ARCHITECTURAL ACOUSTICS ILLUSTRATED

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APARTMENT LAYOUT GRAPHIC QUIZ

From an acoustical point of view, how can this apartment be improved? (Answer on pages 31-32)
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. Only through careful detailing and construction supervision can this be combatted. The most common and troublesome flanking paths involve

1. Partitions that extend above an acoustical tile ceiling, but not all the way to the structural deck above
2. The joint where the floor meets the wall in wood construction
3. Back to back penetrations on either side of a barrier for outlets, built-in cabinets, etc.
4. Unsealed penetrations through walls and floors for ducts, pipes, and conduit
5. Ducts that connect one room to an adjacent room with short, straight runs
6. Doors and windows, which, for sound isolation, are generally more important than the walls they nest in

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: Published acoustics performance data, while helpful in making comparisons, is only a description of the performance of the wall or floor-ceiling assembly absent flanking. It does not account for small seams or installation quirks, better considered with whole-system-thinking.

As a rule, if two spaces share air, they share a common acoustic environment. Open-plan offices, ajar doors, open windows, and rooms that flow into one another in plan or section provide little meaningful acoustic separation, regardless of the robustness of the partial-barrier.

References
Reference
FLANKING NOISE CHECKLIST

1. Use generous quantities of non-hardening caulk and packing to ensure a tight seal along the crack where the wall meets the floor, along the crack where the ceiling meets the walls, and at penetrations from ducts, electrical outlets, pipes, etc.. To seal larger holes use firestop putty.

2. Conduct preliminary tests of the effectiveness of a wall or floor-ceiling prior to painting and final completion. Visually inspect for cracks or gaps in surfaces. Use your ears: 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.

3. Locate electrical outlets, phone jacks, cable wall jacks, recessed cabinets, etc. on one side of a wall so they do not occupy the same inter-stud cavity as similar penetrations on the other side.

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

5. Design for 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 an independent building segment—separated from quiet spaces with building control joints.

6. Resiliently (non-rigidly) connect room surfaces to the structure. This breaks the “weak link” sound path that might bridge, for instance, across a stud rigidly attached to gypsum board.

7. Specify resilient sound isolation clips with hat channel to attach gypsum board to walls. These clip systems outperform resilient channel in acoustic tests and are much less likely to be short-circuited. Flanking issues can arise when improperly long drywall screws are used and short-circuit the resilient channel by biting directly into the joist or stud. Cabinets or baseboard trim attached directly to the studs can also short-circuit the isolation provided by resilient connections.

8. Avoid doors with louvers in all noise sensitive rooms. Doors with seals outperform doors without them; doors with gaps at their bases less than 1/16-inch outperform those with gabs of ¼-inch or more.

9. Extend partitions above dropped ceilings, all the way to the structural deck above. While acoustical ceiling tile is effective at absorbing the sound in a room, it is typically not robust at blocking sound from leaking into an above-ceiling plenum, then from the plenum to an adjacent room. When partitions do not extend all the way to the deck above, either seal the partition to the slab in the plenum with sheets of mass-loaded vinyl, or specify a high ceiling attenuation class (CAC) tile, which provides both a measure of sound absorption and sound isolation.
PRINCIPLES OF PARTITION DESIGN

Base construction

Better

Single-layer gypsum board

Multilayer gypsum board with staggered panel joints

Standard block wall

Grout-filled block wall

Increased Mass

Single surface

Two surfaces with cavity

Use of Airspace
Base construction

Standard stud wall (studs 16" o.c.)

Limp (Wide Spacing Between Studs)

Stud wall (studs 24" o.c.)

Better

Standard stud wall

Staggered studs

Structural Discontinuity

Double stud wall
Base construction

One wythe of CMU

Better

Sound-absorbing blanket (to reduce "coupling" between block layers)

Two wythes of CMU with cavity

Standard stud wall

With resilient brackets

CMU wall

Sound-absorbing blanket (loosely fitted between vertical wood furring)

Metal channel (to resiliently support gyp. bd.)

