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Foundations of Acoustic Security

Author: James M. Atkinson

E-Mail: jmatk@tscm.com

Website: http://www.tscm.com/

Phone: (202) 870-8252

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Chapter 10 Glossary

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PART I. MISSION, THREAT, AND EVIDENCE

Acoustic security begins with a practical question of considerable consequence: under what stated conditions may a protected conversation occur without intelligible speech reaching a person who is not authorised to receive it? The question appears simple only while the room is imagined as an abstract box. An actual room is a conjunction of speech sources, reverberant air, flexible and massive boundaries, doors, frames, glass, ceilings, floors, ducts, pipes, conduits, loudspeakers, communications equipment, maintenance practices, neighbouring spaces, listeners, instruments, and institutional authority. Each element changes the physical result or the meaning that may properly be assigned to it. The purpose of this opening part is therefore not to offer an early catalogue of wall types. It is to define the system, the evidence, and the vocabulary by which later design claims will be judged.

Three disciplines are joined here. Architectural acoustics explains how speech energy is generated, reflected, absorbed, transmitted, flanked, masked, and received. Security engineering identifies the asset, threat, access conditions, failure consequences, and layers of protection. Metrology determines what quantity was measured, by what method, with what uncertainty, and under which boundary conditions. A secure-room project becomes unreliable when one of these disciplines is omitted. A wall may be well tested yet badly installed. A completed enclosure may measure well under one vocal effort yet fail under another. A room may provide

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substantial speech privacy and still lack authority for classified discussion. Conversely, a formal approval record cannot repeal the physics of a later unsealed penetration, damaged door bottom, or altered return-air path.

Part I establishes the propositions that later chapters must keep separate. It also establishes the limits of public-source analysis. Public standards and government pages can explain terminology, programme structures, measurement methods, and broad design principles. They do not reveal every controlled criterion, local threat assumption, waiver practice, or acceptance threshold. The scholarly task is not to fill those absences with plausible-sounding detail. It is to identify what is known, what is measured, what is inferred, and what remains a decision for the competent authority.

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Chapter 1. Acoustic Security as a System-Level Discipline

1.1 The Protected Conversation as an Engineering Object

A protected conversation is an information-bearing physical event. The talker produces a time-varying volume velocity at the mouth; the vocal tract shapes that excitation into a spectrum containing fundamental energy, harmonics, formants, consonantal transients, and pauses; the room modifies the signal through direct propagation and reflections; and the enclosing construction distributes part of the acoustic energy among absorption, reflection, structural vibration, and transmission. A listener outside the room does not need to recover a perfect waveform. The security consequence may arise when enough phonetic, lexical, contextual, or speaker-specific information survives to permit understanding. The relevant engineering object is therefore not merely sound level. It is the chain by which meaning can remain available at an accessible receiving position.

This formulation prevents a common conceptual error; a room is not secure because its interior seems quiet from the corridor during an informal walk-through; nor is it secure because a partition bears a high laboratory rating in a product schedule. Both observations may be useful, but each addresses only a restricted condition; the walk-through depends on who spoke, how loudly, where the listener stood, what background sound was present, how long the listener remained, and whether the door, ventilation system, and adjacent spaces were in their ordinary states. The laboratory rating depends on the exact specimen, the test method, the controlled rooms, the frequency range, and the intended suppression of paths other than the test specimen; ASTM E90 expressly cautions that laboratory sound transmission loss does not relate directly to isolation in buildings because

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field construction admits flanking paths; ASTM E336 exists to measure the completed building condition. [1, 2]

The protected conversation should consequently be described by a complete performance statement. At minimum, the statement identifies the information sensitivity, the authorised participants, the maximum credible vocal effort, the source positions, the room configuration, the operating state of mechanical and electronic systems, the adjacent and accessible receiving locations, the expected background conditions, the measurement method, the decision rule, and the authority that will accept or reject the result. Without those particulars, phrases such as secure room, soundproof room, private conference room, or STC wall are too indefinite to function as engineering requirements. They describe an aspiration, not a testable condition.

Government terminology reinforces this need for precision. The United States Department of State publicly distinguishes an acoustic conference room, a treated conference room, a modular treated conference room, and a secure room. Its definition of secure room is substantially architectural, describing continuous construction, substantial materials, controlled penetrations, and substantial doors, whereas treated conference room terminology adds acoustic and electromagnetic attenuation. Those terms are useful within their institutional setting, but they are not interchangeable with a generic laboratory rating or with another government's room taxonomy. [3, 4] The United Kingdom's National Protective Security Authority

1 MB-0340. ASTM International, ASTM E90-23.
2 MB-0279. ASTM International, ASTM E336-25a.
3 MB-1297. U.S. Department of State, 12 FAM 010.
4 MB-1298. U.S. Department of State, 12 FAM 010.

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similarly warns that secure working areas, secure rooms, and secure speech rooms address different uses and threats. [5] [6] A serious specification must therefore state the governing jurisdiction and purpose before it adopts the label.

1.2 The Security Objective Is Controlled Intelligibility, Not Absolute Silence

The phrase soundproof is misleading because no ordinary building enclosure creates an absolute discontinuity in acoustic energy. Speech may be attenuated to a level that is inaudible, intermittently audible, audible but unintelligible, intelligible only with context, or plainly understandable. These conditions are not separated by one universal decibel value. They depend on source spectrum, frequency-dependent isolation, room absorption, receiving-point noise, listener acuity, observation time, language familiarity, and the possible use of aids. The objective for a protected conversation must therefore be expressed as a bounded criterion for audibility or intelligibility under declared conditions, not as a metaphysical claim that no sound leaves the room.

ASTM E2638 embodies this probabilistic logic for unaided listeners outside a closed room. The method combines the room's sound isolation with the background sound at receiving points and permits an estimate of the probability that speech will be audible or intelligible. It does not declare a universal criterion, because owners and authorities must select an acceptable probability in light of their purposes and circumstances. It also excludes determined listening with electronic or electroacoustic equipment

5 MB-1083. National Protective Security Authority, "Secure Working Areas".
6 MB-1081. National Protective Security Authority, "Secure Rooms".

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and assumes that the listener is not touching the room boundary. [7] The limitation is fundamental. A room may perform well for an unaided corridor listener and still require separate assessment for contact transducers, optical vibrometry, communications equipment, or other technical attack surfaces.

The public description of secure speech environments by FCDO Services adopts a similarly functional proposition; it explains that the objective is not zero emitted decibels. The room and its surrounding environment are configured and tested so that words spoken at maximum vocal effort cannot be understood outside; [8] this statement is valuable because it links performance to meaning, source effort, and receiving context; it does not, however, disclose the controlled test thresholds or create a transferable design formula. Its proper use in a public monograph is to illustrate the difference between an intelligibility objective and an absolute-silence myth.

