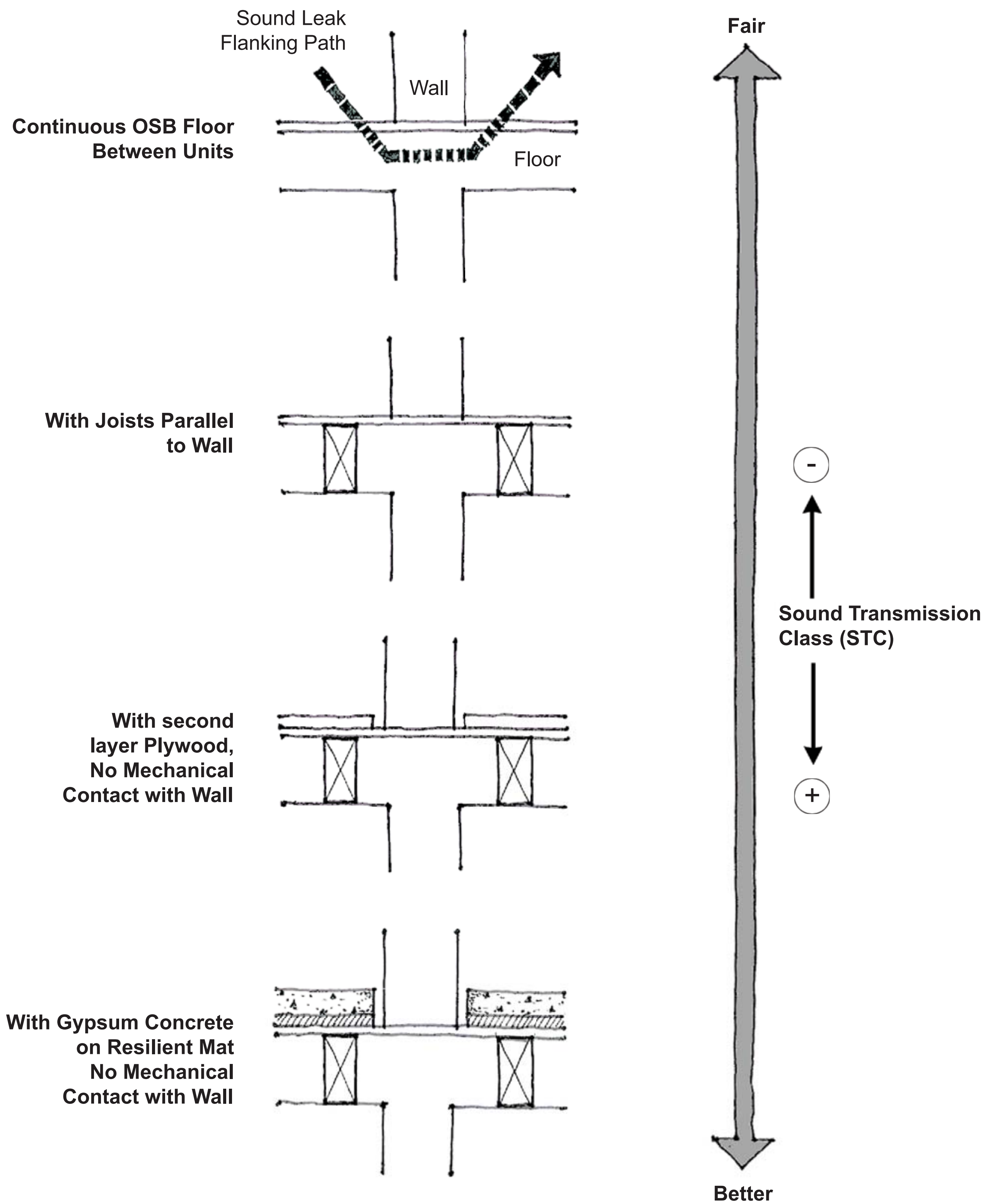
11. Know that firestops and gusset plates can short circuit the separation intended for double wall constructions if they rigidly connect the two walls intended to be structurally separated.

Flanking Transmission of Airborne Noise



A. Open Plenums Over Walls, False Ceilings
B. Unbaffled Duct Runs w/o Min 2 Elbows
C. Outdoor Path, Window to Window
D. Continuous Unbaffled Inductor Units
E. Hall Path, Open Vents
F. Hall Path, Louvered Doors
G. Hall Path, Openings Under Doors
H. Open Troughs in Floor-Ceiling Structure
I. Poor Seal at Ceiling Edges
J. Poor Seal around Duct Penetrations
K. Poor Mortar Joints, Porous Masonry Block
L. Poor Seal at Sidewall, Filler Panel, etc.
M. Back-to-Back Cabinets, Poor Workmanship
N. Holes, Gaps at Wall Penetrations
O. Poor Seal at Floor Edges
P. Back-to-Back Electrical Outlets
Q. Holes, Gaps at Floor Penetrations
R. Back-to-Back Phone/Data Outlets

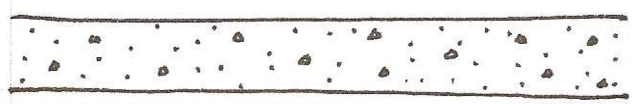
Floor Path Flanking

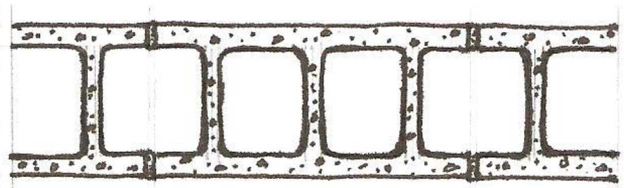


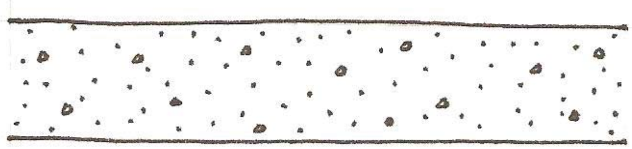
REFERENCE: J.D.Quirt and T.R.T. Nightingale, “Airborne Sound Insulation in Multifamily Buildings”, National Research Council Canada Construction Technology Update No. 66 March 2008.

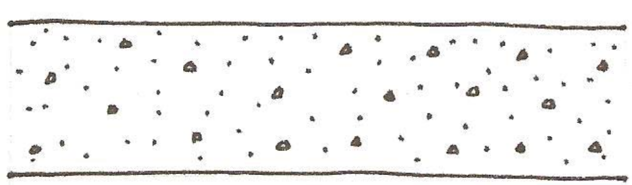
Concrete
Sound Transmission Loss

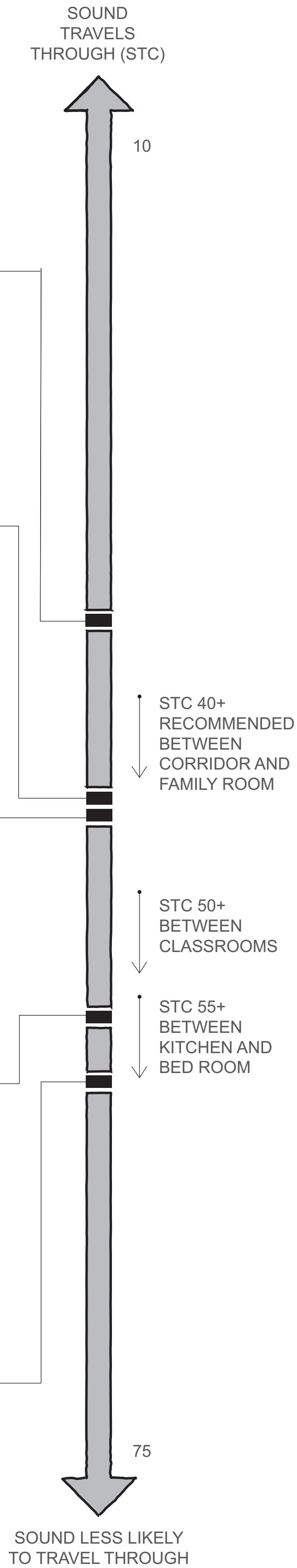
	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
4 x 8 x 16” Solid lightweight Conc. block (23 lbs/block) (100x200x400mm)	24	26	30	35	43	51	35
4” thick (100mm) Flat concrete panel (54 psf)	48	42	45	55	57	67	44
8 x 8 x 16” 3-cell lightweight Conc. Block (28 lbs/block) (200x200x400mm)	33	37	41	45	51	55	45
6” thick (150mm) Flat concrete panel (75 psf)	40	43	51	59	67	72	55
8” thick (200mm) (95 psf)	44	49	55	58	64	67	58











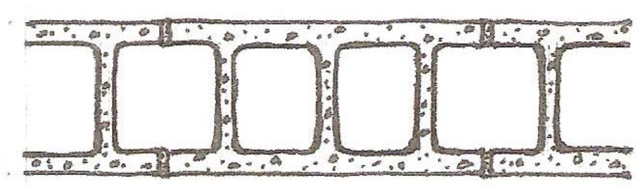
ROBUST LOW FREQUENCY VALUES - USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

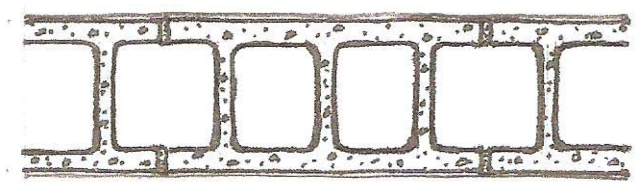
WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

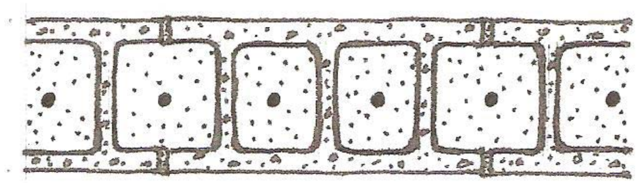
Concrete Masonry Units

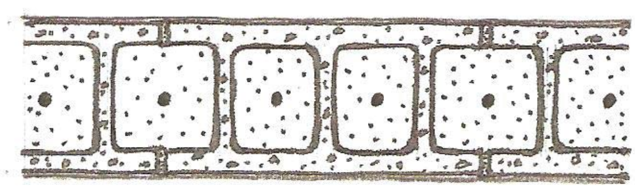
Sound Transmission Loss

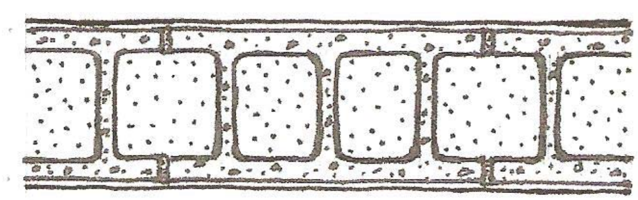
	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
8 x 8 x 16" (200x200x400mm) 3-cell lightweight Concr. block (28 lbs per block)	33	37	41	45	51	55	45
With paint	40	38	41	47	54	58	46
With grout in cells (33 lbs per block)	34	38	43	53	63	72	48
With grout and paint each side	37	43	52	60	69	75	55
With grout and 1/2" (13mm) plaster, both sides	40	45	54	61	70	77	56

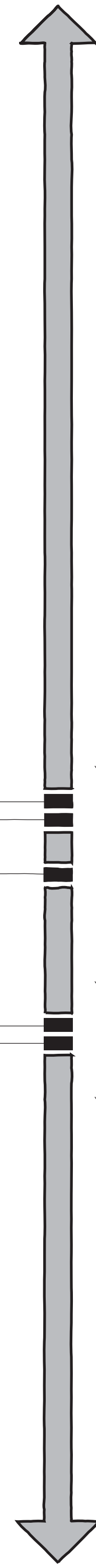








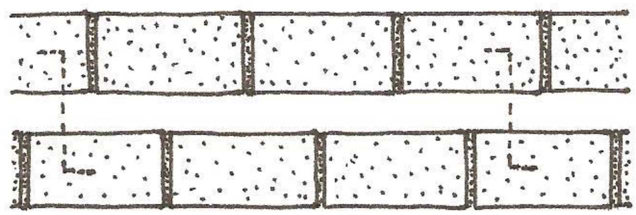


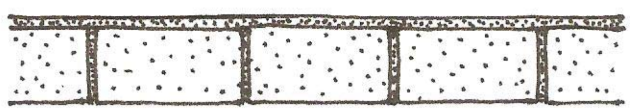


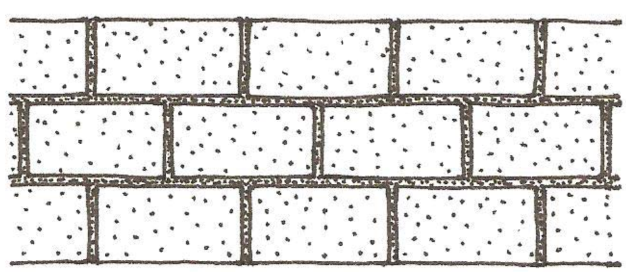
Brick

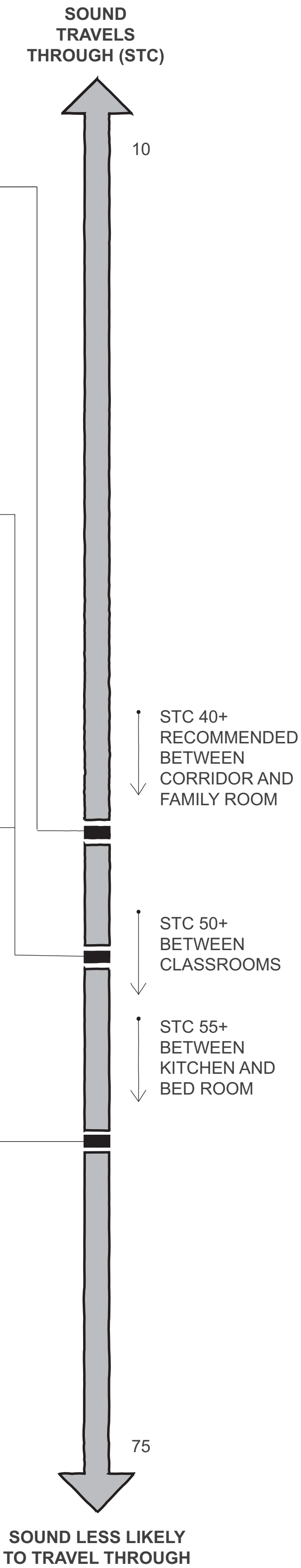
Sound Transmission Loss

	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
4” brick (100mm) Mortared	32	34	40	47	55	60	45
With 2” air space (50mm) Metal ties Another wythe	36	37	47	55	62	66	50
1/2” plaster (13mm) On brick	38	40	46	52	56	60	50
3 layers brick Mortared	44	48	55	61	66	68	59







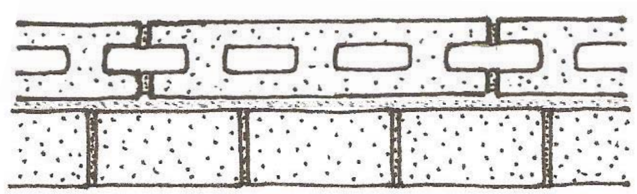


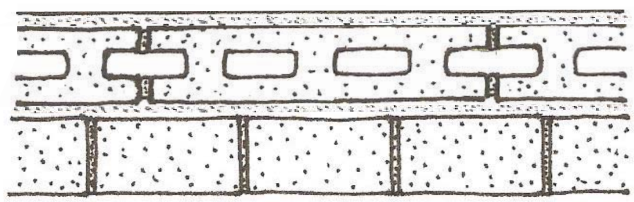
ROBUST LOW FREQUENCY VALUES - USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