CMU wall with furring, resilient clips, and gyp. bd.

Non-hardening caulk (to seal perimeter of gyp. bd.)

Structural discontinuity
Base construction

Standard stud wall

Standard stud wall with insulation in the cavity

Absorption in the airspace

Back-to-back outlets

Sound leak

Stud wall with outlets in the same cavity

Fibrous insulation (to deaden cavity airspace)

2 ft separation so at least one stud between outlets

Plastic vapor barrier type box or mastic applied to electrical box interior

Non-hardening caulk

Gap between outlet box and gypsum board caulked

Stud wall with outlets in separate cavities

Airtight
TRANSMISSION LOSS (TL)

Airborne sound transmission between rooms—or from outside of a building—is generated by people talking or shouting, equipment running, sound amplification associated with stereos and television sets, industrial processes, machines for transportation, and power equipment such as jackhammers and leaf blowers. Sound energy moves through the air to the wall assembly and floor-ceiling assembly, where it is radiated through the panel 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 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 can be particularly vexing.

Transmission loss (TL) quantifies the airborne sound-insulating properties of a building element. The higher the TL values, the more robust the assembly at attenuating the penetration of sound, so generally, we prefer high-sound-transmission-loss assemblies for sensitive adjacencies. Tested building elements will have transmission loss values at each of several octave bands, from low-frequencies to higher-frequencies, and because airborne sound attenuation is only as good as the weakest link, a high value in one octave band will not necessarily make up for a low value in another.

Transmission loss (TL) in decibels can be calculated:

\[ TL = -10 \log \tau \]

Where the sound transmission coefficient, \( \tau \), is the fraction (between 0 and 1) of the total sound energy striking the barrier that is transmitted to the receiving room.
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 is close and the door is opened. In this way low frequency sound energy travels far and easily moves through some building assemblies, particularly those assemblies that are light-weight. The low-pitched hum of an air handling unit in the next room, the groan of a bus accelerating outside, and the amplified bass notes associated with loud stereos and TVs pass through many wall and floor-ceiling assemblies barely attenuated. Designers beware: examine published or measured TL values at low frequencies when low tones will be present in the source spectrum. 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 (TL), 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 includes multiple values (accounting for multiple frequencies) to gauge 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. STC offers an easy method of measuring noise isolation of speech, but the simplification comes at a cost. The value does not sufficiently relate low frequency performance, therefore, STC is often not effective at comparing barriers when the sound sources are rich in low-frequency content such as transportation, sound amplification, or mechanical noises.

While STC must be measured rather than calculated, in the absence of published STC values a conservative STC estimate may be found with the following formula.

Estimation of STC for preliminary design purposes:

\[
\text{STC} \approx 16.8 \log w + 15
\]

Where \( w \) is the weight of the wall in pounds per linear foot. This formula is not accurate for partitions with redundant (i.e., double stud) structure or resilient connections, whose assemblies outperform their weight.
The special case of low-frequencies

Relying on the STC rating misleads the designer when a low-frequency sound-source sits adjacent to a noise-sensitive room. For instance, when a mechanical equipment room sits adjacent to a music practice room (and it is ensured that no door connects the two), individual octave-band TL measurements must guide barrier design. In this case, the rumbling of the motors in the mechanical room may generate too much low-frequency energy for standard gypsum wall board walls to effectively block. The mass of masonry or concrete barriers, extended the full height from floor deck to ceiling deck, is a better choice.

Reference
HOW TO MEASURE SOUND TRANSMISSION CLASS (STC)

Step 1: Measure the assembly noise reduction (NR)

For this example, we'll test the transmission loss of a double-stud wall with two layers of gypsum board on each side and insulation in each cavity. We wish to establish a single-number rating to compare the acoustical performance of this assembly in the attenuation of airborne sound.

Noise reduction (NR) equals the sound level difference between two rooms.

The example used is a wall, but remember that floor-ceiling assemblies also require sufficient noise reduction and their performance values are measured in a similar way.