A designer must also guard against the opposite mistake, namely assuming that unintelligible speech is necessarily harmless; even when individual words cannot be recovered, a transmitted signal may disclose occupancy, meeting cadence, number of speakers, emotional intensity, turn-taking, alarms, or the use of particular equipment; in certain missions, those secondary observables may matter. Acoustic security is thus an information-control discipline with several possible protected attributes; speech intelligibility is central, but the threat assessment may also address audibility, voice identification, activity inference, or structure-borne

7 MB-0238. ASTM International, ASTM E2638-24.
8 MB-0466. FCDO Services, “Secure Speech Environments”.

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signatures; each attribute requires its own evidence and should not be hidden inside a single undifferentiated privacy label.

1.3 Source, Path, Receiver, and Authority

The source-path-receiver model provides the clearest first representation of the problem. The source is not merely a loudspeaker or talker. It is a defined acoustic emission with a spatial position, orientation, time history, spectrum, and statistical range; the path is not merely the nominal separating wall; it includes the direct partition, junctions, doors, glazing, floors, ceilings, ducts, pipes, conduits, structural frames, and any equipment capable of converting one form of energy into another. The receiver is not merely a microphone; it is the receiving condition, including position, access, background sound, listening duration, sensor capability, and the criterion by which recovered information will be judged; ASHRAE employs the same source-path-receiver logic for building sound and vibration, including paths through air and structure. [9]

9 MB-0052. ASHRAE, “Noise and Vibration Control”.

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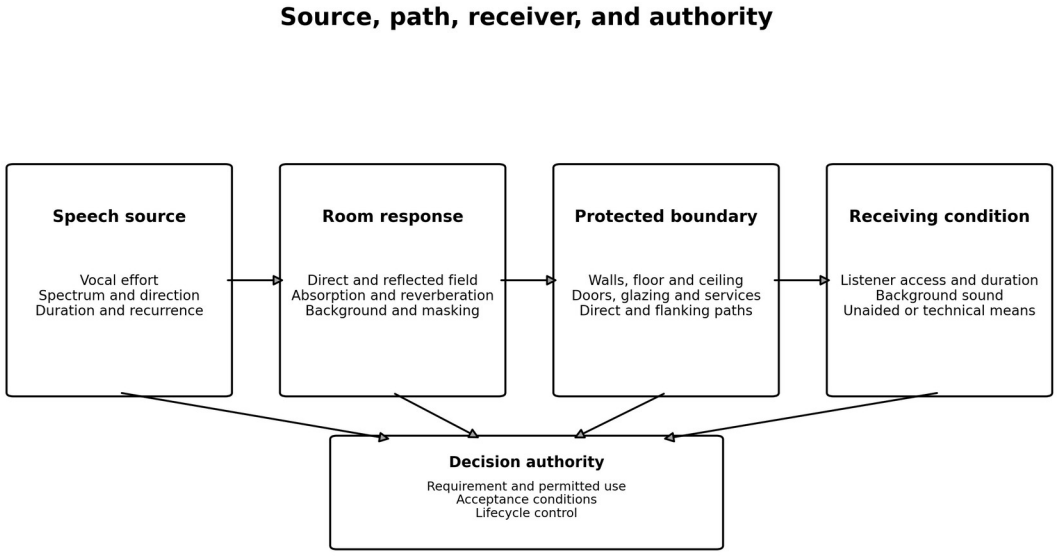

Figure 1.1. Source-path-receiver representation of a protected conversation. The security judgement depends on a defined source, a complete path inventory, a receiving condition, and an authority.

A fourth element must be added for secure-room work: authority. Ordinary building acoustics may be satisfied when a contractually specified sound-isolation value is achieved; a room intended for classified or otherwise specially controlled discussion may additionally require accreditation, certification, authority to operate, or another institutional acceptance; the authority determines which mission, information class, threat environment, and operating constraints are covered. The United States Department of State states that SCI may be discussed only in accredited SCIFs and describes accreditation as the beginning of continuous monitoring, periodic re-evaluation, and documentation review; [10] Canada's Contract Security Program identifies speech privacy rooms and SCIFs as specialised facilities that require prior approval, accreditation, and authority to operate before use. [11] These are governance acts, not acoustical units.

10 MB-1300. U.S. Department of State, 12 FAM 710.
11 MB-1130. Public Services and Procurement Canada, "Specialized secure facilities".

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The model should therefore be read as two linked systems. The physical system asks how information-bearing energy reaches a receiver. The institutional system asks who defined the acceptable residual risk, who witnessed the evidence, who approved deviations, and who remains responsible after changes. A measurement report without an identified decision authority may be technically competent yet administratively incomplete. An approval memorandum without traceable measurement and construction records may be procedurally valid within its narrow context, but it does not teach a later engineer why the room performed or whether a subsequent alteration has preserved that performance.

This dual model also clarifies the role of professional judgement. The acoustician determines methods, limitations, and uncertainty. The architect coordinates boundaries, openings, finishes, life-safety requirements, and constructability. Structural and mechanical engineers control vibration and service paths; security personnel define access, threats, construction surveillance, and operational controls; the accrediting or responsible authority determines acceptance; none can safely replace the others; the strongest project record makes those roles visible and preserves the interfaces between them.

1.4 The Complete Envelope and the Weakest Available Path

Sound transmission through a room is a parallel-path problem. Speech energy may cross the main wall, but it may also pass through the door perimeter, a glazing frame, a suspended ceiling, a common plenum, a raised floor, a return-air duct, a pipe sleeve, a cable bundle, a structural slab, or a rigidly connected partition head. The received energy is the sum of contributions that differ in frequency response, phase, temporal stability,

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and dependence on operating conditions. Improving one path can leave the total result almost unchanged when another path dominates. For that reason, the phrase wall rating is often an inadequate proxy for room performance.

The weakest-path principle is sometimes stated too casually; the controlling path is not always the component with the lowest catalogue rating; area matters, junction geometry matters, source and receiver position matter, and the path may change with frequency. A small door gap can dominate high-frequency consonantal transmission, while a flexible slab or duct may govern lower bands; a large high-performing wall and a small poor-performing opening combine according to transmitted energy, not according to an arithmetic average of their ratings; later chapters will derive the composite transmission relation. At this stage, the decisive point is that the room must be tested and analysed as an interconnected network rather than as a shopping list of individually rated products.