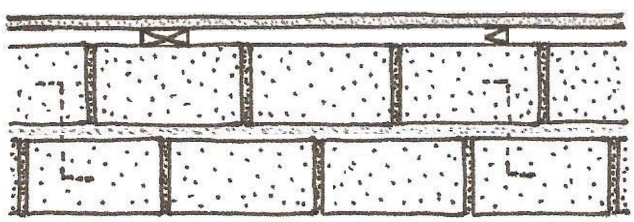
WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

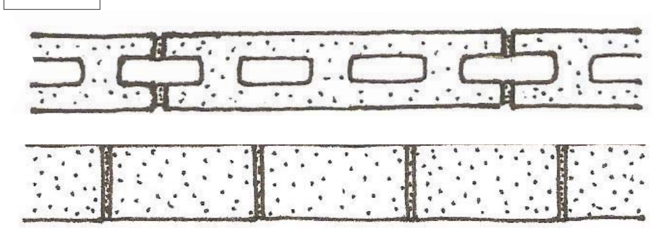
Brick and CMU

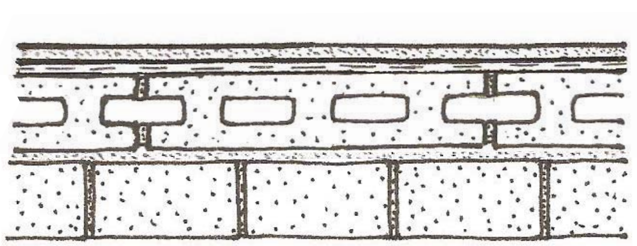
Assembly	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
4x8x18 3-cell (100x200x450mm) lightwt concrete blk (19 lbs/block) Common brick mortared together	36	40	46	54	62	68	51
With 1/2” plaster (12mm)	37	42	50	55	63	70	53
1/2” gypsum board (12mm) furring strips 2 wythes brick	37	41	56	63	70	70	53
Concrete block 2” air cavity (50mm) Brick	39	43	50	58	71	75	54
1/2” gypsum board Resilient mounting Concrete Block Brick	38	46	53	60	70	74	56



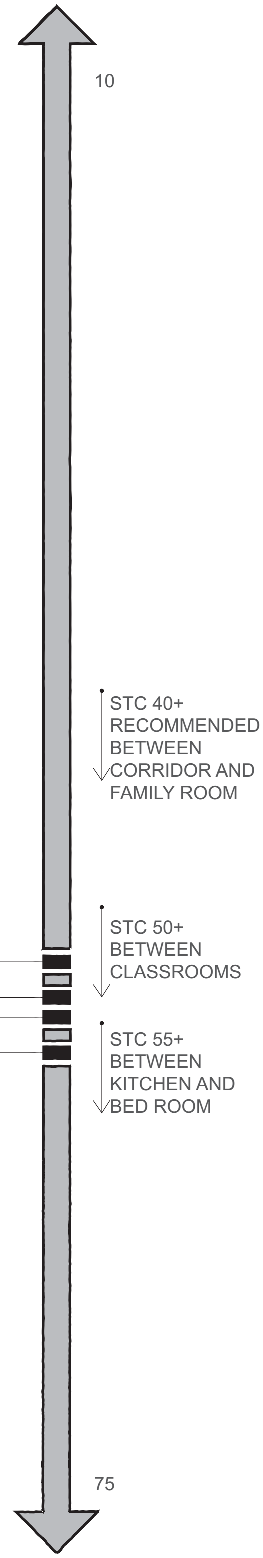








SOUND TRAVELS THROUGH (STC)



SOUND LESS LIKELY TO TRAVEL THROUGH

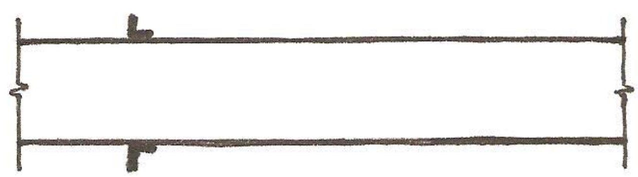
ROBUST LOW FREQUENCY VALUES - USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

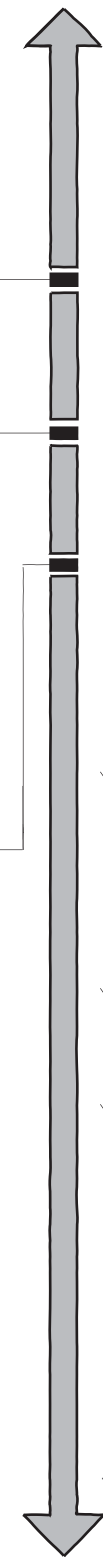
WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

Metal

Sound Transmission Loss

	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
26 gauge sheet metal (1.5 psf)	14	18	22	20	21	26	22
22 gauge galvanized steel	15	18	24	29	34	37	28
With 5.5” space (140mm) and another layer	17	24	31	38	52	61	34

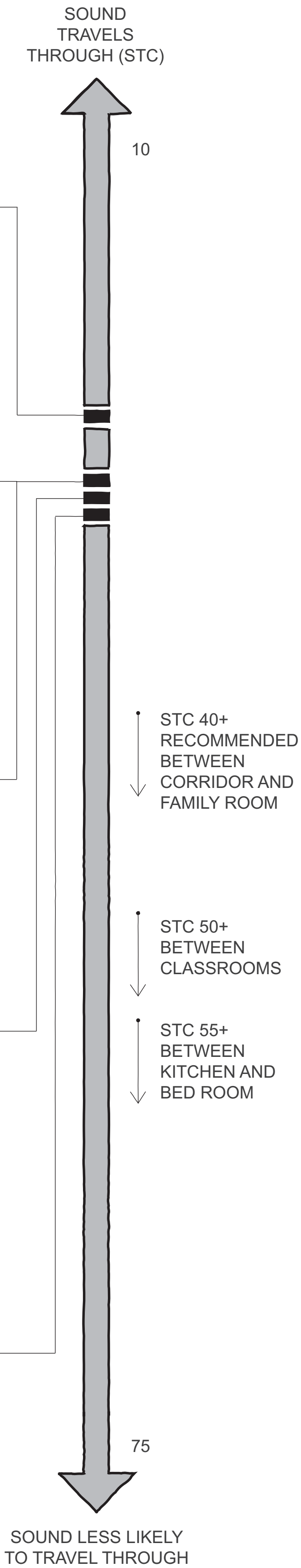




Gypsum Board

Sound Transmission Loss

	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
3/8” gypsum board (10mm)	14	18	23	28	32	25	26
1/2” gypsum board (13mm)	17	20	25	31	31	26	28
3/16” plywood (5mm) laminated to 1/2” gypsum board (13mm)	16	20	25	29	32	31	28
5/8” gypsum board (16mm)	18	22	27	31	29	30	29
sheet lead (1psf) laminated to 1/2” gypsum board (12mm)	19	21	26	31	33	33	30



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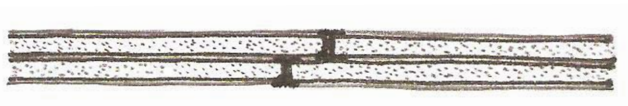
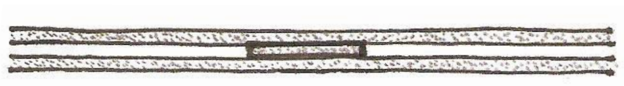
WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

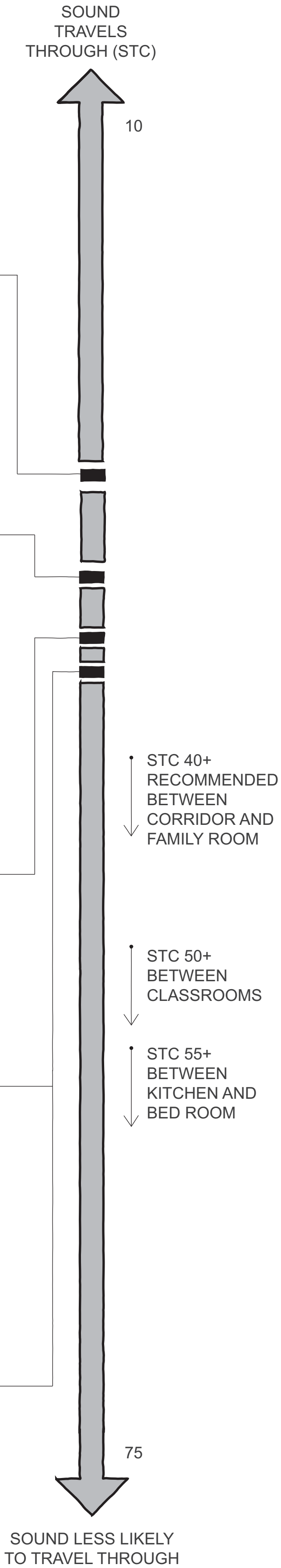
Gypsum Board

Sound Transmission Loss

	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
3/8” gypsum board (10mm)	14	18	23	28	32	25	26
1/2” gypsum board (13mm) laminated to 1/2” gypsum board	22	26	30	31	29	36	31
Two 1” thick (25mm) gypsum bd panels	25	29	32	33	36	42	34
5/8” gypsum bd (16mm) laminated to 5/8“ ribs 5/8” gypsum board	21	27	36	39	36	39	36
5/8” gypsum bd (16mm) 1” gypsum bd (25mm) 5/8” gypsum board	28	31	35	35	37	42	36



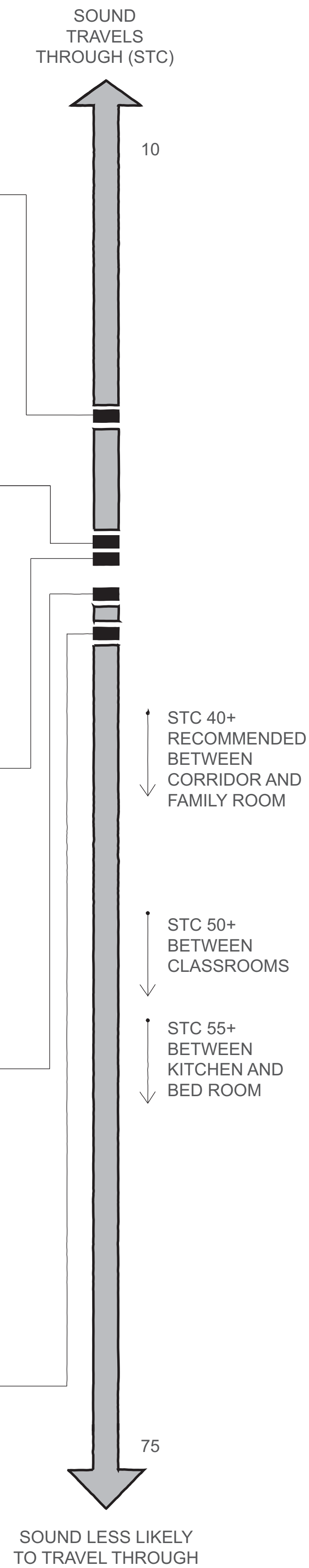




Gypsum Board

Sound Transmission Loss

	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
3/8" gypsum board (10mm)	14	18	23	28	32	25	26
1/2" gypsum bd (13mm) no studs 1 1/2" air space (40mm) 1/2" gypsum board	15	23	30	37	36	38	32
With 3 5/8" air space (90mm)	16	22	30	43	47	41	33
With 1 psf sheet lead laminated to one side	20	22	32	42	46	45	35
With second 1/2" gypsum board (13mm) laminated instead of lead	20	26	34	44	47	49	37



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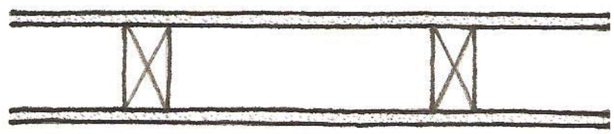
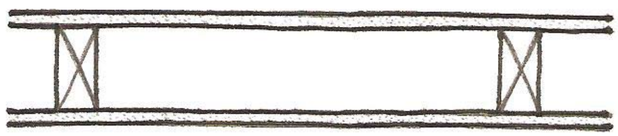
WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

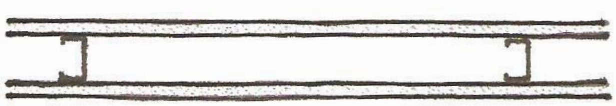
Stud Walls

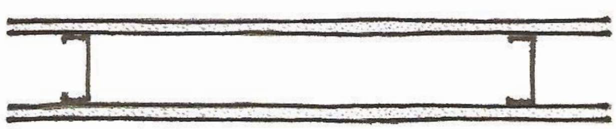
Sound Transmission Loss

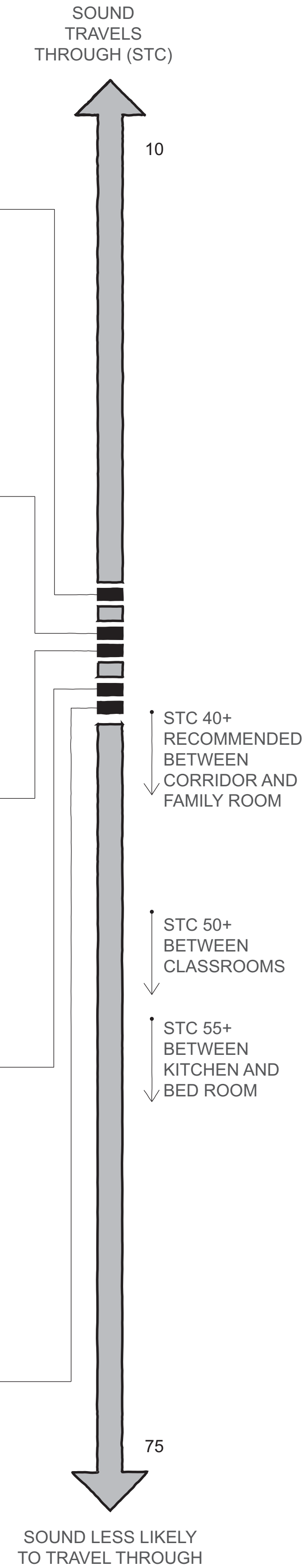
Wall	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
5/8” gypsum bd (16mm) 2x4 wood studs (38x89mm) 16” o. c. (400mm) 5/8” gypsum bd	15	24	32	40	38	41	34
With studs 24” o. c. (600mm)	23	27	33	41	37	40	36
With 1 1/2” (40mm) metal studs 24” o. c. (600mm)	17	30	43	49	37	46	37
With 2 5/8” metal studs (65mm)	23	33	42	50	39	41	39
With 3 5/8” metal studs (90mm)	20	35	44	51	39	44	40