Step 2: Plot the corresponding sound transmission loss (TL)

The noise reduction (NR) is normalized to account for both the wall area tested and the absorption profile of the receiving room. The resulting transmission loss (TL) values of the wall are plotted at one-third octave band resolution from 125 Hz to 4000 Hz.

Step 3: Plot the sound transmission loss (STC) contour on a transparent overlay

While plotted at the same scale as the TL in the previous step, there are no absolute values ascribed to the Y-axis.

The low-frequency portion of the contour dips down, establishing a 'low hurdle' for the partition to clear in its bass tone attenuation.
Notes
In practice, this procedure is often executed with a spreadsheet rather than graphical overlays. Field sound transmission loss (FTL) and its corresponding field sound transmission class (FSTC) tests measured in actual buildings often suffer a five, ten, or more, STC point deficit relative to the flanking-path-controlled lab tests used to derive published data. Europe and some other countries outside the US use the weighted sound reduction index ($R_w$) instead of STC. The two are similar; see standard ISO 717-1. Noise Isolation Class (NIC) describes the sound isolation between two spaces in the condition found (without adjusting for room effects). It provides a single number rating for the every-octave noise reduction (NR). Apparent sound transmission loss (ATL) and apparent sound transmission class (ASTC) procedures ascribe all flanking present to the partition tested. Normalized noise reduction (NNR) and normalized noise isolation class (NNIC) may be used for small unfurnished areas to simulate an assembly’s performance if furniture were in place. See ASTM standards E966 (for field testing of building facades), E336 (field testing of interior partitions), E90 (laboratory testing of interior partitions), E1414 (common plenum shared by two rooms), E1408 (door and panel systems), E413 (data analysis for STC), E597 (establishing target values for building specifications), and E1332 (outside inside sound transmission loss (OISTC)).

References
Note
When a conversation in one room is sensitive, and should not be heard in an adjacent room, a barrier with a minimum STC 55 should be used (and flanking paths addressed). For extremely sensitive speech content where overhearing might pose a security threat, more detailed analysis is warranted. See B. Grover and J. Bradley, "Measures for Assessing Architectural Speech Security (Privacy) of Closed Offices and Meeting Rooms," National Research Council Canada Report No. NRCC-47039, March 2008.

References
NOISE REDUCTION (NR)

When shopping for a car, it is best to know the vehicle’s fuel efficiency (miles per gallon) as measured in a standard test, with standard operating conditions. Once driven off the dealer’s lot, however, the car’s actual fuel efficiency will depend on its current operating conditions, for instance, tire pressure, headwind speed, and traffic congestion. While TL might be thought of the advertised fuel efficiency, NR would then be considered the actual road performance.

Designers use the transmission loss (TL) metric to compare building assemblies in airborne noise transmission effectiveness, but TL does not precisely describe how many decibels quieter one specific receiver room will be relative to an adjacent source room. Adjacencies with large common partitions allow more sound energy to flow between them than if there was instead a smaller partition separating the two rooms; and sound-reflective receiving rooms allow the sound energy that has passed through the partition to linger, creating a louder environment than would be the case in a more sound-absorbent receiving room. For these reasons, the transmission loss data for an assembly must be supplemented with information about both the area of the common partition and the total absorption in the receiver room to find the noise reduction (NR) between rooms.

NR describes the measured or predicted sound pressure level difference between the source and receiver rooms, taking the assembly performance into account, but also the area of the common partition and the total receiver room absorption.

\[ NR = L_{\text{level in source room number 1}} - L_{\text{level in receiving room number 2}} \]

It can be predicted with the equation:

\[ NR = TL + 10 \log \left( \frac{A_2}{s} \right) \]

Where TL is the sound transmission loss of the common partition measured in decibels.

\( A_2 \) is the total absorption in the receiving room measured in sabines (multiply each surface’s area by its corresponding absorption coefficient and add the results, see page XX).

\( s \) is the surface area of the common barrier.