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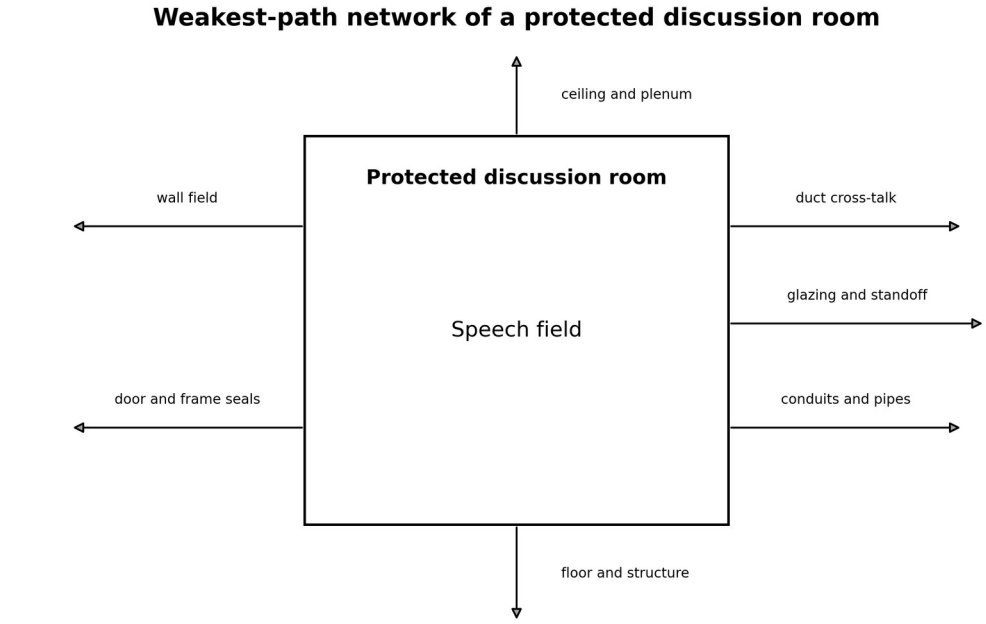

Figure 1.2. Representative parallel paths from a protected discussion room. The effective boundary is governed by the path that delivers the greatest useful speech information to an accessible receiver.

ASTM E336's field framework is important precisely because it includes direct and flanking transmission. It distinguishes noise reduction, normalised noise reduction, and apparent transmission loss, and states that the corresponding single-number ratings are not interchangeable. [12] The standard also recognises non-structural flanking through common ducts and corridor doors. A secure-room commissioning plan should therefore avoid temporary measures that make the room look better than it operates. Sealing a grille only for the test, covering a door gap with tape, switching off an ordinary mechanical system, or moving furnishings into an atypical configuration may produce diagnostic information, but the resulting value must not be reported as the ordinary operational condition.

12 MB-0090. ASTM E336-25a.

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The complete-envelope approach changes design review. Every drawing that penetrates or terminates at the protected boundary becomes acoustically relevant. The architect’s wall type, the structural engineer’s slab edge, the mechanical engineer’s duct route, the electrical engineer’s conduit bank, the fire-protection engineer’s sprinkler penetration, the audiovisual designer’s display mount, and the contractor’s access panel all alter the path network. Coordination cannot be deferred until final testing. By then, the most economical opportunities to change geometry or separate systems have often vanished behind finishes.

1.4.1 Why Small Discontinuities Can Defeat Large Assemblies

The area of a discontinuity may be small while its acoustic consequence is large. Consider a substantial partition whose transmitted power fraction is very low. If a narrow perimeter gap, unsealed sleeve, or open grille has a transmission coefficient many orders of magnitude greater, the gap’s contribution can dominate the combined result despite occupying only a small fraction of the total area. The addition occurs in power, so the poor element is not diluted by averaging decibel ratings. Later chapters will calculate this effect explicitly, but the design implication belongs at the outset: continuity is a measurable performance variable.

Gap geometry affects frequency response. A long, narrow crack can behave differently from an equivalent circular hole. The surrounding cavity, backing material, depth, surface impedance, and line of sight influence attenuation. Door leakage changes as seals compress, thresholds wear, leaves warp, and latches are adjusted. A conduit may appear filled at one face while remaining open through the wall depth. A pipe collar may be

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visually neat but rigidly bridge an isolated lining. Inspection must therefore address the three-dimensional path, not merely the finished surface.

The consequence is particularly severe for speech because a small leak may transmit higher-frequency detail efficiently. The overall level outside the room may remain low, yet fricative and stop information can become recognisable during quiet periods. An engineer who listens only for loudness may miss the problem. Frequency-band measurement near likely discontinuities, combined with speech-based assessment, is more informative.

Small defects also challenge sampling. A room-average microphone array may dilute a highly localised leak near a door corner or grille. Acceptance plans should include systematic boundary scanning or diagnostic observations in addition to room-average metrics where the threat justifies it. The method and result should be described separately so that local diagnostic evidence is not confused with the primary field rating.

1.4.2 Boundary Topology and Parallel-Path Addition

A room boundary is better represented as a transmission network than as a single rated plane; the direct wall, door leaf, door seals, glazing, ceiling return, floor junction, structural frame, duct, conduit, pipe sleeve, and common plenum form parallel routes between the source and receiving domains; each route possesses a frequency-dependent transfer function. The relative importance of a route is therefore not fixed across the spectrum. A heavy wall may dominate little at mid and high frequencies while a perimeter crack governs speech consonants, yet the same wall or its structural junction may remain influential at low frequencies; the engineer

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should map the topology before selecting materials, because a high-performing element cannot compensate arithmetically for a path that bypasses it.

Where separate receiving contributions are sufficiently incoherent for an energetic approximation, their sound-pressure levels combine logarithmically rather than arithmetically. If L_i is the band sound-pressure level produced by path i at a defined receiving position, the combined band level is:

$$L_{total} = 10 \log_{10}\left(\Sigma_i 10^{(L_i/10)} \right) \quad (1.1)$$

The variables are expressed in decibels referenced to the same acoustic pressure; the expression assumes that the mean-square pressures may be added, which is ordinarily a reasonable engineering approximation for multiple broadband building paths averaged over time and space. It is not a universal phase-coherent summation rule. Where deterministic phase relationships, low modal density, tonal excitation, or closely coupled structural paths govern, complex pressures or transfer mobilities may be required. The important first lesson is simpler. The result is controlled by energetic contribution, not by the arithmetic mean of ratings.

Consider three independent paths that produce receiving levels of 31 dB, 28 dB, and 21 dB in one one-third-octave band; their linear energy terms are approximately 1,259, 631, and 126 relative units. The sum is 2,016, giving a combined level of about 33.0 dB. Removing the weakest 21 dB path changes the total only to about 32.8 dB; improving the dominant 31 dB path by 10 dB, without changing the other two, produces contributions of 126, 631, and 126, for a combined level of about 29.5 dB. The calculation shows why a

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small path may be visually conspicuous but acoustically secondary, and why treatment of one dominant route can reveal another path that was previously masked; diagnostic work should therefore be iterative; after each substantial repair, the path ranking must be measured again.