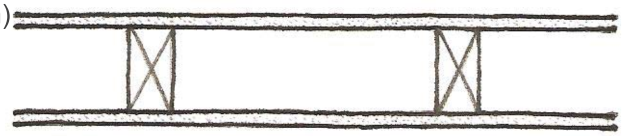


Stud Walls

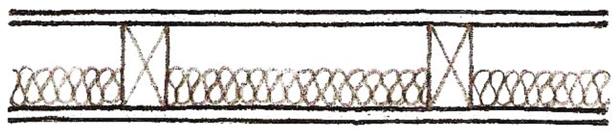
Sound Transmission Loss

Wall assembly	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
5/8” gypsum bd (16mm), 2x4 wood studs (38x89mm), 16” o. c. (400mm), 5/8” gypsum bd	15	24	32	40	38	41	34
With 2“ batt insulation (50mm)	17	31	36	43	40	43	38
With wood studs 24” on center (600mm)	30	35	37	42	38	42	39
With 3 5/8” metal studs (90mm), 1 1/2” insulation (40mm)	27	39	45	51	43	43	41
With 2” insulation (50mm)	30	40	45	53	48	48	47

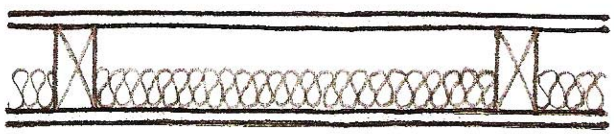
5/8” gypsum bd (16mm)
2x4 wood studs
(38x89mm)
16” o. c. (400mm)
5/8” gypsum bd



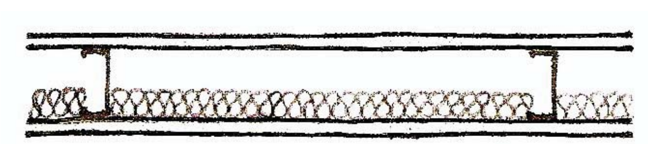
With 2“ batt
insulation (50mm)



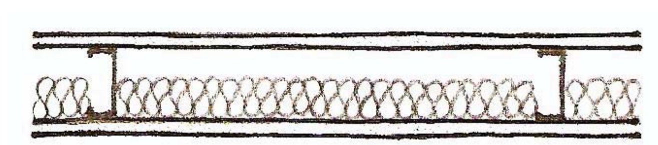
With wood studs
24” on center
(600mm)

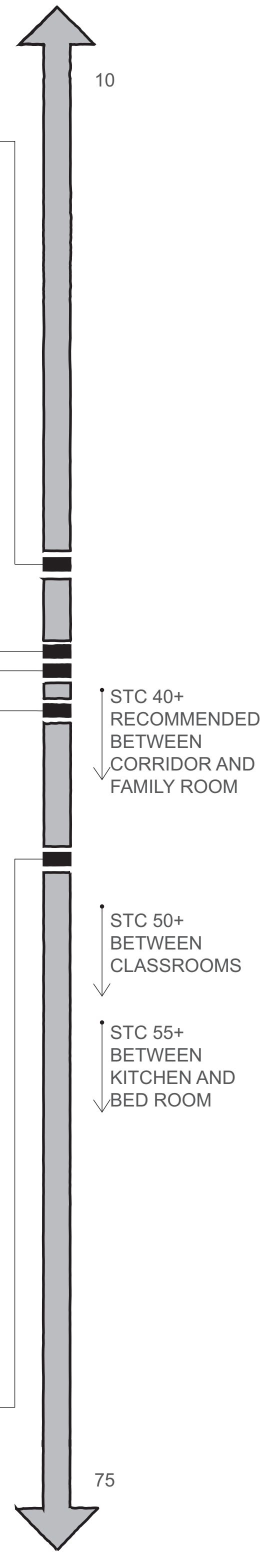


With 3 5/8” metal
studs (90mm)
1 1/2” insulation
(40mm)



With 2” insulation
(50mm)





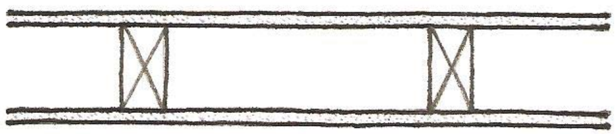
ROBUST LOW FREQUENCY VALUES - USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

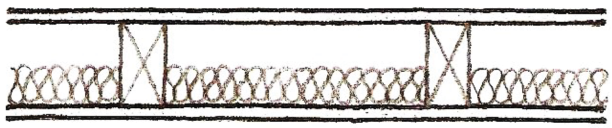
WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

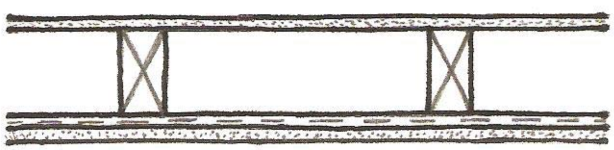
Stud Walls

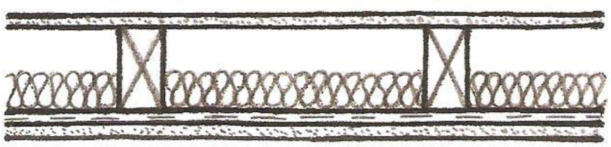
Sound Transmission Loss

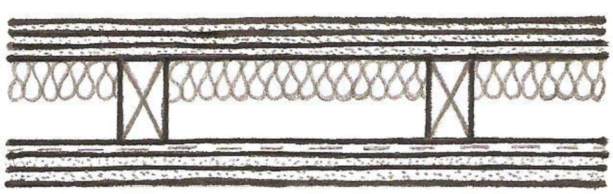
Wall	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
5/8” gypsum bd (16mm) 2x4 studs (38x89mm) 16“ on center (400mm) 5/8” gypsum bd	15	24	32	40	38	41	34
With 2” thick sound attenuation blanket	17	31	36	43	40	43	38
Without insulation One side of gypsum wall mounted on resilient channel	18	28	37	47	43	47	38
With 2” thick sound attenuation blanket and one side mounted on resilient channel	28	38	49	54	49	53	48
One side with three layers gypsum board The other side with two layers mounted on resilient channel	39	53	61	63	65	65	61

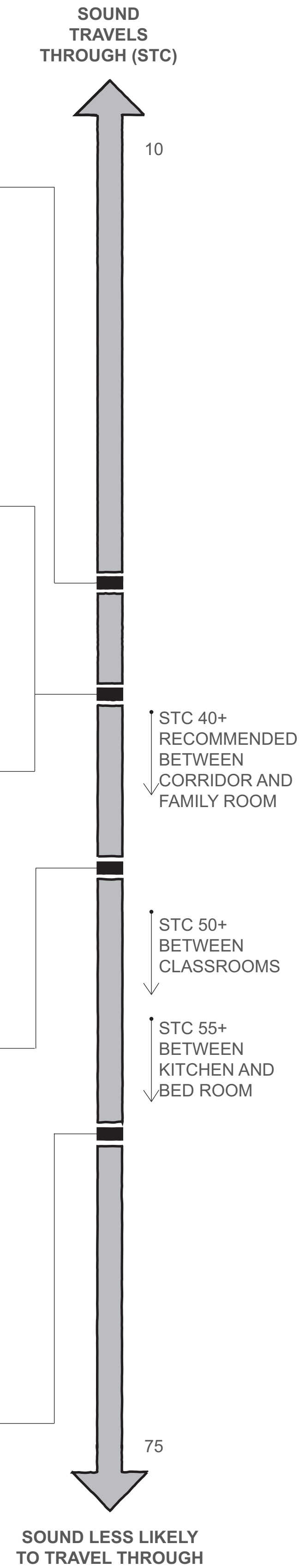








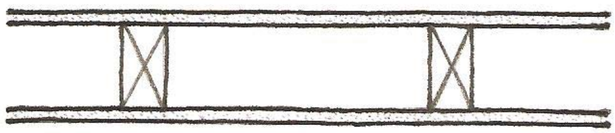


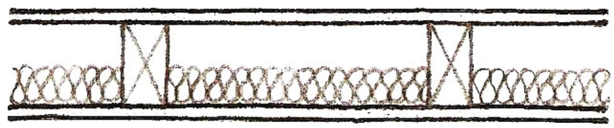


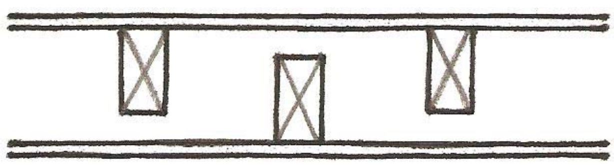
Stud Walls

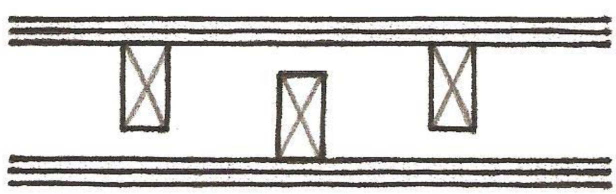
Sound Transmission Loss

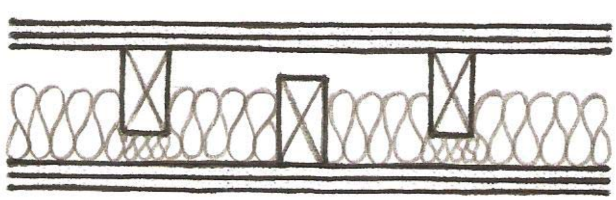
Wall	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
5/8” gypsum bd (16mm) 2x4 studs (38x89mm) 16“ on center (400mm) 5/8” gypsum bd	15	24	32	40	38	41	34
With 2” thick sound attenuation blanket	17	31	36	43	40	43	38
With staggered studs 2x4 studs, spaced 16” o. c. and staggered 8” o. c. on 2x6 plates	29	36	44	47	44	48	43
With 2 layers of gypsum board each side	33	41	49	55	53	57	51
With 2” thick sound attenuation blanket	37	46	51	55	54	55	53

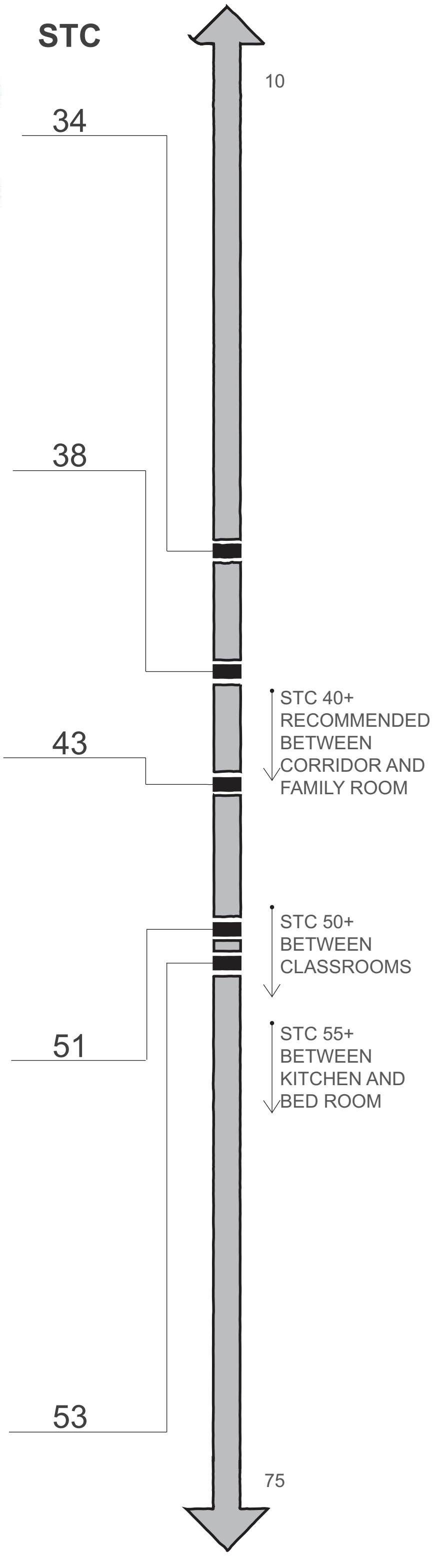










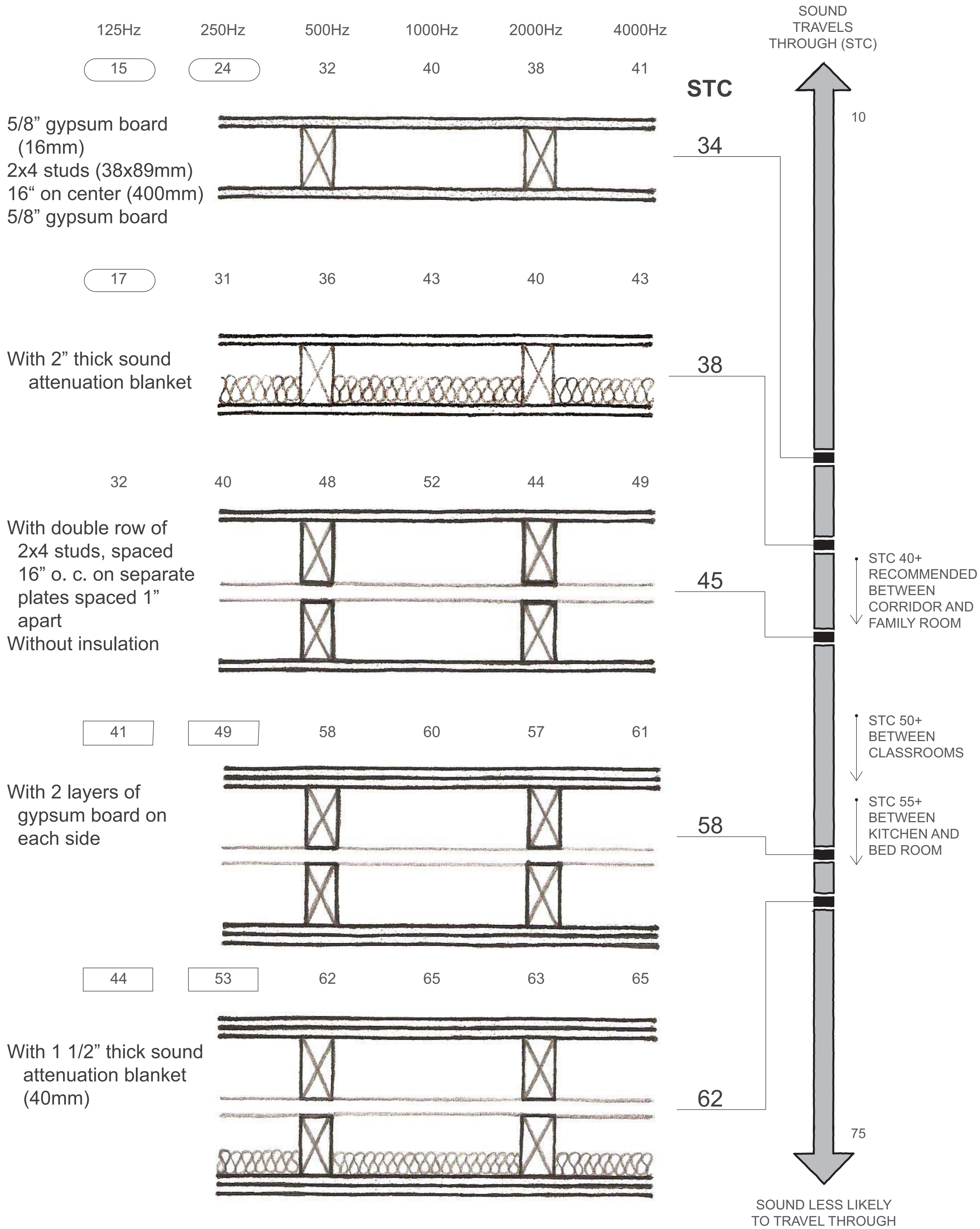


ROBUST LOW FREQUENCY VALUES - USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE (values in rectangular boxes)

WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE (values in rounded boxes)

Stud Walls

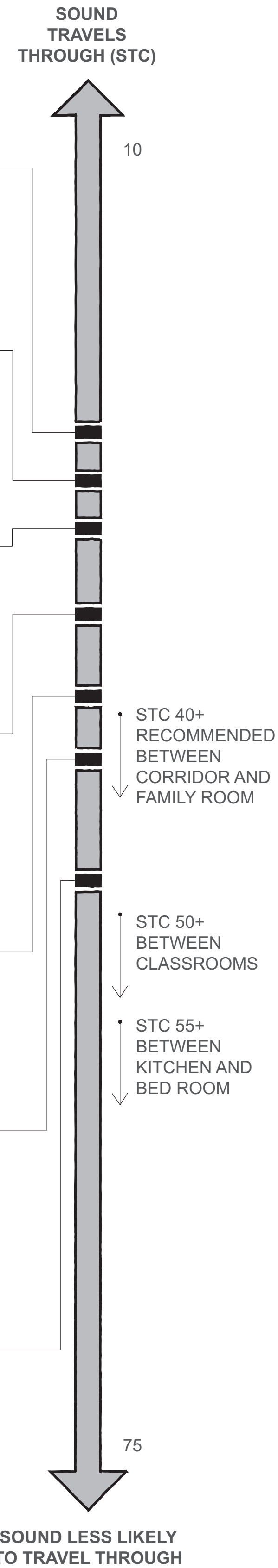
Sound Transmission Loss



Glass

Sound Transmission Loss

	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
1/8” monolithic float glass (3mm) (1.4 lb / sq. ft.)	18	21	26	31	33	22	26
1/2” insulated glass (13mm): 1/8” + 1/8” double glass With 1/4” air space	21	26	24	33	44	34	28
1/4” monolithic float glass (6mm) (2.9 lb / sq. ft.)	25	28	31	34	30	37	31
Double glass: 1/4” laminated + 3/16” monolithic glass With 2” air space (50mm)	25	28	32	35	36	43	35
1/4” + 1/8” double glass With 2” air space	18	31	35	42	44	44	39
Double glass: 1/4” laminated + 1/4” laminated With 1/2” air space	21	30	40	44	46	57	42
Double glass: 1/4” laminated + 3/16” monolithic glass With 4” air space (5.9 lb / sq. ft.)	36	37	48	51	50	58	48



TO MAINTAIN ADEQUATE SOUND ISOLATION, ENSURE THAT WINDOWS AND DOORS HAVE STC VALUES NO LOWER THAN 5 POINTS BELOW THE WALL

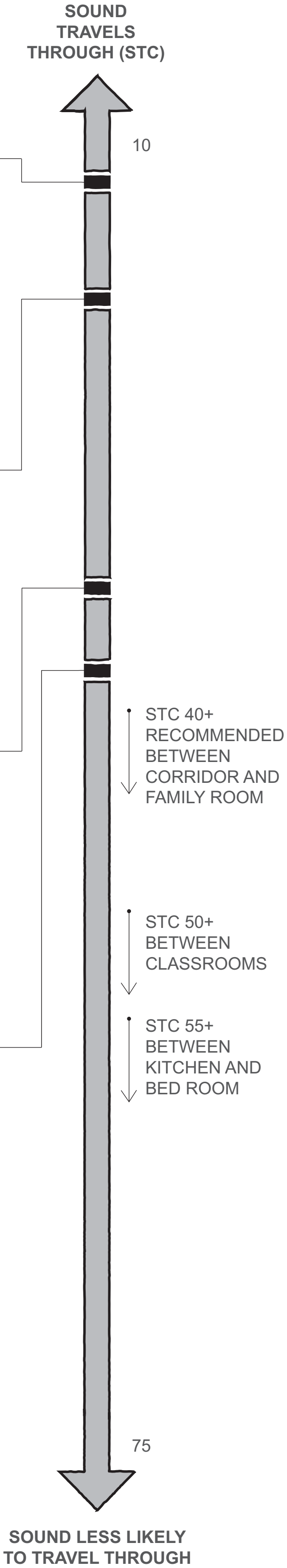
ROBUST LOW FREQUENCY VALUES - USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

WEAK LOW FREQUENCY VALUES - NOT USEFUL FOR TRANSP. NOISE, AMPLIFIED MUSIC, AND MECHANICAL NOISE

Doors

Sound Transmission Loss

	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	STC
Louvered door, 25 to 30% open	10	12	12	12	12	11	12
1 3/4" hollow-core (45mm) wood door, no gaskets, 1/4" air gap at sill (6mm) (1.5 lb / sq. ft.)	14	19	23	18	17	21	19
With gaskets, and drop seal	29	31	31	31	39	43	34
1 3/4 hollow-core 16 gauge steel door, glass fiber filled with gaskets, and drop seal (7 lb / sq. ft.)	23	28	36	41	39	44	38



TO MAINTAIN ADEQUATE SOUND ISOLATION, ENSURE THAT WINDOWS AND DOORS HAVE STC VALUES NO LOWER THAN 5 POINTS BELOW THE WALL

COMMUNITY NOISE

Annoyance. Excessive community noise is annoying—indeed, it may be dangerous. The US census puts the proportion of Americans complaining of street noise at one in four. Noise ranks above crime, litter, and the other neighborhood problems surveyed as the greatest single source of dissatisfaction related to where people live. Studies have linked environmental noise with impairment of reading comprehension and memory, and increased risk of heart attack, hypertension and high blood pressure.

Sources. Noise sources include

1. Predictable noise that you can account for: vehicles, trains, aircraft, night clubs (especially those with outdoor amplified music), amphitheaters, dog kennels, firing ranges, auto raceways, industrial activities, noisy motor sports (boats, ATVs, snowmobiles), and fixed emergency sirens.

2. Predictable noises over which you may have control: A building's outdoor fans, air conditioners, compressors, pumps, cooling towers, refrigeration equipment, garage door openers, dumpsters, noisy fitness activities (playgrounds, basketball courts), and areas with frequent loudspeaker use.

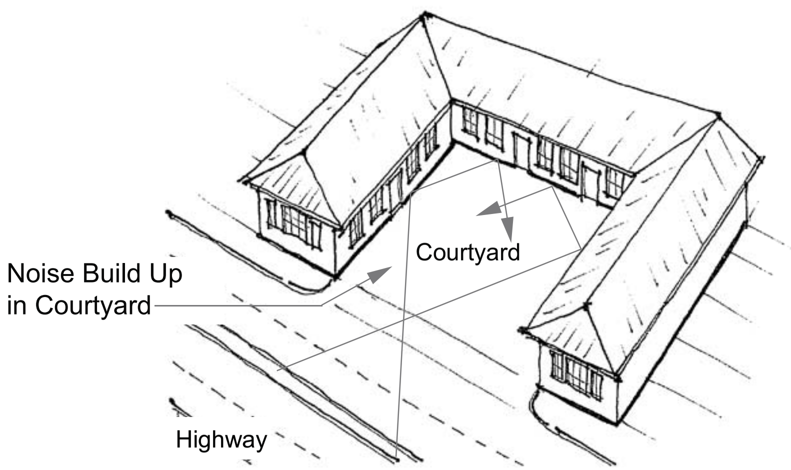
Community Noise

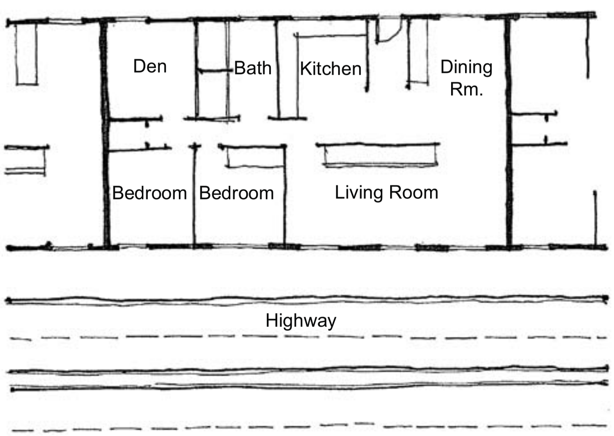
3. Occasional noises over which you likely have little control or recourse and are likely not accounted for in design: motorcycles and cars with intentionally altered mufflers, emergency vehicle sirens, power lawn equipment, construction equipment, parties with amplified music, loud outdoor conversations, and bird/insect noise.

It's the windows and doors, not the walls. Keeping sound out is like keeping water out; effectiveness is governed by the weakest region of the building envelope. If a wall with a Sound Transmission Class (STC) of 45 contains windows with an STC rating of 26 covering 30% of the wall area, the composite STC of the partition will be 31. Because of this, windows and doors—not solid walls—are almost always the path of choice for community noise. This cannot be stressed enough, especially since residential construction generally includes operable windows which may be left opened, and a wall with open windows provides little in the way of a meaningful barrier against exterior noise. Maintaining a noise-tight barrier typically means careful selection and *orientation* of appropriate windows and doors.

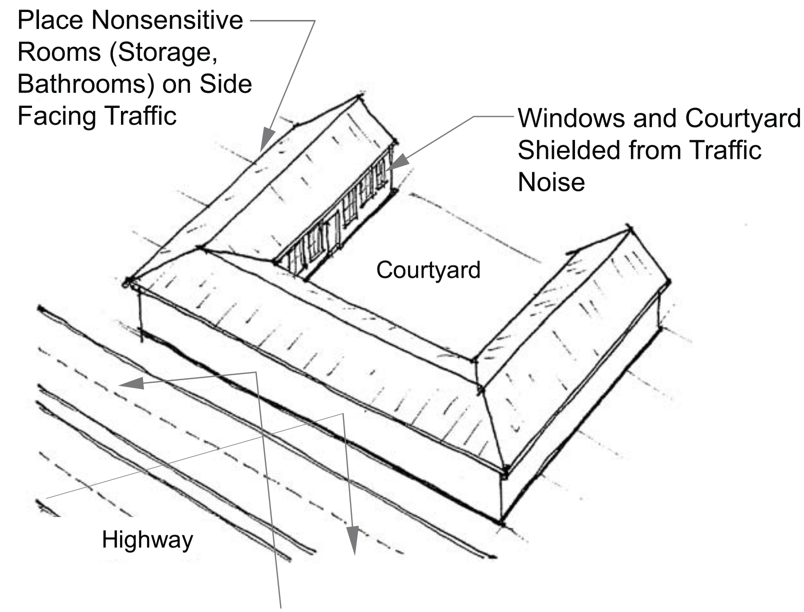
Planning for Community Noise

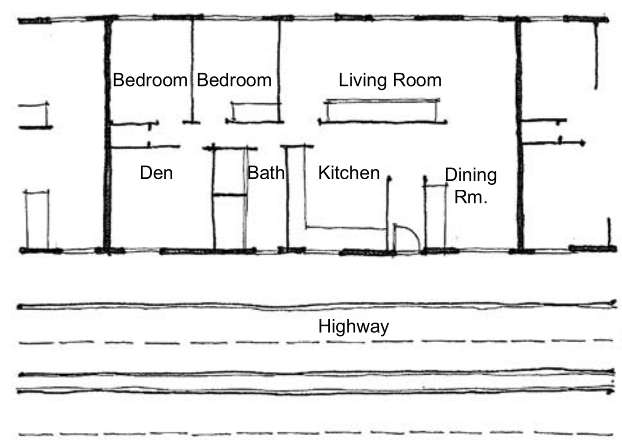
Poor





Better





Community Noise

Distance. Because in residential construction, occupant satisfaction may rest on the open-window condition, it is imperative to build far from noise sources. Recognize that some sites in close proximity to noise will not provide acceptable levels of occupant satisfaction independent of noise ordinances, land zoning practices, or building envelope design. Barriers generally have limited effectiveness in bringing noise down to appropriate levels.

Community Noise Checklist

Site

1. Recognize that on some sites it is too noisy to build housing, even if it is permissible under noise zoning.

2. Consider occupant expectations. Rural residents are likely to have a lower threshold for community noise than downtown residents. Of course, at some sound levels, there is too much noise for the occupant regardless of expectations.

3. Know that noise ordinances and noise zoning policies are blunt instruments. Some are effective, objective, or common-sense oriented, but few are all three. They may change for a given neighborhood during the life of the building.

4. When possible, don't locate housing within 1500 feet (500 meters) of a train track or highway. Locations near airports should be handled on a case-by-case basis with the help of an acoustical consultant.

5. Beware of sites with statistically "acceptable" noise levels, but periodic loud noises, separated in time

by quiet. Intermittent noises are more annoying than continuous ones, so if a loud noise source arrives regularly, it is often the maximum level that governs occupant satisfaction. Sites with regular spikes in noise levels, such as those near airports, train lines, firing ranges, and night clubs can have relatively low *average* noise levels that aren't representative of the true subjective response to the site noise. An effective approach involves analyzing *both* average *and* maximum noise levels.

6. Know that what is now a quiet site might not be in some years. While it is difficult to predict the path of a future expressway or industrial plant, ask around: There may be, for instance, plans to build an outdoor animal shelter nearby.

7. Check zoning ordinances. Areas that are primarily residential may not be listed as residential noise zones; areas that were once residential may be rezoned to encourage industrial development or thoroughfare construction.

Community Noise

Checklist

Design

8. Remember that trees and other vegetation are ineffective noise barriers unless the vegetated strip is greater than 100 feet (30 meters) wide.

1. Position out-buildings, such as grounds equipment storage buildings, parking garages, and maintenance facilities as buffers to noise. Arrange them so they block the direct-line-of-site from windows to the noise source. Parks and parking lots can be positioned to increase the distance between a noise source and a residence.

2. Orient quiet spaces, such as bedrooms, so their wall exposure is on a building face away from the noise source. Noisier spaces such as kitchens, bathrooms, and utility spaces can be located on the nosier face.

3. Locate exterior doors on the quieter side of a building. Specify outside doors with gaskets and drop-seals. Avoid the use of mail slots, pet doors, or similar openings.

4. Thick window panes outperform thin ones; double pane windows typically outperform single pane windows; windows with larger spacing between each pane outperform those with smaller spacing (for this reason, interior and/or exterior storm windows are effective). Of course, any increased window performance evaporates when the window is opened by the occupant.