If the “room effects” term, \( 10 \log \left( \frac{A_2}{s} \right) \), returns a value greater than 10 decibels (or less than -10 decibels), it is best in practice to substitute the value of 10 decibels (-10 decibels) for that term because room effects are limited to about 10dB in practice.
ACHIEVING HIGHER ACOUSTICAL PRIVACY

Building elements that are massive, airtight, and structurally discontinuous perform the best.

Airtightness. 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 walls and floor-ceiling assemblies between acoustically sensitive adjacencies with doors, windows, and other surface intrusions, such as electrical outlets, doorbells, fire alarms, intercoms, cabinets, phone jacks, and penetrations for conduit, ducts, grilles, and pipes.
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 surface 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.

Cavity depth. Barriers with deeper cavities outperform those with smaller cavities.
**Structurally redundant.** A cavity wall outperforms a solid wall of equal weight, a staggered stud wall outperforms a single-stud wall where the studs bridge the gap. 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.

**Limp, resilient, or non-rigid.** Sound will short-circuit a cavity and bridge the two surfaces of an assembly directly through studs, joists, webbing, concrete, brick, and concrete block. Decoupling one of the two surfaces of a barrier, then, breaks the flanking sound path moving through the structure. This may be achieved with resilient channel, resilient clips with hat channel, or visco-elastic glue. This kind of resilient connection has almost no impact on structurally redundant assemblies like staggered- and double-stud walls because in these constructions, the two surfaces of a wall are already decoupled, eliminating the flanking path through the structure.
Sound absorbing materials in the cavity. In lightweight walls especially, fuzzy material such as fiberglass, mineral wool, or cellulose can improve the performance of a wall significantly. However, sound-absorbing insulation is no substitute for mass and air-tightness. Because sound transmission may move through the structure common to both surfaces of an assembly, bypassing the insulation altogether, the substantial benefit of a wall or ceiling cavity filled with absorption can only be fully-realized with structurally redundant, limp, or resilient constructions (items 4 and 5 above). In the graphs below, note that cavity insulation in wood stud construction fails to improve low frequency performance because long-wave (low-frequency) sound energy bridges across the studs and doesn’t “see” the insulation. By contrast, the limper light-gauge, non-loadbearing, steel studs dissipate low-frequency sound energy that would otherwise bridge across them. (Twenty-gauge or thicker load-bearing steel studs are more rigid and behave like wood studs.) When viewed together, the graphs also speak to the better overall sound-transmission performance of limp structure (see above).

References
Kinetics Noise Control, Pac International, and Pliteq resilient clip sound transmission data.
BACKGROUND NOISE

In the late 1990s forty experienced female clerical workers answered an advertisement to take part in a study at Cornell University. They were split into two groups and each was assigned a manuscript to type into a computer for three hours. Researchers told participants they were part of an experiment of office furniture effects, and assigned one group to a quiet office and another group to a noisier office. The “noisy” office was not very noisy, but rather filled with the kind of low-intensity buzz common to many open-plan offices. Urine samples comparisons revealed those working in the noisy office had stress hormone levels significantly higher than those working in the quiet office. The noisy group also displayed signs of reduced motivation.

These findings parallel legions of others derived from a century’s worth of research into the effects of noise. Long-term exposure to high-intensity sounds contributes to hearing loss; those who sleep in noisier environments are more prone to heart disease; subjects suffer cognitively when assigned to tasks that involve careful listening in noisy environments.

One can measure background noise in A-weighted decibels. This single-number weights noise per human sensitivity to frequency, is common in environmental (outdoor) noise measurements, and is easily read from the most rudimentary sound level meters. While the A-weighted metric is sometimes used for measuring indoor noise, it is not the best way to do so because it lacks enough spectral information. For this reason, A-weighted decibels should never be used for maximum room noise design specifications.