A complementary area-weighted model applies to composite separating surfaces; if a wall comprises elements of area S_i and power transmission coefficient tau_i, a first-order composite coefficient may be written as the area-weighted sum of the element coefficients divided by total area. The logarithmic rating derived from that coefficient is commonly much closer to the performance of the weakest large opening than to the arithmetic average of the individual decibel ratings; this is why a modest door, vision panel, or transfer grille can dominate an otherwise massive enclosure; later chapters derive the composite expression and its limitations in detail. At this stage, it is sufficient to recognise that decibels conceal large linear ratios; a 10 dB difference corresponds to a factor of ten in transmitted power, and a 20 dB difference corresponds to a factor of one hundred.

The topology must include routes that do not terminate in the immediately adjoining room. Speech energy may enter a slab, travel along a beam, radiate into a remote office, or pass through a duct branch to a space that is not visually adjacent. The receiving domain must therefore be defined by access, not by architectural proximity alone. A locked plant room above the meeting space may be a more consequential receiving position than the public corridor, particularly if its ductwork or structure is strongly coupled and maintenance access is broad. Conversely, an acoustically weak path into a continuously controlled buffer zone may present less practical exposure than a stronger path into an uncontrolled tenant space.

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ASTM E336 frames field performance as the combination of direct and flanking transmission and requires the reported quantity to remain tied to the tested location and condition; [13] that principle supports a network view without turning the field standard into a security criterion; the security analysis extends the path inventory to every accessible receiver and then asks which physical and operational controls bound access. A topology drawing should therefore show both energy paths and control boundaries; it should identify doors, structural junctions, services, voids, accessible spaces, and the ordinary operating state; when the drawing changes because a cable tray is extended, a ceiling is opened, or a room use changes, the security argument has changed as well.

1.5 Threat Classes and Listener Access

A room’s required performance cannot be specified intelligently without a threat model; the simplest threat is incidental overhearing by a person occupying a normal adjacent location without special effort. A more demanding condition involves deliberate listening by a person who can select a favourable position, remain for an extended period, or exploit quiet periods; more capable threats may use contact with a boundary, place sensors in adjacent service spaces, observe glazing from a standoff position, or exploit communications and building systems. An insider or maintenance actor may create a new path by altering a seal, opening a damper, introducing equipment, or leaving a ceiling tile displaced; each threat changes both the receiving condition and the evidence needed to claim control.

13 MB-0090. ASTM E336-25a.

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The public scope of ASTM E2638 is deliberately narrower than the full security problem; its assumed eavesdropper is unaided and not touching the boundary; [14] that makes it useful for a defined class of speech-privacy assessment, but it should not be enlarged by rhetoric into proof against determined technical collection. FCDO Services' public TSCM description is broader in method; it includes examination of physical boundaries, human behaviour, physical search, and technical search of the electromagnetic and acoustic environment; [15] the two sources are not contradictory. They describe different questions. One supplies a measurement method for a bounded listener model. The other describes a multidisciplinary counter-eavesdropping activity.

Standoff optical collection illustrates why apparently non-acoustic surfaces may matter. Public UK NACE guidance explains that speech-induced vibration of windows or other hard objects can modulate reflected laser energy and permit remote reconstruction of sound. [16] The appropriate design response is not to assume that a thicker wall solves the problem. The project must consider lines of sight, glazing vibration, curtains or blinds, room layout, object placement, and the broader technical-security programme. This example also demonstrates why the phrase acoustic attack can encompass energy conversion across mechanical and optical domains.

Threat models should remain realistic and authorised. Overstating an exotic attack can waste resources, complicate fire safety, and create a room that is difficult to use. Understating a plausible adjacent-space or service-

14 MB-0077. ASTM E2638-24.
15 MB-0462. FCDO Services, "Technical Surveillance Countermeasures".
16 MB-0461. FCDO Services, "Listening with Lasers".

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path threat can make a costly construction ineffective. The appropriate method is to identify protected information, credible adversary access, available observation time, likely tools, consequences, and compensating controls. Where the controlling programme uses non-public threat assumptions, a public design document should record the existence of that dependency without attempting to reveal or invent it.

Table 1.1. Threat classes, representative receiving conditions, primary evidence, and limitations.

Threat class	Representative receiver condition	Primary evidence	Principal limitation
Incidental overhearing	Ordinary adjacent occupancy, no deliberate positioning	Operational listening observations, field isolation, background sound	Does not address intentional listening
Deliberate unaided listening	Favourable accessible position, extended observation	Speech privacy measurement at defined receiving points	Listener model and vocal effort must be stated
Contact or structural listening	Sensor or listener coupled to a boundary	Vibration survey, structural-path analysis, controlled diagnostic testing	Requires methods beyond ordinary airborne privacy testing
Duct and service-path exploitation	Access to grilles, plenums, shafts, conduits or connected rooms	Path tracing, duct tests, inspection, system-state records	Performance may change with dampers, fans and maintenance state
Standoff optical or other technical collection	Line of sight or remote sensor access	Technical-security assessment, glazing and surface analysis, operational controls	Public methods do not disclose all government countermeasure criteria
Insider or maintenance alteration	Authorised or semi-authorised access to construction and equipment	Configuration control, inspection records, seals, photographs and change approval	A previously accepted room can be degraded without obvious damage

1.5.1 Frequency, Phonetic Information, and Security Relevance

Speech is not uniformly informative across frequency. Vowel energy is often concentrated in lower and middle bands and contributes substantially

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to loudness, prosody, and speaker character. Many consonants, especially fricatives and stop transients, depend on higher-frequency energy and carry a disproportionate share of lexical discrimination. A boundary that provides strong attenuation in one range and a narrow weakness in another may therefore transmit little total energy while preserving information that assists word recognition. This is one reason that a single broadband difference or casual listening impression can misrepresent security performance.

The frequency response of the path network is shaped by different mechanisms. Lightweight panels exhibit stiffness-controlled and resonance-controlled behaviour at lower frequencies, mass-controlled behaviour over an intermediate region, and coincidence effects at higher frequencies. Double-leaf systems introduce a mass-air-mass resonance. Doors and seals commonly display local leakage that becomes particularly important where wavelengths are short relative to gap geometry. Ducts can support longitudinal modes and direct line-of-sight paths, while massive structures may transmit low-frequency vibration over long distances. The dominant path can therefore migrate across the speech spectrum.

A security analysis should preserve one-third-octave or octave-band evidence for that reason. The band data permit comparison with speech spectra, identification of narrow defects, and evaluation of source conditions that differ from the ordinary speech spectrum used implicitly by a rating method. The band result also supports diagnosis after failure. A broad low-frequency depression suggests a different mechanism from an isolated high-frequency leak. The same headline rating can conceal those distinctions.