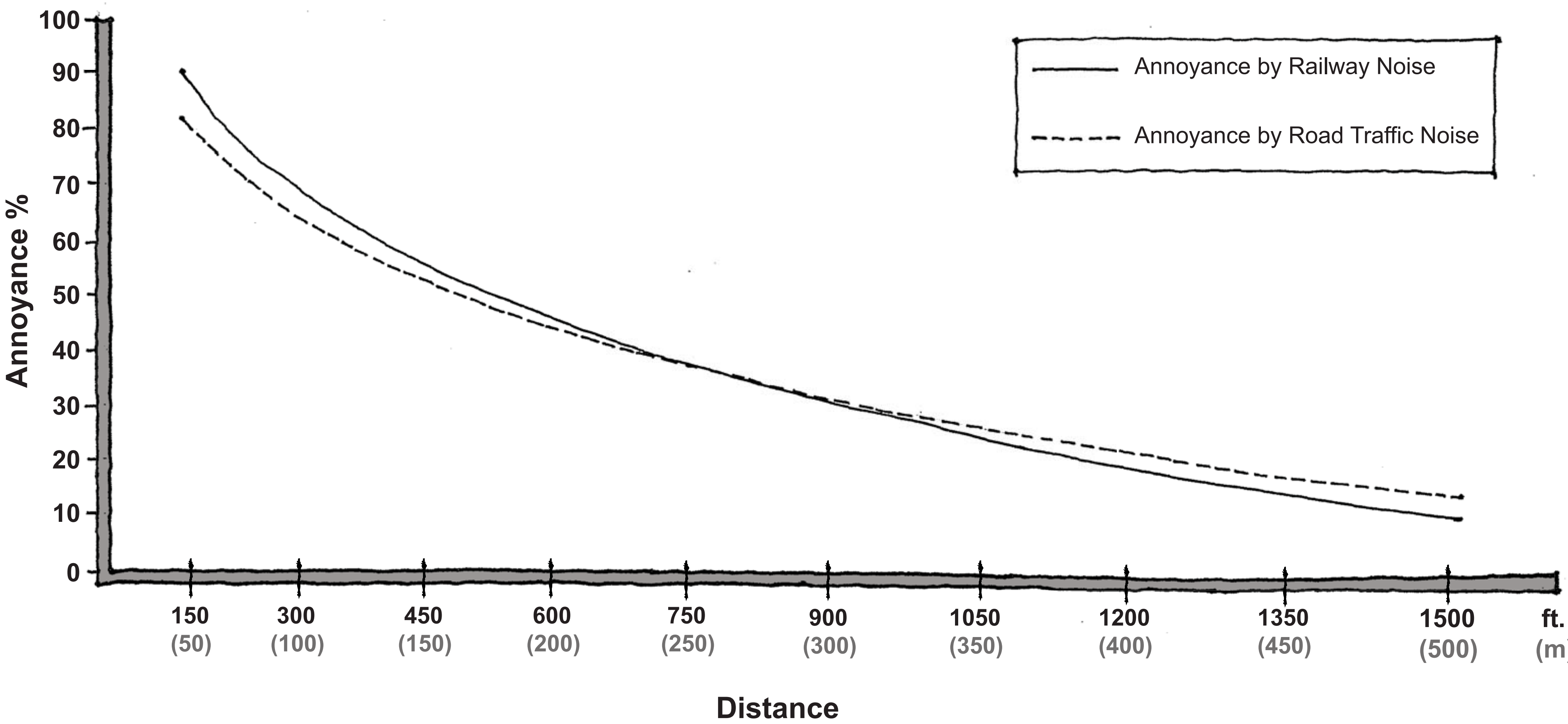
5. Keep noisy exterior building equipment such as fans, air conditioning compressors, cooling towers, pumps, generators, electrical transformers, and dumpsters (whose lids slam shut) out of direct-line-of-site from—and far from—windows. Noise from air-cooled outdoor condenser-compressors in split-system air conditioning systems is a particularly common problem.

6. Design outdoor mechanical systems so that they are far from neighbors' bedroom windows and outdoor gathering spaces. Normative condenser-compressor installations often don't meet noise

ordinance requirements, enforcement of which is typically measured at the boundary of the two lots.

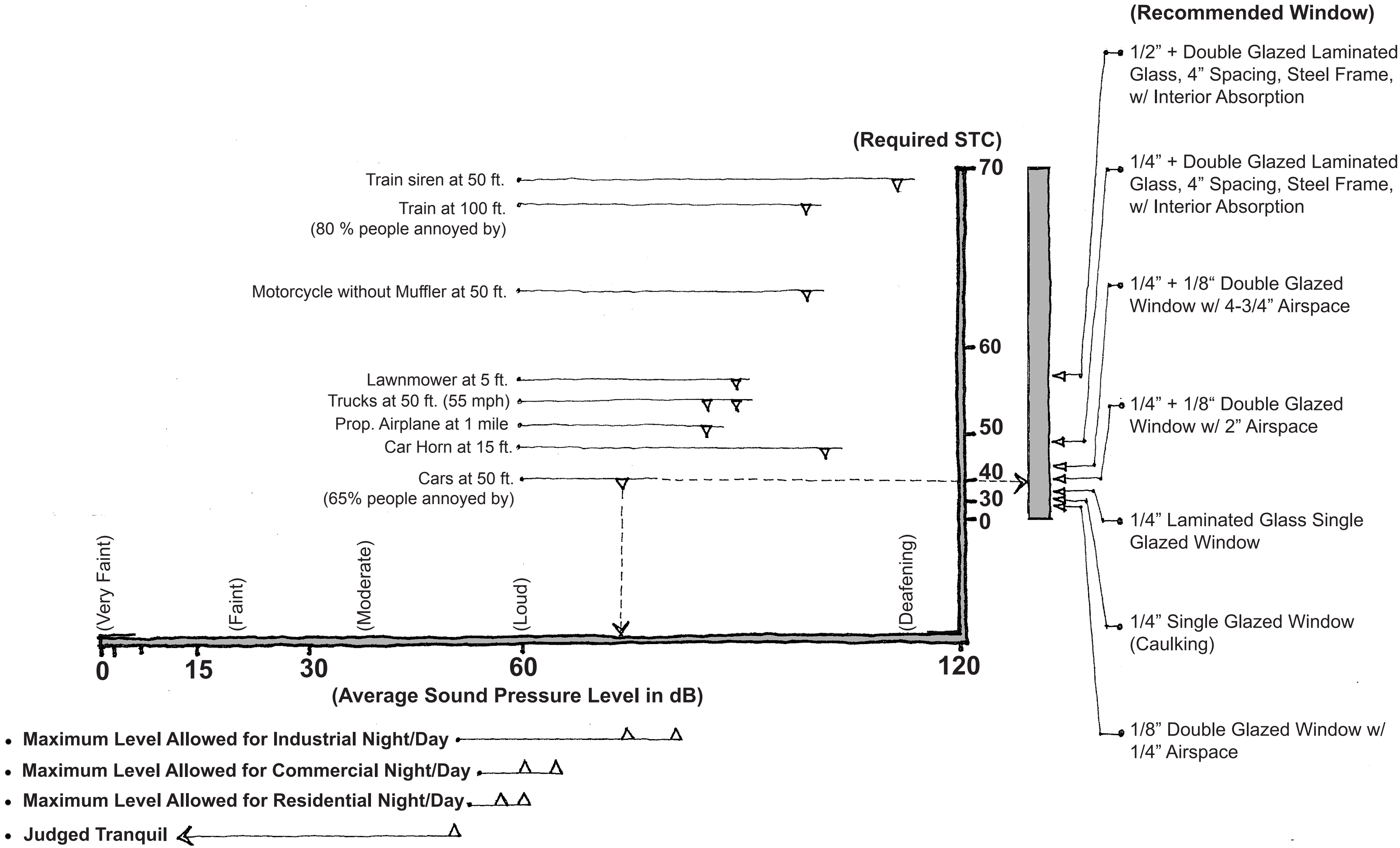
7. Low-energy mechanical systems can be low-noise system. Often efficient equipment is also quieter. Passive thermal design can reduce the size of (or need for) outdoor mechanical equipment. Ground-source-coupled “geo-thermal” heat pumps have no noisy outdoor equipment (though they may pose an indoor noise threat if located near occupied spaces).

Percentage of People Annoyed vs. Distance from Road and Rail Lines



REFERENCE: Öhrström, E, Barregard, L, Andersson, E, Skanberg, A, Svensson, H, Angerheim, P, "Annoyance due to single and combined sound exposure from railway and road noise," J Acoustical Society of America, Vol 122, 2642-2652.

Recommended Window STC



Typical Ordinances for US Cities

Note: To use chart, choose the loudest noise source present in your community and then draw a horizontal line to find the type of window required to avoid annoyance from it. By drawing a vertical line from the same starting point, you can find where your site stands in relation to city ordinances. In the example above, the site is 50 ft. from a street. Start with “Cars at 50 ft.” and draw a horizontal line. The user can choose a “1/4” + 1/8” Double Glazed with 2” airspace” window. The user’s site is quieter than most zoning allows for industrial areas but noisier than commercial or residential zones

MECHANICAL EQUIPMENT NOISE

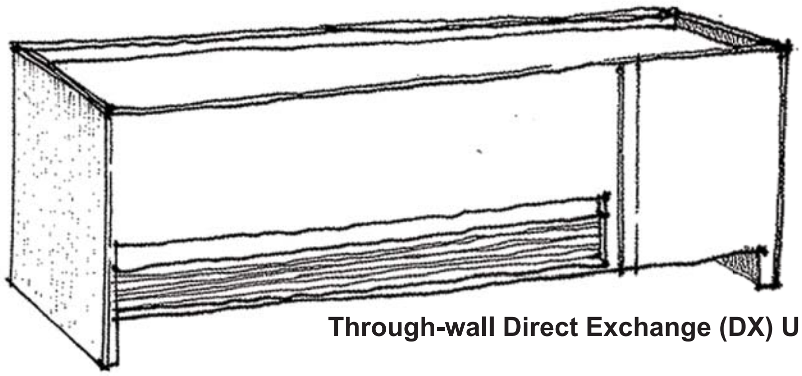
Sources. Mechanical equipment systems transmit both airborne and structure-borne (vibration) sound. Common sources in multi-family residences include fans, chillers, motors, pumps, generators, compressors, electrical transformers, swimming pool equipment, duct air turbulence, whistling across duct outlet registers, creaking associated with expanding heating elements, dishwashers, clothes washers, dryers, garbage disposals, trash shoots, elevator equipment, and garage door openers.

Location. Location. Location. Likely the most important concept in quiet mechanical system design is maintaining distances (as long as feasible) between noisy equipment and quiet living spaces. While this would seem obvious, it is often not carried out in practice, likely because (1) it is not given sufficient attention in early stages of design, (2) locating mechanical equipment, particularly air handling units, in close proximity to the spaces they serve minimizes construction costs associated with conditioned air distribution, and (3) in multifamily housing, the perception of metering limitations inherent to central systems make the use of in-dwelling distributed systems more palatable. Yet airborne noise generated in mechanical rooms can best be mitigated with long distances and buffer rooms (storage, janitorial, trash) between the noisy and quiet spaces; structure borne noise can best be mitigated by long distances and building control joints between the vibrating equipment and the quiet spaces; and air handler noise can best be mitigated by long duct runs between the fan and quiet spaces.

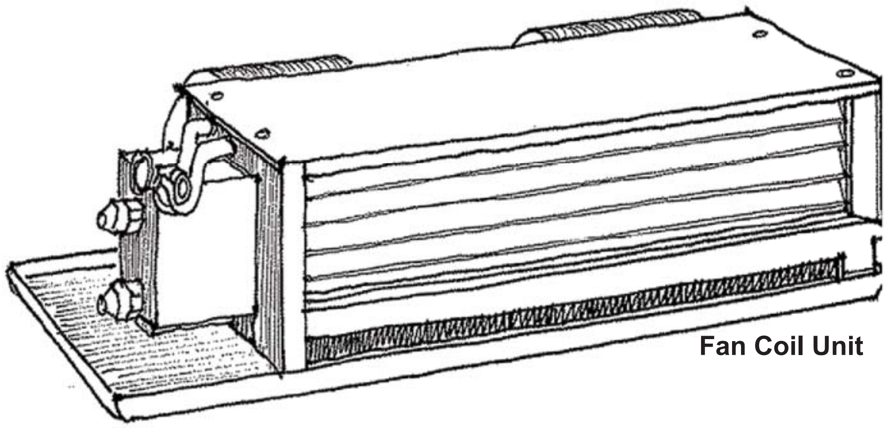
Central systems. While it often the case in multifamily residential buildings that mechanical systems, particularly air handling units, are located within the dwelling itself, designers should be aware that this is almost always a noisier solution than provided by centralized systems.

Ducted returns too. When air handling units are located in individual dwelling units, they should have ducted supply *and* return air networks. Their doors should open to a space that is not acoustically sensitive, like a storage room. Outfitting mechanical closets with slotted doors to avoid the need to run return air ducts is often the source of occupant complaints, especially if the mechanical closet door faces a living space.

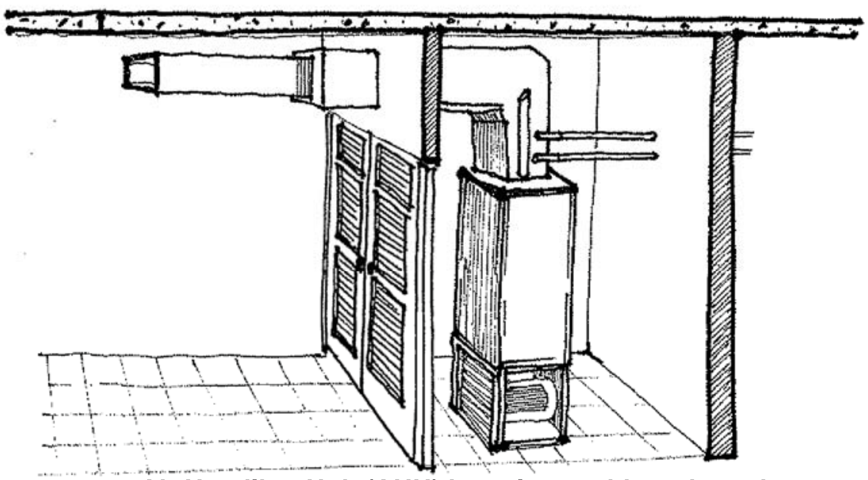
Mechanical System Types



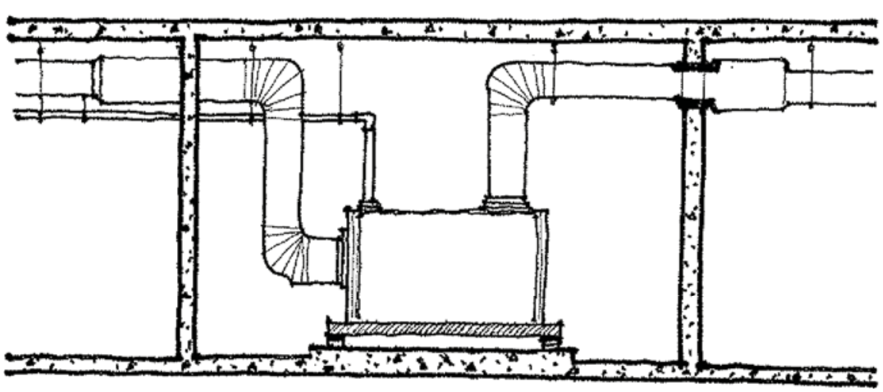
Through-wall Direct Exchange (DX) Unit



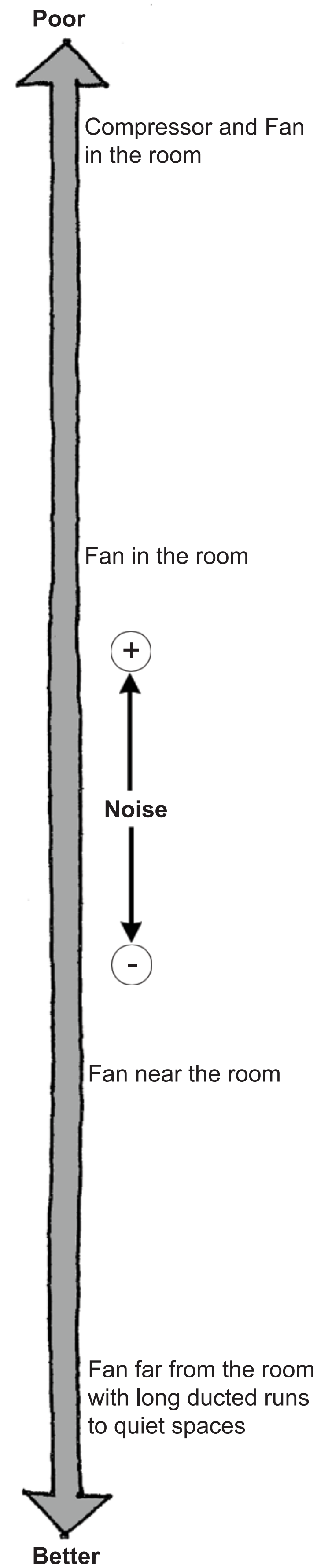
Fan Coil Unit



Air Handling Unit (AHU) in a closet with unducted return



Remote Ducted Air Handling Unit (AHU)



REFERENCE: GS Siebein, et al, “Ten ways to provide a high quality acoustical environment in schools,” *Language Speech, and Hearing Services in Schools*, Oct 2000, 382. NC levels were measured in classrooms.