More appropriate, and more common, is the noise criteria (NC) metric. Room noise is measured at octave bands (or one-third-octave bands) and plotted on a graph with NC curves. The noise criteria then is the highest NC curve “touched” by the noise spectrum measured. Like A-weighted decibels, noise criteria allows for diminished human sensitivity to noise in the lower frequencies. The higher the NC level, the noisier the environment; occupants judge an NC-25 room as quiet and an NC-60 room as noisy.

Note
Researchers and practitioners have developed other less-commonly-used methods of measuring background noise in order to refine noise criteria (NC). Room Noise Criteria (RNC), complicated to execute, measures low-frequency modulations or surging associated with high duct velocities adjacent to noise-sensitive spaces. Speech-interference level (SIL) averages the sound pressure level measurements at speech frequencies (500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz). Balanced noise criteria (NCB), room criteria (RC), and room criteria mark II (RC Mark II) are now-obsolete attempts to add low- and high- frequency resolution to the more common NC metric. For most applications, use noise criteria (NC) to both specify maximum sound levels and measure in-situ room noise conditions.
Noise criteria curves follow human-perception-equal-loudness curves: we are less sensitive to low frequencies so NC curves are also less sensitive at lower frequencies.
References
SPEECH INTELLIGIBILITY AND NOISE

Speech intelligibility describes the capacity of listeners to hear a dinner-party toast or a classroom lecture. While the quality of intelligibility is governed by both room acoustics and noise control considerations, it can be most clearly examined with a signal-to-noise approach. Listeners clearly comprehend the speaker when his signal is sufficiently loud (+15dB) relative to the noise at the listener location, but intelligibility drops precipitously as background noise approaches, then exceeds, the level of the person speaking.

The speaker’s voice may be enhanced by a loudspeaker system, but for unamplified speech, beneficial early reflections, the absence of excessive reverberation, and a short distance between source and receiver may all be used to bolster the signal. Provide some minimum quantity of absorbing material (average absorption coefficient for the whole room of 0.3 or greater) to limit the racquetball-court-effect associated with excessive reverberance. Shape sound reflective portions of walls and ceilings to direct first- and second-order reflections to the rear seats of a room, which is especially important in large spaces.

Even more significant is limiting the noise. Air traffic or lawn equipment introduce noise from outside a building; the corridors or adjacent rooms introduce noise from within a building; and a computer projector or other audience members speaking over the source introduce noise from within a room. Yet the most common enemy of speech intelligibility is noisy HVAC systems. When they are 10dB less than the person speaking (or louder), even heroic room acoustics measures may not combat the setback introduced by the noise.

Even though adults can comprehend speech with signal-to-noise ratios of six decibels, 10 or 15 decibel minimum spreads are best for full comprehension. Children younger than fifteen, those with hearing impairment, non-native speakers of a language, and older adults require even greater signal-to-noise ratios because they are less able to filter out the background noise and concentrate on the source. Children require 15 to 20 decibel signal to noise ratios and no fewer than 40 studies have linked noisy environments to poor concentration or poor test scores among school children.

Speech intelligibility may be quantified in a space objectively by the metrics speech intelligibility index (SII or SI), speech transmission index (STI), or rapid speech transmission index (RASTI). An older metric, Articulation Index (AI) is generally no longer used in research because it fails to effectively account for reverberation.
Intelligibility (and it’s inverse, speech privacy)

<table>
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<tr>
<th>Intelligibility</th>
<th>Speech Transmission Index (STI) or Rapid Speech Transmission Index (RASTI)</th>
<th>Speech Intelligibility Index (SII or SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect intelligibility (no privacy)</td>
<td>1.0</td>
<td>100%</td>
</tr>
<tr>
<td>Excellent intelligibility</td>
<td>≥ 0.80</td>
<td>≥ 98%</td>
</tr>
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<td>Very good intelligibility</td>
<td>0.65-0.80</td>
<td>96%-97%</td>
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<tr>
<td>Good intelligibility</td>
<td>0.50-0.65</td>
<td>93%-95%</td>
</tr>
<tr>
<td>Fair intelligibility (poor speech privacy)</td>
<td>0.40-0.50</td>
<td>88%-92%</td>
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<tr>
<td>Poor intelligibility</td>
<td>0.30-0.40</td>
<td>80%-87%</td>
</tr>
<tr>
<td>Bad intelligibility (good speech privacy)</td>
<td>&lt; 0.30</td>
<td>&lt; 80%</td>
</tr>
<tr>
<td>Completely unintelligible (confidential)</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