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Information recovery is also contextual. A listener who hears only fragments may infer missing words from topic, cadence, names, or repeated phrases. Longer observation increases the opportunity to combine fragments. Foreign-language or coded speech may alter the relevance of particular bands. A room used for short scripted briefings may present a different inference risk from one used for prolonged negotiation. These considerations do not make engineering impossible. They require the source and listener assumptions to be explicit and the conclusion to remain bounded.

1.6 Human Behaviour, Equipment, and Operational State

The built envelope cannot be separated from the way the room is used. A door held open for convenience, a conversation continued in the vestibule, a mobile telephone brought into the room, an unapproved conferencing device, or a speakerphone operated at excessive level can defeat an otherwise competent enclosure. The United States Department of State's public SCI policy treats portable electronic devices, new technology, maintenance, and physical modifications as controlled matters within SCIF operations. [17] The policy is not an acoustic manual, but it demonstrates the lifecycle principle: equipment and behaviour change the security condition.

Voice level is an operational variable with direct physical consequences. A person who cannot hear a remote participant may raise vocal effort; a poor reverberant environment may reduce intelligibility within the room and prompt louder speech; an open microphone may encourage the use of loudspeakers; and high background noise may produce a Lombard response. FCDO Services' reference to maximum vocal effort recognises that

17 MB-1262. U.S. Department of State, 12 FAM 710.

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acceptance should not be based solely on comfortable conversational speech. [18] The design basis must state whether the room is intended for normal conversation, formal presentations, amplified programme audio, heated debate, or emergency use. These states have different source levels and spectra.

Equipment also creates paths that are not visible in the architectural section. Loudspeakers couple energy into air and structure. Table microphones and conferencing bars contain transducers, processors, radios, memory, and software; building-automation sensors may include microphones or wireless interfaces. A wall-mounted display creates fastener and cable penetrations; a return-air grille may connect the room to a ceiling void containing other equipment; the correct project question is not whether the equipment is ordinary; it is whether its physical, electrical, acoustic, radio-frequency, software, maintenance, and supply-chain characteristics are compatible with the protected use.

Operational acceptance should be tested under representative states; mechanical systems should be set as they will ordinarily operate, including low-flow and high-flow modes where relevant; doors should be cycled and latched normally. Masking systems should be at approved settings. Conference equipment should be installed. Furniture and absorption should reflect the intended occupancy; if a diagnostic test changes one of these conditions, the change should be documented and the result labelled accordingly; this discipline prevents a laboratory-like demonstration from being mistaken for evidence about the occupied room.

18 MB-0467. FCDO Services, “Secure Speech Environments”.

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1.6.1 Security, Usability, Life Safety, and Resilience

A protected room that cannot be used safely or comfortably will be defeated by its occupants. Excessive door-closing force encourages wedges. Inadequate ventilation encourages doors to be opened. Poor internal intelligibility produces louder speech. Overly aggressive masking causes complaints and unauthorised adjustment. A room that overheats during long meetings may be abandoned for a less controlled space. Security engineering must therefore integrate usability rather than treating it as an indulgence.

Life-safety requirements remain controlling. Fire resistance, smoke control, egress, accessibility, sprinkler coverage, emergency communications, and structural movement cannot be ignored in pursuit of acoustic continuity. The design task is to satisfy both sets of requirements through coordinated details. A fire-rated penetration system may need acoustic analysis. An automatic door bottom must not create an inaccessible threshold. A duct silencer must meet airflow and smoke-control requirements. A room-within-room structure must preserve sprinkler and detector performance.

Resilience also matters. Power loss may disable active masking, powered seals, access control, ventilation, or conferencing systems. The security case should state the acceptable failure state. Some controls should fail secure, while others must fail safe for life protection. Emergency responders may require access under conditions that differ from ordinary operation. The room’s acoustic status during an emergency may be secondary to life safety, but the post-event inspection and restoration process should be planned.

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Maintenance access must be designed rather than improvised. Removable panels, filter access, valve access, and equipment replacement routes can preserve continuity when they are detailed, gasketed, controlled, and inspected. If maintenance requires cutting an unplanned opening, the room's reliability becomes dependent on field improvisation. The most durable secure room is not the one with the fewest conceivable access points. It is the one whose necessary access points have defined performance, custody, and restoration procedures.

1.6.2 Configuration Drift and the Loss of the Trusted State

A secure room is commissioned in one physical and operational state but is used through a succession of later states; lamps are replaced, displays are mounted, conferencing equipment is upgraded, door closers are adjusted, carpet is renewed, ceiling tiles are lifted, ducts are cleaned, sprinklers are altered, and new data cables are introduced. Most changes appear minor when considered by an individual trade; collectively, they can alter the acoustic envelope, the background field, the technical attack surface, or the authority basis on which the room was accepted; configuration drift is therefore not an administrative inconvenience; it is a mechanism of security degradation.

The trusted baseline should describe more than wall construction. It should record the exact door and frame set, seals, closer force, threshold, glazing, ceiling and floor construction, service routes, masking settings, mechanical operating modes, room furnishings, communications equipment, access-control components, and all penetrations. Photographs should establish concealed-work conditions before closure. Drawings should identify dimensions and path relationships, while equipment schedules

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should identify model, firmware where relevant, and authorised interfaces. Field measurements should be linked to that baseline so that a later result can be compared with a known state rather than with an abstract project name.

Change control begins with a screening question: could the proposed work alter a protected path, introduce a receiver, change source conditions, affect background sound, or invalidate an authority decision? The answer is not limited to obvious holes through walls; a wall-mounted display can create rigid bridging, conceal a service opening, add loudspeakers and microphones, or require networked equipment; a new variable-air-volume terminal may change duct breakout and background masking simultaneously; a replacement door bottom may look equivalent but seal differently under floor irregularity. A furniture reconfiguration may move talkers closer to glazing or a duct grille; the review must therefore be multidisciplinary.

The Department of State’s public SCI policy requires prior coordination before physical alterations and before introduction or change of certain equipment within Department SCI facilities. [19] The Department of Energy’s public TSCM workflow likewise illustrates that equipment and construction changes may require technical review. [20] These sources establish governance principles, not universal acoustic procedures. Their relevance lies in the recognition that a protected facility is not permanently validated by its opening-day test. Technical and physical changes can alter the conditions on which acceptance rested.

19 MB-1262. U.S. Department of State, 12 FAM 710.
20 MB-1255. U.S. Department of Energy, Technical Surveillance Countermeasures, public guide.

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A disciplined programme classifies proposed changes by consequence. Category One changes have no credible relationship to the acoustic or technical boundary and may be documented administratively. Category Two changes approach the boundary or alter room use and require design review, inspection, or targeted testing. Category Three changes penetrate, bridge, replace, or materially alter the boundary, building services, secure communications equipment, or receiving-space access and require formal approval and recommissioning. The categories should be defined by the responsible authority, not improvised by the contractor after work begins.