Mechanical System Noise Checklist

Early Design

1. Locate mechanical equipment far from quiet spaces such as bedrooms or living rooms.

2. Design buffer zones—rooms with little need for quiet—between rooms housing mechanical equipment and quiet rooms.

3. Recognize that noise moves in plan *and* section. Noisy sources directly below or above quiet spaces can pose problems too. This is magnified when vibrating equipment, like a clothes washer, is located above a quiet space, such as a living room.

4. Design for long duct runs—supply and return. They are often the best defense against mechanical system noise.

5. Know that central systems are generally quieter than distributed systems; remote chillers (far from occupants) are generally quieter than individual split system air conditioners; hydronic systems (without fans) are almost always quieter than forced air systems. This can include chilled beam technology.

Mechanical Noise

Checklist

Early Design

6. Specify quiet equipment; some equipment is noisier than other equipment. Some air handling units are much quieter than others of the same size; some dishwashers can barely be heard, even when standing next to them. Establish lists of multiple products from different manufacturers that meet required performance criteria and then consult with a qualified professional to determine the quietest ones to use.

7. Avoid rooftop mechanical systems as they often cause noise problems, especially for top-floor residents.

8. Mechanical room doors should open to rooms with little need for quiet. Mechanical room walls should be massive—and airtight around duct, pipe, and other penetrations.

9. Locate vibrating equipment (such as air handling units, pumps, chillers, generators, fans, compactors, compressors, and elevator equipment

rooms) on grade where possible. When equipment must be located on higher floors, it should be located above a structural support (rather than at a floor's midspan).

Air distribution System

1. Allow for mechanical rooms of adequate size. Mechanical rooms that are too small often precipitate smaller ducts, more duct turns, smaller equipment, and insufficient maintenance, all of which make for noise.

2. In space planning, recognize that ductwork—especially the larger ductwork associated with slow air velocities and quiet spaces—requires a lot of room.

3. Specify fans running at high efficiency and low static pressure

4. Use flexible connections where supply and return ducts meet the air handling unit.

Mechanical Noise

Checklist

Air distribution System

5. Design for smooth airflow to avoid noise associated with air turbulence. Use radiused duct elbows, turning vanes, and gradual (8 degrees or less) duct take-offs and branch-offs.

6. Keep duct air velocities low. This typically translates into larger ducts.

7. Duct silencers may be required on supply *and* return ducts. This will necessitate a straight duct run on the order of 20 feet (7 meters) on both the main supply and main return ducts between the air handling unit and first duct branch-off.

8. Locate exhaust fans to maximize the duct length between the fan and the inlet. Specify quiet exhaust fans and locate the inlets in spaces that are not noise-sensitive.

9. Use ducts with a low cross-section aspect ratio. It’s best if the width is less than three times the depth of the duct. Avoid ducts with aspect ratios of greater than eight-to-one.

Mechanical Noise

Checklist

Air distribution System

10. Locate dampers, such as those found in Variable Air Volume (VAV) boxes, as far upstream from outlets as possible. Put dampers in spaces that are less sensitive to noise.

11. Insert 6 to 9 feet of flexible duct immediately upstream of air outlets, especially if Variable Air Volume (VAV) boxes are used.

12. Know that a configuration of more (slow moving) air outlets in a room proves a quieter configuration than a configuration of fewer air outlets in the same room.

13. Install at least two duct elbows and as much duct as reasonable between two rooms that share an air distribution system and would require speech privacy, such as would be found in adjacent dwelling units.

14. Know that sound travelling in building elements such as columns, beams and floor slabs may be radiated as airborne sound far from the source.

Mechanical Noise

Checklist

Vibration Noise

1. Utilize structural breaks or independent structural elements to structurally separate the parts of a building that house vibrating equipment from the parts that house quiet spaces. Often these are required anyway in large buildings to account for differential expansion, differential settling, and seismic concerns.

2. Isolate vibrating equipment on springs, pads, or inertia blocks. These should be sized by a qualified professional.

3. Resiliently mount the nearest 30 feet (10 meters) of pipe or conduit serving vibrating equipment, such as an air handling unit. Use flexible conduit to connect electrical services to vibrating equipment.

Appliance Noise

1. Purchase quiet equipment, such as dishwashers with double-wall construction and double pump design.

Mechanical Noise

Checklist

Appliance Noise

2. Locate vibrating appliances such as dishwashers, clothes washers, and clothes dryers on grade where possible. Check that they are balanced. Put these types of appliances on neoprene “appliance pads.” If they are located on upper floors, design so the rooms beneath them are not noise-sensitive.

3. Resiliently mount garbage disposals by floating the cabinet that houses them on top of an isolated floor.

4. Locate laundry rooms, trash shoots and elevators so that they are not immediately adjacent to dwellings.

5. Avoid the use of garage door openers, especially when the garage is under “someone else’s” apartment. Where they must be used, detail both the opener and the door with extreme care.

PLUMBING NOISE

Nuisance. Though plumbing noise often isn't especially loud, it can be disproportionately annoying to occupants. This is because (1) it comes in an on-off cycle, and intermittent noises are judged to be more annoying than continuous ones, (2) when it comes at night, even if it isn't very loud, it may be loud enough to interrupt rest, and (3) when associated with bathroom activities it can be embarrassing and feel like an invasion of privacy.

Amplification. Pipes and fixtures are, by themselves, poor radiators of noise. Rather, it is when a noisy or vibrating plumbing system is coupled to efficient noise radiators such as walls, ceilings, and floors that these sounds are amplified. For this reason plumbing noise can best be mitigated by decoupling the plumbing system from the structure. This is important enough to repeat: water noise would typically *not* be a problem if pipes weren't rigidly attached to lightweight radiating surfaces.

Turbulent flow and cavitation. High water pressure and the resulting high water velocities cause turbulence and cavitation (noise from the collapse of water bubbles). This is particularly troublesome at bends, valves, taps and connectors and is associated with the hissing sound sometimes found around partially opened fixtures.

Plumbing Noise Sources

Water hammer. The sudden interruption of water flow, as when one abruptly turns off a tap, forms a shock wave. This can also occur if one abruptly turns on a tap.

Defective parts. Loose or worn fittings and valves can cause chattering. These are typically easy to pinpoint by listening, and the noise often occurs when a tap is partially opened but disappears as it is opened further.

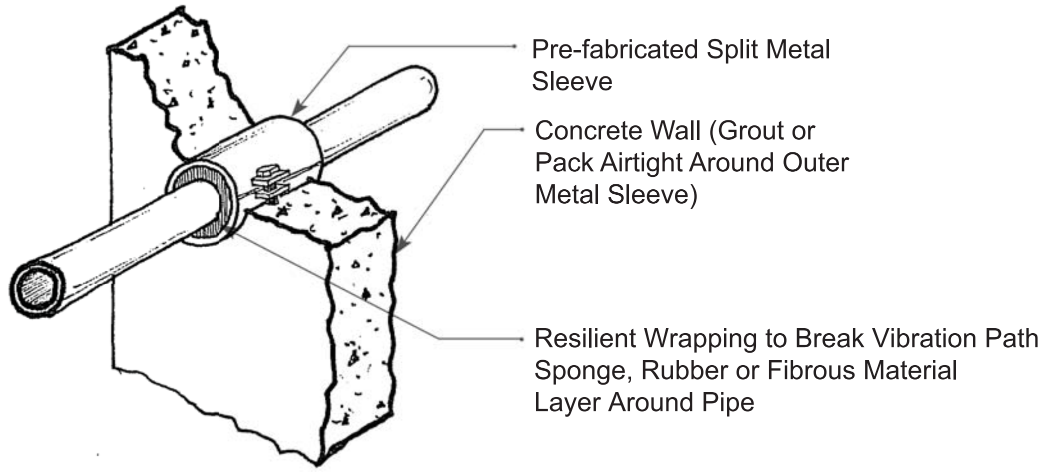
Expansion and contraction. Often, but not always, associated with hydronic heating, the expansion and contraction of pipes can cause snapping and creaking, especially when pipes are rigidly connected to structure.

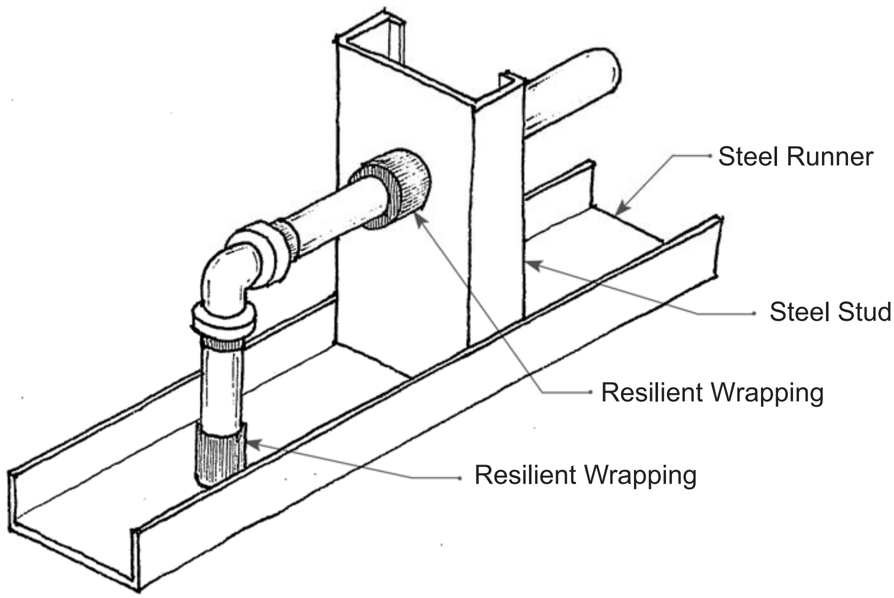
Draining water. The draining of a fixture annoys with a gurgling sound. This is especially acute when drain pipes move horizontally, as water falling hits the horizontal pipe. When the horizontal pipe is attached to a ceiling, it can excite the structure, amplifying the noise of the draining water.

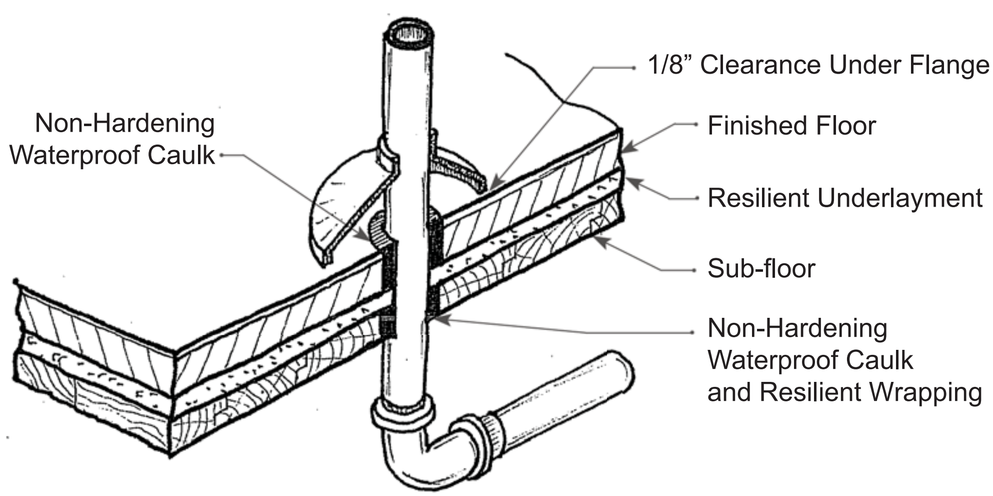
Running water. Running water from fixtures can hiss.

Isolating the Plumbing System

Penetrating Pipes:

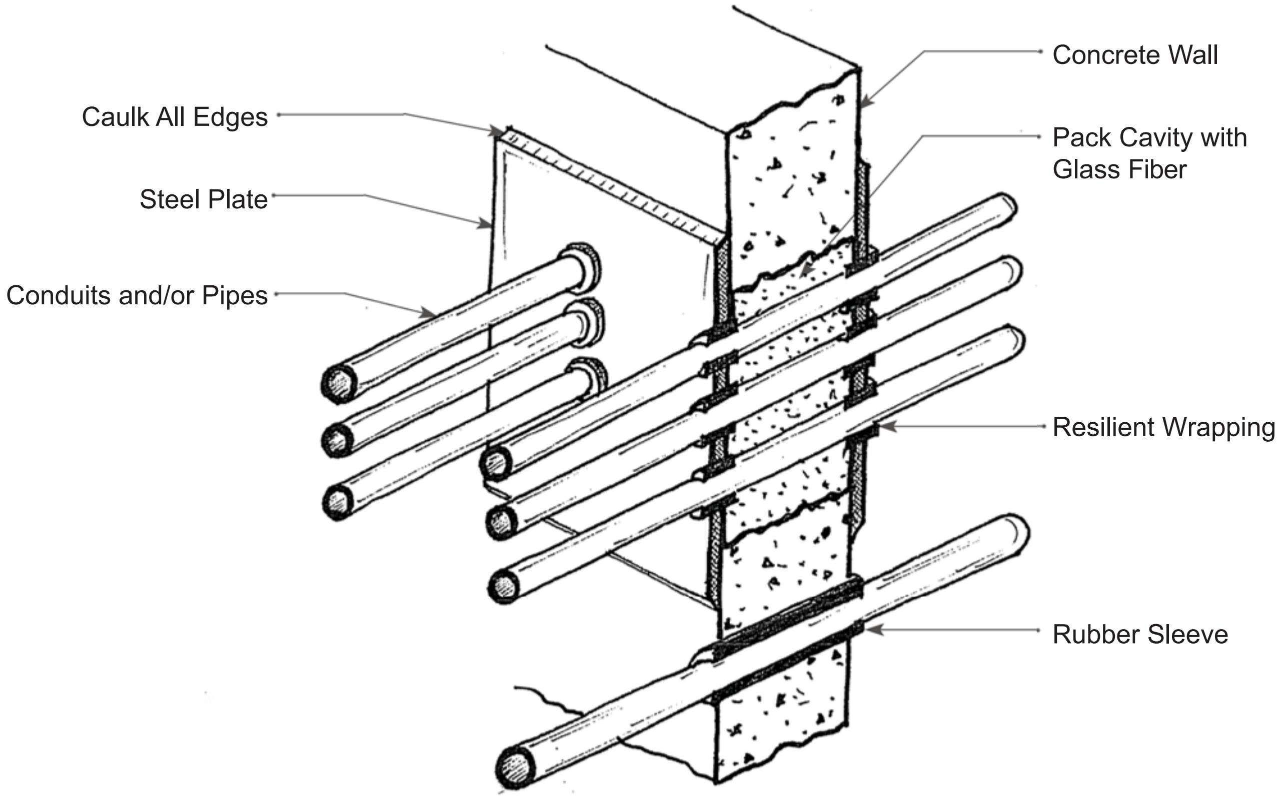


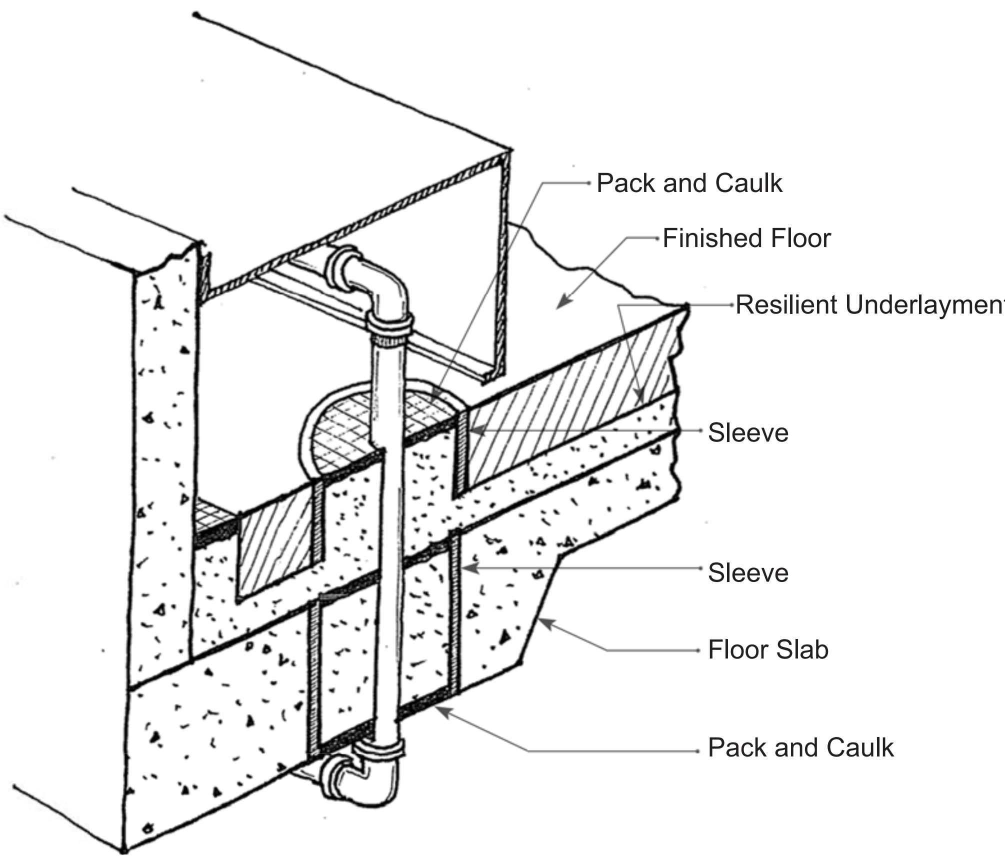




Isolating the Plumbing System

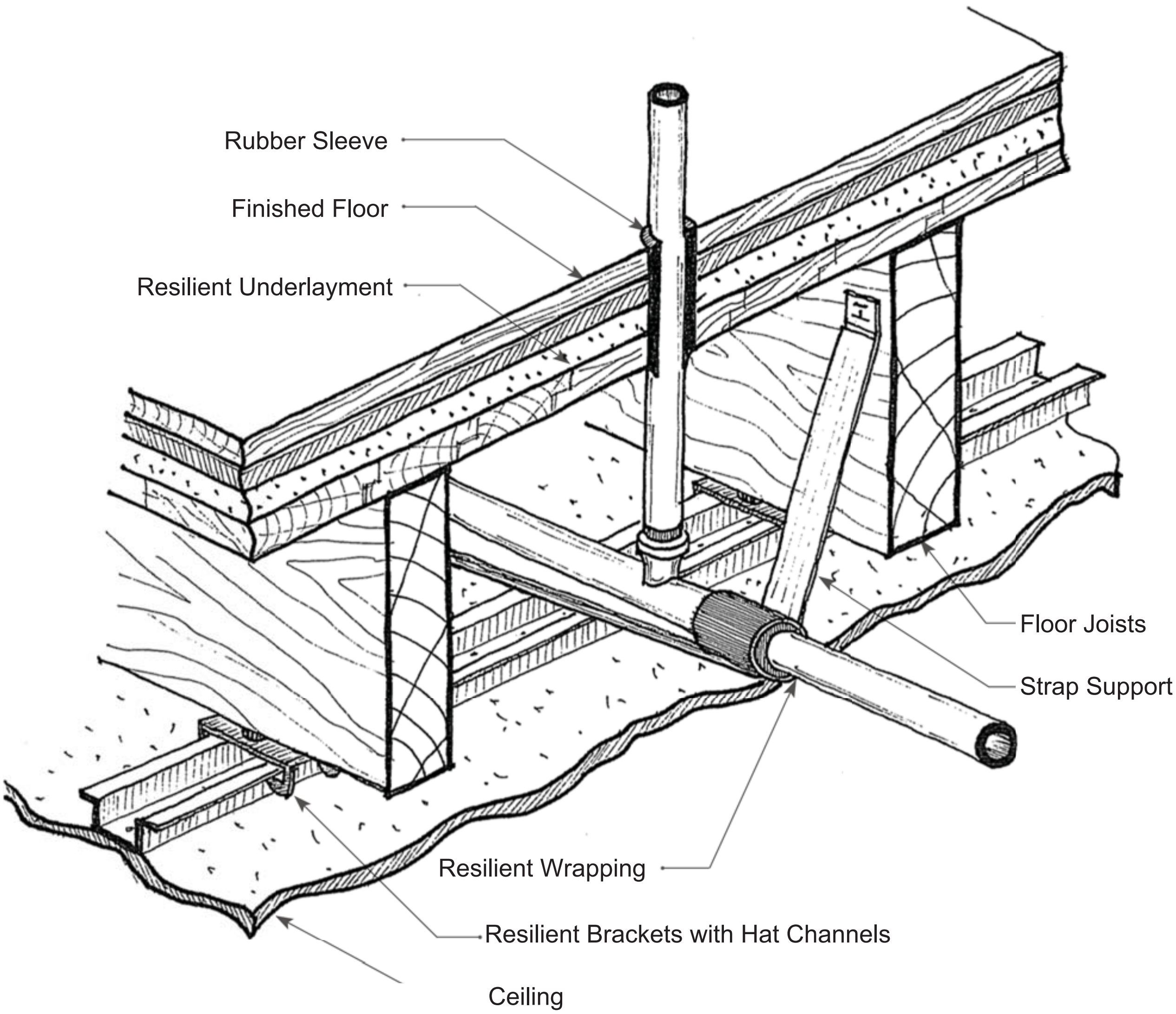
Penetrating Pipes:





Isolating the Plumbing System

Penetrating/Supported Pipes:



Plumbing noise checklist

Early Design

1. Locate supply and drain lines away from quiet areas such as walls common to bathrooms and bedrooms.

2. Locate bathrooms, laundry rooms, and kitchens to minimize the need for horizontal drain lines.

3. Use a simple plumbing layout to minimize the need for fittings and bends, and allow for large radius turns in piping to minimize turbulence noise.

4. Avoid designing plumbing fixtures on sensitive walls, such as party walls, or those shared with a bedroom.

5. Back to back bathrooms should have completely separate framing, such as a double wall so that one unit's piping does not contact a neighbor's unit. Similarly double walls should be used wherever a chase wall joins a bedroom.

Plumbing Noise

Checklist

Isolation from the Structure

1. Oversize pipe supports such as clamps, straps, and hangers, and wrap pipes in a collar of resilient material (rubber, neoprene, mineral wool, or fiberglass) at the band where the pipe would otherwise make contact with the support.

2. When possible, attach pipes resiliently to the most massive structural elements such as masonry walls.

3. Where pipes penetrate a wall or floor-ceiling assembly, use an oversized sleeve and wrap the pipe at the penetration point with a band of resilient material. Seal the penetration well—on both sides of the penetration—with water resistant non-hardening caulk to avoid airborne noise transmission.

4. If resilient underlayments are not used in the floor, Isolate bath tubs, showers, washers, dryers, and toilets on a pad of cork, neoprene, rubber, or other resilient material to mitigate sounds from falling water, rotating equipment, and slamming toilet seats.

Plumbing Noise Checklist

5. Assure the use of quiet vacuum breakers, commonly required on hose bibs, as they can be especially loud.

Materials

1. Use cast iron waste pipes rather than PVC waste pipes. They are much quieter. For supply lines, plastic is often quieter than metal.

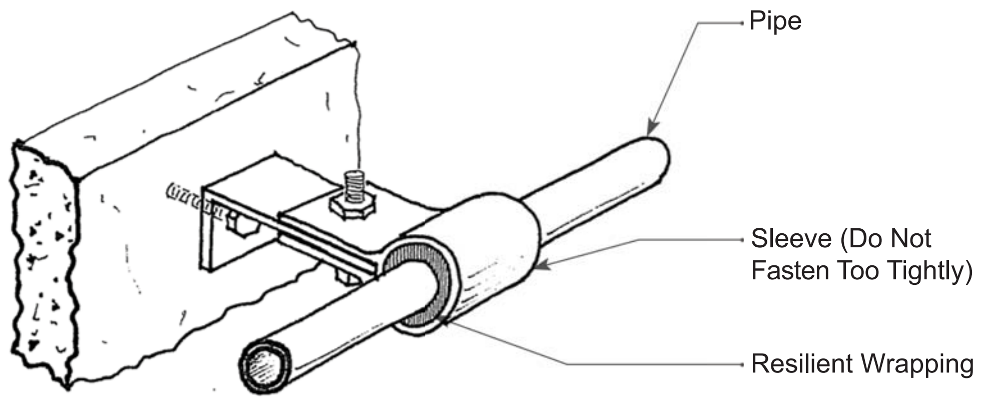
2. Recognize that some fixtures, such as pressure-assist toilets, are inherently noisier than other types of fixtures.

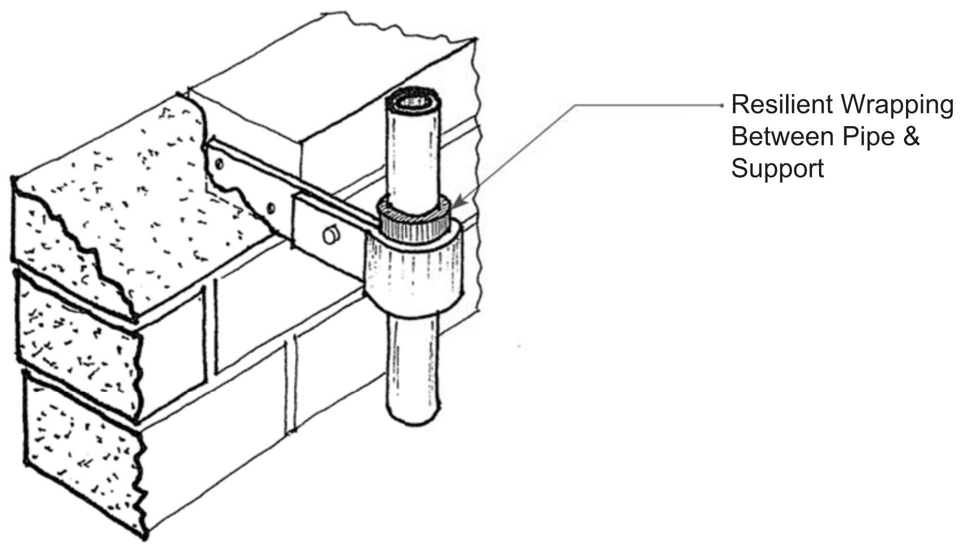
System Design

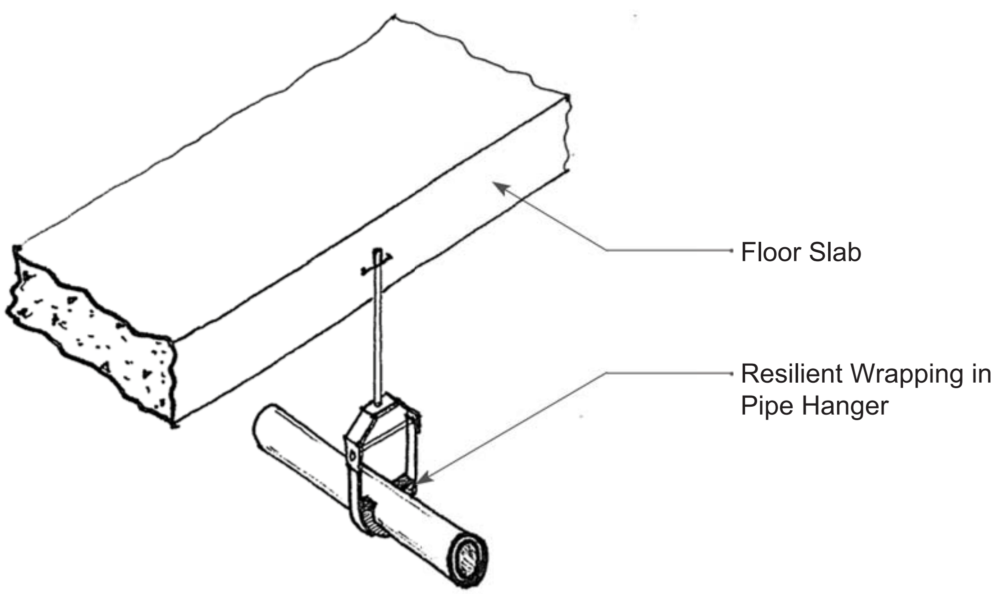
1. Know that high pressure plumbing systems, including those associated with chilled water distribution, are inherently noisy. Maintain the static pressure of main water supply lines of buildings with three stories or less at less than 50psi. Branch lines serving individual apartments should not exceed 35psi. In high rise structures where high pressure main supply lines are required, pressure reducers or regulators should be used in supply branches to meet these limits.