Reference
OPEN-PLAN OFFICE ACOUSTICS

Researchers at the University of California Berkeley Center for the Built Environment asked more than 20,000 study participants—office workers in 142 buildings—a series of questions aimed at gauging building occupant satisfaction. Respondents were most unhappy with the acoustics in their workplace, which consistently received the lowest average satisfaction score of the nine core satisfaction categories (lighting, thermal comfort, air quality, office furniture, etc.). The survey results highlight dissatisfaction with the acoustics of open-plan offices in particular. Of course there is the copier, printer, and mechanical system noise—and cubicle culture has long noted the lack of privacy when conversing—but it is those instances when a worker sits within ear-shot, yet is not part of the conversation that earn the most contempt. Those occupying private offices in the same study, by contrast, were on average satisfied with the acoustics of their workplace. Those with shared offices expressed dissatisfaction with sound privacy, but fared better than their coworkers in cubicles.

Two somewhat-less-intuitive statistically significant findings also came out of the study. First, those with high cubicle walls (defined as above standing eye height) were not more satisfied acoustically than those with low cubicle walls, and second, those sitting in open plans without any partitions expressed less dissatisfaction than those in cubicles with partitions. This may be due to some increased comfort we develop when we can see the conversation we are hearing, to lowered privacy expectations in offices without partitions, to an increased sensitivity of the talkers to those around them who might hear (because potential listeners are seen), to spill-over satisfaction from the access to views and daylight that an office without obstructions provide, or to the types, ages, or tasks associated with employees who work in environments without partitions. One astute participant in the study explained, “People sometimes forget that just because they cannot be seen does not mean that they cannot be heard.” In summary, while the presence of partitions (and of higher partitions) has a benefit by slightly reducing the sound level of the talker, this modest benefit doesn’t seem to carry over to the reported satisfaction of the office worker.

References
As discussed in the sound flanking chapter, a barrier that is not air-tight is acoustic weak tea. A cubicle wall, therefore, fails to keep the conversation in (or out) of the cubicle, as sound energy associated with nearby conversations easily diffracts over and around the partial-height partition, and reflects off the ceiling and other surfaces in the office. Offices with sound-absorbing surfaces, particularly sound-absorbing ceilings, remain quieter than those with reflective surfaces, but only slightly quieter.

For open-plan office design, perhaps more important than the movement of sound energy in the realm of physics, is the interpretation of that sound in the realm of psychoacoustics. For all the chatter on the merits of multi-tasking, researchers have known for 75 years that multi-tasking is ineffective, at least when one of the tasks requires significant mental attention. Thus human performance in the execution of cognitively intensive tasks (proofreading an important document, or memorizing a series of numbers, for instance) drops off when there is a conversation nearby. We can do two things at once, provided they are both rote or routine tasks (stapling packets of paper while watching TV, for instance), but when we clearly hear a conversation we are not part of, performance drops with increasing clarity of the conversation.

Because speech privacy relates to speech intelligibility inversely, researchers studying the effects of open plan office distractions have borrowed metrics of speech intelligibility (signal-to-noise ratio, STI, RaSTI). They’ve found that workers who can only understand a small part of a conversation still might not be distracted, but performance drops when the sound transmission index (STI) between the source and receiver reaches 0.20 on a scale from 0.00 (completely unintelligible) to 1.00 (completely intelligible). Performance continues to drop as intelligibility increases.