Emergency work presents a harder case. Life safety, water damage, fire response, and continuity may require immediate access or alteration. The security programme should anticipate this conflict by identifying emergency contacts, escort rules, temporary protection, evidence-preservation steps, and post-event inspection. A burst pipe above a secure ceiling can compel rapid intervention, but the urgency does not make the restored condition equivalent to the former baseline. The room may need to remain out of service until the repair, access history, introduced materials, and affected paths have been examined.

The baseline should also record operational states that are not visible in construction drawings; a masking system may have occupied and unoccupied schedules; mechanical equipment may operate at several airflow states. A door may be routinely propped during setup. An audiovisual system may enter a remote-support mode. Security performance should be judged against the most adverse credible authorised state, not merely the easiest state to test; if the room is secure only when users follow an unrecorded ritual, the control is fragile; this

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volume therefore treats configuration management as part of acoustic security engineering, and later chapters connect each material and service detail to inspection triggers and retest obligations.

1.7 Security in Depth and the Life of the Room

Acoustic isolation is one layer in a larger system of protection. Site selection, stand-off, controlled adjoining space, access control, visitor procedures, construction surveillance, equipment approval, TSCM, visual privacy, secure communications, records management, and user training may reduce the probability that any one architectural weakness will produce compromise. Security in depth does not excuse a defective acoustic boundary. It changes the complete risk picture and may supply compensating controls where the competent authority accepts them.

The Department of State's public SCIF policy describes accreditation as the beginning rather than the end of a lifecycle. It requires continuous monitoring, periodic re-evaluation, documentation review, prior approval for physical changes, and control over equipment introduction. [21] Canada's public contract-security manual similarly requires approval before construction of specialised facilities, because unauthorised work can jeopardise later accreditation. [22] These provisions support a general engineering rule: the accepted room is a controlled configuration. The security claim applies to that configuration and to the conditions recorded at acceptance.

Changes need not be dramatic to matter. A replaced door closer may alter latch compression. A carpet renovation may change the automatic

21 MB-1262. U.S. Department of State, 12 FAM 710.
22 MB-1131. Public Services and Procurement Canada, Contract Security Manual, sec. 5.5.

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door bottom’s contact; a new cable pathway may create an unsealed aperture. A fire-alarm upgrade may disturb wall linings. A mechanical balancing exercise may open a damper that was previously closed; a ceiling contractor may remove absorptive lining from a return path; a furniture change may alter internal reverberation and vocal effort; lifecycle assurance therefore requires a change register, defined triggers for technical review, and a means of deciding when retesting is necessary.

The room’s age also affects interpretation. Seal compression, hinge wear, joint cracking, moisture, thermal movement, vibration, and repeated maintenance can change performance gradually; a periodic survey should not be reduced to repeating a single number; it should compare door operation, visible boundaries, service records, room configuration, background conditions, spectral measurements, and prior anomalies. Trend evidence may reveal deterioration before the room crosses an acceptance threshold; the objective is not simply to preserve a certificate; it is to preserve the physical and operational condition on which the certificate depended.

1.7.1 Adjoining Space as a Protective Control

The construction immediately surrounding a protected room can be as important as the room itself. A controlled buffer corridor, secure equipment room, dedicated service zone, or restricted exterior setback changes receiver access. It may move the nearest credible listener farther from a weak path, prevent contact with a boundary, reduce observation time, or permit detection before sustained listening occurs. In a source-path-receiver model, the adjoining space is not empty background. It is part of the path and receiver definition.

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This control must be documented rather than assumed. A neighbouring office assigned to cleared personnel today may be leased to another tenant tomorrow. A locked service cupboard may be opened routinely by contractors. A ceiling void may connect to an uncontrolled corridor. An exterior façade may become overlooked after nearby construction. If the security case relies on controlled adjacency, the facility record should identify the area, access rule, responsible owner, inspection frequency, and trigger for reassessment.

Controlled adjacency can also influence the appropriate engineering balance. A highly isolated inner room within a controlled suite may achieve acceptable risk through combined architectural and operational layers. A room placed directly against an uncontrolled public corridor may require more stringent door, wall, ceiling, and duct performance. The authority may accept different solutions for different sites, but the design team should not conceal the dependence by citing only the partition rating.

The principle has a forensic consequence. When an incident or performance failure is investigated, access history to adjoining areas becomes relevant evidence. Maintenance logs, keys, electronic access records, ceiling work, furniture placement, and temporary occupancy may explain a path or opportunity that was not present during commissioning. The acoustic survey should therefore be coordinated with physical-security records rather than treated as an isolated laboratory exercise.

1.8 The Evidentiary Record

A protected-room claim should be capable of reconstruction by a competent professional who did not witness the original project. That

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requirement does not justify repetitive prose or indiscriminate paperwork. It requires a disciplined set of records that connects mission, design, construction, measurement, and authority. The core file ordinarily includes the owner's requirement, threat and access assumptions, basis of design, drawings, specifications, product and assembly evidence, approved substitutions, mock-up results, inspection records, photographs of concealed work, penetration and door schedules, calibration records, raw measurement data, processing settings, uncertainty analysis, deviations, corrective actions, and the final acceptance instrument.

The evidentiary value of a record depends on provenance and scope; a manufacturer's laboratory report may establish the performance of one specimen, but only if the specimen configuration, dimensions, mounting, materials, laboratory, method, and date are known; an as-built drawing may show intended routing but not prove that a sleeve was sealed. A photograph may prove visible workmanship at one moment but not concealed continuity outside the frame; a field result may describe the room as tested but not a later modification; each record should therefore state what proposition it supports and what it does not.

Measurement records require particular care. NIST Technical Note 1297 and the international Guide to the Expression of Uncertainty in Measurement treat a result as incomplete without a suitable statement of uncertainty and a defined measurement model. [23, 24] For acoustic isolation, significant inputs may include source stability, microphone calibration, spatial sampling, background correction, receiving-room absorption, room

23 MB-0360. NIST Technical Note 1297.
24 MB-0989. JCGM 100:2008.

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volume, instrument linearity, repeatability, and the influence of non-diffuse fields. The uncertainty statement is not an ornamental plus-or-minus value. It informs the risk of accepting a room whose true performance may lie on the wrong side of a decision limit.

Digital integrity must also be proportionate and clear. Raw analyser files, photographs, reports, and spreadsheets should carry stable identifiers, dates, operator information, and checksums where appropriate. Processing steps should be recorded. A screenshot without the underlying data may be useful for communication but is weak as the sole evidence. The project need not imitate a criminal laboratory for every routine measurement, yet a room intended for consequential discussions deserves a record capable of surviving staff turnover, dispute, and later forensic review.