Isolating the Plumbing System

Supported Pipes:

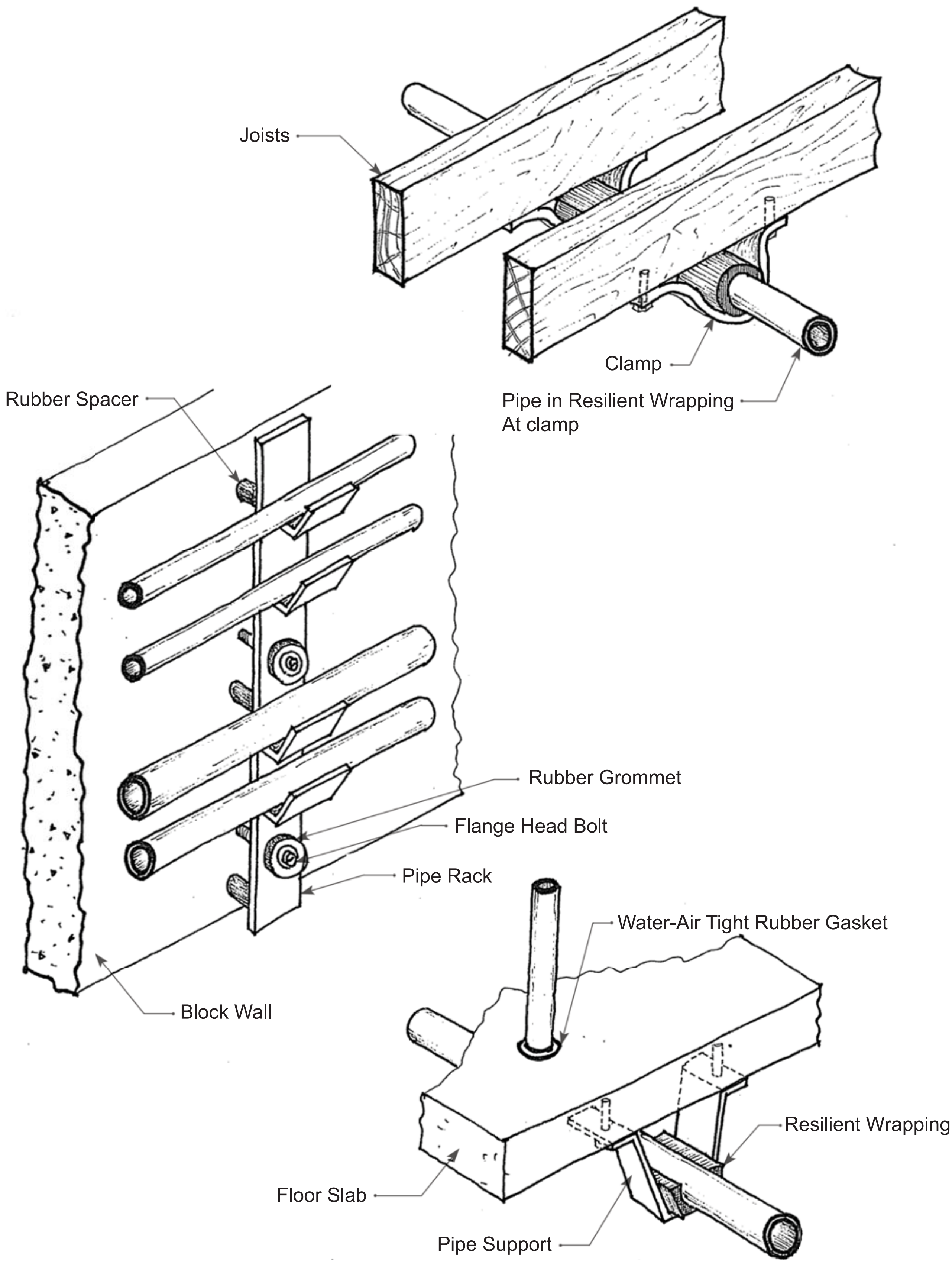






Isolating the Plumbing System

Supported Pipes:



Plumbing Noise

Checklist

System Design

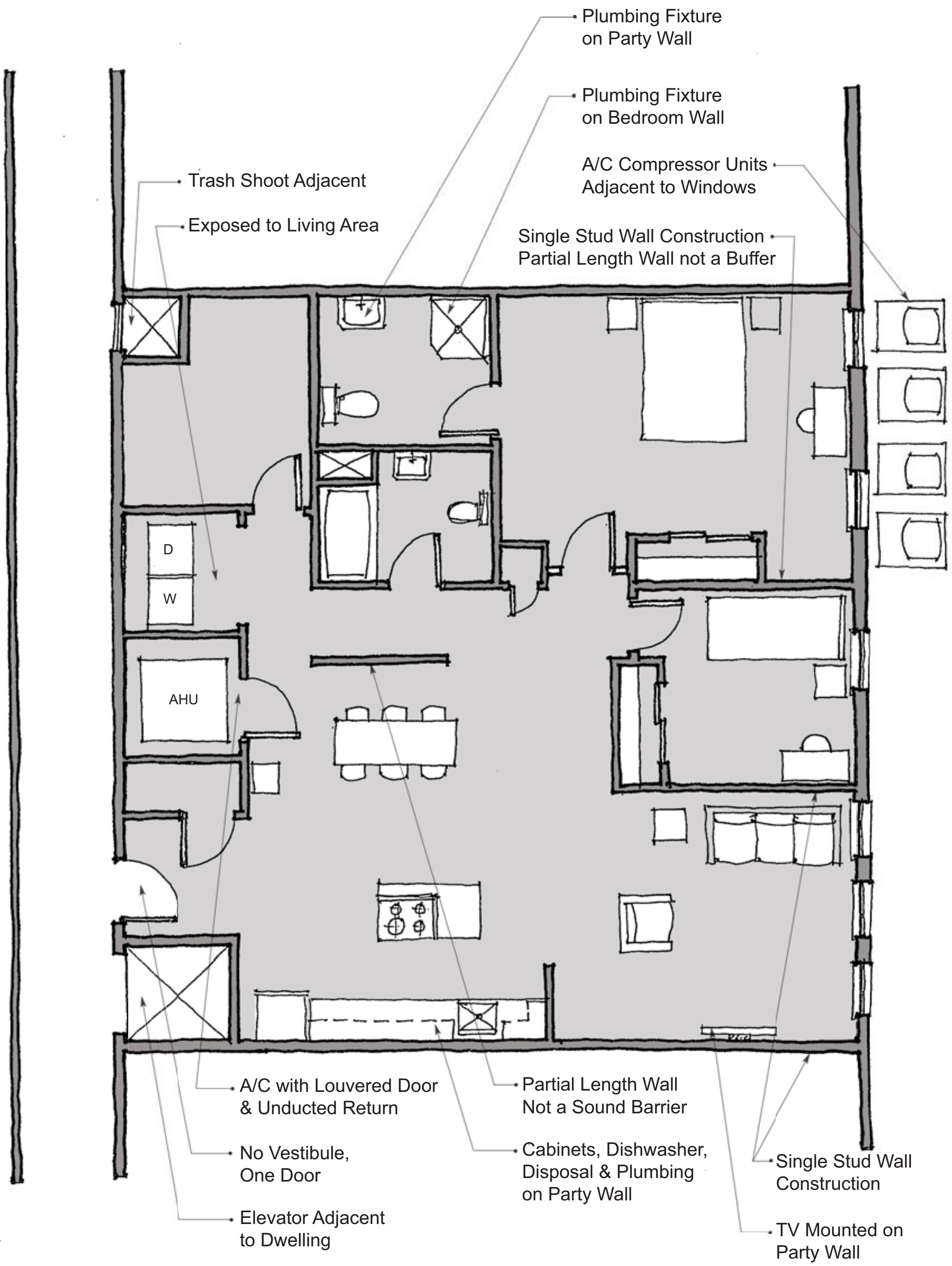
2. Properly size piping so that plumbing systems are not under high pressure and velocity. Flow velocities on the order of 6ft/sec or less in domestic systems have been found to be acceptable.

3. Design flexible connectors to attach the plumbing system to vibrating equipment such as pumps, washers, dishwashers, garbage disposals and chillers.

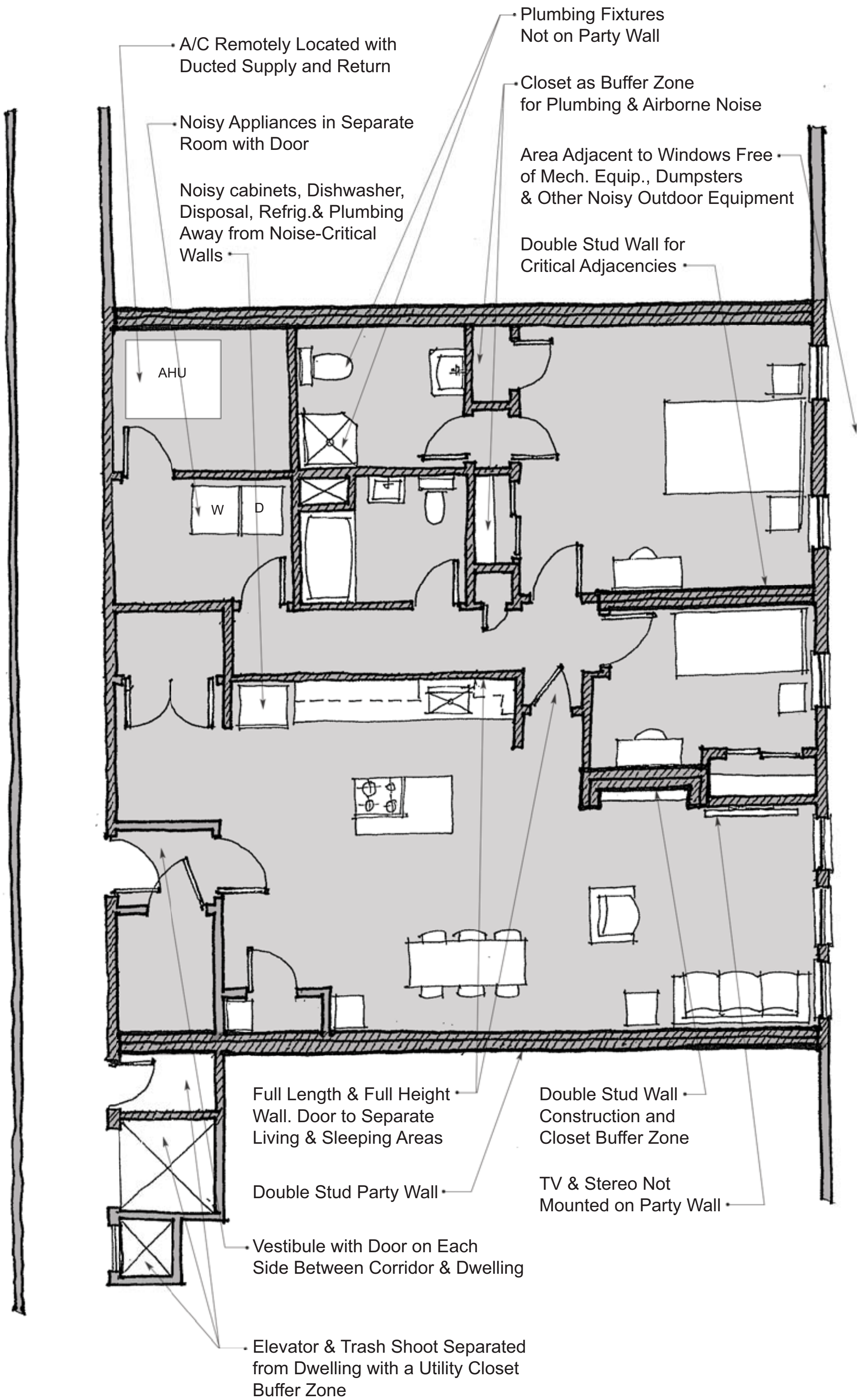
4. Box large diameter supply and drain pipes, particularly in high pressure systems, in gypsum board enclosures. Install fiberglass insulation on the inside of the enclosure.

5. Design waste pipes and pipes associated with roof drains to run in walls adjacent to rooms that are less noise-sensitive like utility rooms or kitchens. Avoid running pipes (especially PVC waste pipes) in walls adjacent to bedrooms, living rooms, or dining rooms.

Not-Recommended Dwelling Layout



Recommended Dwelling Layout



RESOURCES

Consultants

Bring a consultant in architectural acoustics on the design team *and bring him in early in the design process*. For a roster of consultants, contact the National Council of Acoustical Consultants, the Institute of Noise Control Engineering, or the Acoustical Society of America. Below is a list of useful publications.

Publications

Applications Handbook, *Fundamentals Handbook,* and *Systems and Equipment Handbook,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta.

W. Blazier and R. DuPree, "Investigation of low-frequency footfall noise in wood-frame, multifamily building construction," *Journal of the Acoustical Society of America* January, 1994, pp 1521-1532. (Overview of difficulties associated with impact noise in wood frame construction)

R. Berendt, G. Winzer, and C. Burroughs, *A guide to airborne, impact, and structure borne noise—control in multifamily dwellings* National Bureau of Standards and US Department of Housing and Urban Development, Washington, DC, September 1967. (Overview of all aspects of multifamily noise control, but especially useful for information on plumbing noise)

W. Cavanaugh, and J. Wilkes (ed.), *Architectural Acoustics*, Wiley, New York, 1999.

R. Dupree, "Catalog of STC and IIC Ratings for Wall and Floor/Ceiling Assemblies with TL and ISPL Data Plots," *Report from the California Department of Health Services, Local Environmental Health Services Branch Office of Noise Control,* September 1981. (Acoustical data for large numbers of floor-ceiling and wall assemblies)

M. D. Egan, *Architectural Acoustics*, J Ross Publishing, Ft Lauderdale, 2007. (Architectural acoustics primer, written in the language of designers)

C. M. Harris, *Handbook of Acoustical Measurements and Noise Control*, Acoustical Society of America, 1998.

V. O. Knudsen and C. M. Harris, *Acoustical Designing In Architecture*, Acoustical Society of America, 1978.

The Noise Guidebook, U.S. Department of Housing and Urban Development, Environmental Planning Division, Office of Environment and Energy, Washington DC, http://www.hud.gov/offices/cpd/environment/training/...
guide books/noise/index.cfm (Comprehensive overview with particular use in community noise planning)

Noise Pollution Clearing House, *EPA Document Collection,* http://www.nonoise.org/epa/ (vast collection of EPA noise studies, many dealing with community noise)

J. D. Quirt, A.C.C Warnock, and J.A. Birta, “Gypsum Board Walls: Sound Transmission Results,” *National Research Council Canada IRC Internal Report IR-693*, October, 1995. (Acoustical data for large numbers of gypsum board wall assemblies)

A.C.C. Warnock and J.A. Birta, “Detailed Report for Consortium on Fire Resistance and Sound Insulation of Floors: Sound Transmission and Impact Insulation Data in 1/3 Octave Bands,” *National Research Council Canada IRC Internal Report IR-811*, July 2000. (Acoustical data for large numbers of floor-ceiling assemblies)

Author Bio

Michael Ermann is Undergraduate Architecture Co-Chairman and an associate professor at Virginia Tech’s School of Architecture + Design, where he teaches architectural acoustics, environmental building systems, and design studio. Professor Ermann has authored or co-authored eight journal papers in the field of acoustics, and presented more than twenty papers on the topic—many of them invited. He currently is coauthoring the third edition of *Architectural Acoustics*, which has been for decades the most widely used textbook in the field. He’s won design, teaching, research, and outreach awards for his work.

Prior to joining the VT faculty Mr. Ermann was an acoustical consultant at Artec in New York and at Siebein Associates in Gainesville, Florida. He currently maintains an architectural acoustics consultancy.

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Disclaimer

This booklet is intended to translate architectural acoustics in to the language of architecture with the primary intent of driving early design decisions—the ones with the most impact on acoustics. It is, therefore, general in nature and obviously not all of its content is germane to a given project, with its own particulars. It is NEVER intended to replace the services of a qualified professional. As it was written by a sole author (with considerable help from a few colleagues and students) to assist acoustical laypeople, under no circumstances should ANYTHING in this booklet be interpreted to reflect a formal consensus of the members or committees of the Acoustical Society of America.

THE ORANGE BOOK