In light of these research findings, designers might consider private offices where cognitively intensive activities are part of the job description. Where open plans are desired, speech privacy can be enhanced by increasing the background noise to a level where it interferes with speech, or at least interferes with conversations that are not too close to your cubicle. When the background noise levels are high enough such that unwanted conversations are 10 decibels (or more) below the background level, almost no one is annoyed; when background noise levels are low enough such that conversations are 5 decibels (or more) above the background noise, almost everyone is annoyed. That makes for a narrow 15-decibel signal-to-noise ratio window with extreme reactions on either end of the range.

Electronic sound masking systems pump loudspeaker background noise into a space in order to cover up conversations. By adjusting the volume of the background noise, one can tune the space so that the more distant and quieter conversations are not heard in other cubicles. Typically located in the plenum above open-office ceilings, these systems make use of a special sound spectrum that drowns out speech, sounds somewhat like a forced air HVAC system, and is thought to be acceptable to occupants, many of whom don’t know such a system exists in their office. Unlike its more annoying cousins—white noise (near-equal sound energy at each frequency) which hisses, and pink noise (near-equal sound energy at each octave band) which whooshes—masking spectra typically fall 3 to 6 decibels per octave at middle- and high-frequencies to “blend in” to an office.
Note
Take care interpreting this graph. It is a compellation of three different studies, one relating performance to speech privacy, a second relating speech privacy to room conditions, and a third relating productivity to office rent. For instance, researchers have not found an 8% drop in productivity in open offices relative to private offices with a door closed, but rather an 8% drop on performance in the kind of speech-privacy acoustical environment found in an open office 15 feet from a talker.

Reference

Background noise levels from masking systems should be no louder than absolutely necessary for satisfactory speech privacy, and should never be louder than 50 dBA. Masking should also be uniformly distributed throughout the space and unobtrusive. Its worth noting that while the Cornell study (cited in the Background Noise section) found significantly higher levels of stress hormones in the urine of the group subjected to performing tasks in the presence of low-level background noise, they were not more likely to report that they were stressed by noise than the group working in quiet. This suggests that, perhaps, even background noise levels that aren’t reported as annoying may trigger physiological stress indicators. To date there are no studies comparing the stress borne of overhearing conversations while working to the stress borne from working in low-level continuous masking noise.
Executives, facilities management personnel, and workers, may prefer open-floor plans because they save space by allowing for greater worker density and they require simpler HVAC and lighting systems. Conventional wisdom has it that open plans foster communication and collaboration because they encourage informal meetings and casual conversations. It’s true that in open plans you don’t have to make an appointment with someone to talk to them, however studies show that conversations in open offices tend to be more superficial because those conversing are self-conscious about being overheard. Again the type of work being done in the space becomes important because the need for continuous collaboration inherent in newsrooms, trading floors, and political campaign offices is not the same as the needs of a call center.

All of this plays out with a backdrop of evolving open-office etiquette. Headphones are ubiquitous in some open plan offices, either to drown out the nearby conversations, or as a sign to colleagues that this cubicle is not taking meetings right now. As the typewriter gave way to the computer, and phone gives ground to email and text messaging, will quieter offices translate to fewer distractions? Will the drop in background noise make conversations more audible to more neighbors, or will, as happened in Boston Public Library’s reverberant reading room (see page XX), office workers become ever more aware that their voices are carrying to those outside the circle of conversation and hush themselves?

The stakes are high because office workers are expensive. On average, an office worker who occupies a given area of floor will cost 6.5 times the rent of that same area of floor, so slight improvements in occupant productivity in offices can leverage large gains in profit. Bolstering the many studies that demonstrate a fall-off in open-office concentration is a Finnish study of 689 workers in 11 offices that found self-estimated daily waste of working time due to noise was twofold for those in open offices compared to those in private offices. As built-environment research disseminates into management courses, decisions will increasingly be filtered through a lenses that includes the effect of indoor quality life-cycle analysis on productivity (or absenteeism, or health effect) gains.

Reference
APARTMENT LAYOUT QUIZ ANSWER

The apartment plan below identifies acoustic concerns in the quiz found on page 2. The plan illustration on the adjacent page improves the apartment, from an acoustic-point of-view.