1.8.1 Acceptance Evidence as a Structured Argument

A final technical report is strongest when it is organised as an argument rather than a collection of attachments; the first element states the requirement and authority; the second describes the as-built room and operating state; the third identifies methods, instruments, calibration, sampling, and uncertainty; the fourth presents frequency-band observations and valid ratings. The fifth tests alternative explanations for anomalies. The sixth records repairs and comparable retests. The final element states the narrow conclusion and the matters reserved to the authority.

This structure makes omissions visible. If the report contains a rating but no as-built description, the reader cannot know what was measured. If it contains photographs but no path analysis, the evidentiary purpose of the images is unclear. If it contains a pass statement without uncertainty or

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decision rule, the risk of false acceptance is hidden. If it contains technical results but no authority, the relationship to permitted use remains unknown.

The report should distinguish primary data from presentation graphics. Frequency-band tables, analyser files, calibration records, and room dimensions are primary or near-primary evidence. A plot is a representation of those data; a summary rating is a derived quantity; a narrative conclusion is an interpretation; all are useful, but they occupy different levels of the evidentiary chain; preserving that hierarchy allows a later reviewer to recalculate or reinterpret the result without relying on the author's rhetoric.

A secure-room report may also contain sensitive location, vulnerability, or configuration information. Distribution, storage, redaction, and disclosure should therefore be planned. The public scholarly model can describe the required record structure without publishing an actual facility's exploitable details. This distinction enables rigorous professional practice while respecting operational security.

1.8.2 Acceptance Evidence and the Burden of Proof

Acceptance should be understood as a structured argument supported by traceable evidence. The burden is not satisfied by a collection of favourable numbers detached from configuration. The submission must show that the requirement was applicable, the tested object was the object described in the drawings, the method was suitable for the measurand, the instruments were fit for use, the data were processed correctly, uncertainty and environmental limitations were considered, and the result met the

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decision rule. It must also show that the competent authority reviewed the evidence for the intended use.

The argument begins with identity. The room, separating boundaries, source and receiving spaces, doors, services, and operating state must be uniquely described. A floor plan with room names is insufficient where spaces have been renumbered or altered. The record should use stable identifiers, dated drawings, photographs, equipment schedules, and a change log. Each measurement file should carry the same project and configuration identifiers. This prevents a result from one test state being attributed to another after staff changes or later renovation.

Method suitability follows. A test can be performed competently yet answer the wrong question. Laboratory transmission loss cannot establish the field result. A field isolation rating may not establish speech security at a grille or remote flanking receiver. A speech-privacy method bounded to unaided listeners cannot establish resistance to contact or optical collection. The acceptance file should contain a proposition-to-method matrix identifying exactly which claim each test supports and what remains outside its scope. This matrix is especially valuable when different authorities require separate physical, technical, and operational evidence.

Measurement quality should be presented through an uncertainty statement rather than a ritual recital of calibration dates. NIST Technical Note 1297 and the JCGM Guide describe the separation of Type A and Type B uncertainty components, their combination as standard uncertainty, and the use of expanded uncertainty where an interval is required. [25, 26] A secure-

25 MB-1175. Taylor and Kuyatt, NIST Technical Note 1297.
26 MB-0965. JCGM 100:2008., JCGM 100:2008.

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room report need not reproduce a metrology textbook, but it should identify the components that could change the decision: source repeatability, microphone calibration, spatial sampling, background correction, reverberation measurement, room geometry, processing, and environmental or operational variability. The size and treatment of those components should be proportionate to the decision margin.

The decision rule must be explicit before the result is known. If a specification requires a minimum value, the project must state whether compliance is based on the measured value alone, a guard band, or a rule that accounts for expanded uncertainty. Retrospective selection of the most favourable rule is indefensible. A narrow pass may justify acceptance with restrictions, further measurement, or a conservative remediation, depending on the consequence of false acceptance. The authority should record the rationale.

Acceptance also has a temporal boundary. The record proves the condition at a stated date, subject to the validity of the method and the continued integrity of the configuration. The Canadian Contract Security Manual publicly describes specialised secure facilities as requiring accreditation and an authority to operate before use. [27] The State Department's SCI policy describes accreditation as the beginning of continuing monitoring and re-evaluation rather than a terminal event. [28] These programme statements support a general principle: acceptance creates an authorised baseline, not an immutable property.

27 MB-1131. Public Services and Procurement Canada, Contract Security Manual, sec. 5.5.
28 MB-1262. U.S. Department of State, 12 FAM 710.

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A complete acceptance package should therefore contain, at minimum, the approved requirement, authority correspondence, final drawings, submittals and laboratory evidence, concealed-work records, nonconformance dispositions, test plan, calibration records, raw data, processing files, uncertainty statement, diagnostic records, final results, configuration photographs, restrictions, change triggers, and the signed decision. The package should permit an independent reviewer to reconstruct why the room was accepted without relying on undocumented recollection. Where a document is controlled, the public report should identify its existence and custodial route without reproducing protected content. The strength of the argument lies in traceability and bounded claims, not in the volume of paper.

1.9 Boundaries of This Volume

This volume addresses the public engineering of acoustic isolation, speech privacy, secure-room construction, measurement, and lifecycle assurance. It draws distinctions that are applicable to government, legal, medical, commercial, and other protected discussions. It does not publish controlled criteria, claim access to non-public standards, or provide a formula by which an unauthorised person may certify a classified facility. Public government materials are used to explain terminology, organisational roles, broad lifecycle requirements, and the difference between physical performance and formal approval.

The acoustic boundary is treated in depth, but it is not represented as a complete defence against all technical surveillance. Electromagnetic emanations, radio-frequency systems, optical collection, communications compromise, cyber intrusion, covert devices, and insider activity require

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specialised controls and competent programmes. Canada's public guidance, for example, places electromagnetic information leakage under national EMSEC policy, while its current ITSG-11A content is distributed at Protected A and is not publicly available. [29, 30] The existence of that controlled boundary is a fact. Its technical contents are not available for reconstruction here.

Nor does the book treat consensus standards as regulatory commands in every jurisdiction. ASTM and ISO methods define measurements and ratings. Building regulations may adopt some metrics for civil purposes. Government security programmes may impose additional requirements, use different terminology, or select acceptance conditions that are not public. The project team must identify the applicable authority for the specific facility and date. A standard cited in an academic chapter cannot by itself confer permission to discuss classified information.

The appropriate ambition is therefore rigorous but bounded. Later chapters will explain the physics, construction, testing, and forensic analysis needed to create reliable evidence. They will compare public governmental doctrine without manufacturing equivalence. They will also retain unresolved matters as unresolved. In secure engineering, an explicit limitation is more valuable than a confident invention.

1.10 Principles Carried Forward

The protected conversation is a system-level object. Its performance depends on the source, room, path network, receiver access, operational state, measurement method, and accepting authority. The nominal wall is only one element in that system. A useful design begins by specifying the

29 MB-0402. Canadian Centre for Cyber Security, "Physical and Environmental Protection".
30 MB-0401. Canadian Centre for Cyber Security, "Emission Security Guidance ITSG-11A".

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conversation and the receiver conditions rather than by selecting a headline rating.

The security objective must be stated in terms that can be measured and governed. Absolute silence is neither a realistic physical description nor a satisfactory acceptance criterion. Depending on the mission, the requirement may concern audibility, intelligibility, activity inference, or several attributes together. The source effort and listener model must be declared.

Laboratory evidence, field evidence, occupied speech evidence, and accreditation evidence answer different questions. Their separation is the central discipline of this volume. The next two chapters establish the evidence hierarchy and the terminology needed to preserve that separation throughout design, construction, testing, and lifecycle management.

Chapter 1 Glossary

Acoustic boundary. The complete set of building elements and service interfaces intended to control transmission from a protected room, including walls, floors, ceilings, doors, glazing, ducts, pipes, conduits, joints, and structural connections.

Acoustic security. The risk-governed control of information-bearing sound and vibration so that protected speech or activity does not become usefully available at unauthorised receiving conditions.

Accessible receiving position. A location that a defined listener or sensor can occupy under the threat model, including ordinary adjacent areas, service spaces, exterior lines of sight, or other authorised test positions.

Accreditation. A formal decision by a competent authority that a facility may be used for a defined protected purpose under stated conditions. Accreditation is not a synonym for a measured acoustic rating.

Authority to operate. The institutional permission required before certain specialised facilities may be used. See also accreditation.

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Composite transmission. The combined transmission through several parallel elements or paths, weighted by their energetic contribution rather than by a simple arithmetic average of single-number ratings.

Configuration control. The documented process by which physical, mechanical, electrical, electronic, and operational changes to an accepted room are reviewed and authorised.

Direct path. Transmission through the nominal separating element between source and receiver spaces.

Flanking path. An indirect path around or through the nominal separating element, including structural junctions, adjoining surfaces, ducts, plenums, floors, ceilings, and services.

Listener model. The declared assumptions about a receiver's position, access, acuity, duration, intent, and use or non-use of technical aids.

Maximum vocal effort. A specified high speech-source condition used to test or assess whether words remain understandable outside a protected room. It is not a universal numerical value and must be defined by the applicable method or authority.

Operational state. The documented condition of doors, mechanical systems, masking, equipment, furnishings, and occupancy during use or test.

Protected conversation. Speech whose unauthorised disclosure would create legal, commercial, personal, diplomatic, military, intelligence, or institutional harm.

Receiving condition. The total physical and operational state at the listener or sensor, including location, background sound, access, observation time, and equipment.

Security in depth. The use of multiple independent or complementary protective layers so that failure of one control does not automatically cause compromise.

Source-path-receiver model. An analytical model that describes the generating source, every relevant transmission path, and the receiving condition. Secure-room work adds the decision authority as a linked institutional element.

Speech audibility. The condition in which speech sound can be detected, whether or not the words can be understood.

Speech intelligibility. The degree to which linguistic content can be understood from received speech.

Technical Surveillance Countermeasures. Authorised activities used to identify and mitigate technical surveillance devices, vulnerabilities, and anomalous technical conditions. Acoustic testing may form one part of a wider programme.

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Weakest path. The path or combination of paths that contributes the greatest security-relevant received information under a stated frequency, source, and receiver condition.

Acoustic path topology. A representation of all direct, flanking, service, structural, and equipment routes connecting a defined source domain with accessible receiving domains.

Configuration baseline. The dated and uniquely identified physical and operational state against which later changes, tests, and acceptance decisions are compared.

Configuration drift. Cumulative change in construction, services, equipment, settings, access, or use that can invalidate the conditions on which earlier security evidence depended.

Energetic path addition. Logarithmic combination of incoherent or suitably averaged sound contributions after conversion from decibels to linear mean-square or power quantities.

Parallel path. One of several simultaneous transmission routes between a source and receiver. Treating only the nominal separating wall omits the complete network.

Proposition-to-method matrix. A record identifying which measurement or inspection supports each claimed conclusion and which questions remain outside the method.

Trusted state. The approved and documented configuration whose construction, operating conditions, and evidence form the basis for authorised use.

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Chapter 2. Evidence Hierarchy, Source Method, and Public-Source Boundaries

2.1 Why Source Method Is a Technical Requirement

A secure-room monograph cannot be made reliable by accumulating impressive document titles; the decisive question is how each source supports each proposition; an agency policy may establish who has authority, yet say little about transmission loss. A test standard may define a measurand, yet confer no permission to use a room for classified discussion; a manufacturer’s report may describe one specimen, yet provide no evidence about the field assembly; a field survey may document an installed condition, yet remain silent about the project’s threat assumptions. Source method is therefore part of the engineering method. It controls the boundary between established fact, measured observation, professional inference, and institutional decision.

The need is especially acute in secure-facility work because public and non-public authorities coexist; government websites often disclose programme structure, terminology, responsible offices, and broad requirements; detailed criteria may be incorporated by reference, distributed through controlled channels, or applied by an accrediting official to a particular project. The public scholar must resist two symmetrical errors. The first is to ignore official public material because it is incomplete; the second is to invent the missing content, or to treat a secondary summary as though it were the unavailable primary standard; a defensible volume uses the public material to its full legitimate extent and marks the inaccessible boundary without theatrical speculation.

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Revision control is equally technical. A sound-insulation standard can change its terminology, scope, metrics, or reporting requirements. ASTM E336-25a, for example, distinguishes NIC, NNIC, and ASTC and records a history in which older field-prefixed terms were removed or reframed. [31] ISO 717-1:2020 remains the current published edition and was confirmed through ISO's systematic review process in 2026. [32, 33] A manuscript that cites only the number without edition and date may silently combine incompatible procedures. The same hazard applies to government manuals, building regulations, facilities criteria, and programme checklists.

Source discipline also protects the reader from false certainty; a public standard abstract may establish purpose and scope but not reproduce the normative calculation or all exceptions; a project report may use a proprietary method. A historical document may be valuable for institutional development but no longer govern current work; a controlled document may be publicly named without its contents being available; the source register should make these distinctions visible so that later analysis can be reproduced without pretending that all evidence has equal authority.

2.2 The Evidence Ladder

The evidence hierarchy begins with the authority that governs the facility; law, regulation, executive direction, departmental policy, and programme standards establish obligations, powers, and approval routes; their authority is jurisdictional and date-specific. A United States Department of State facility, a United Kingdom government room, a Canadian contractor facility, and a commercial legal conference suite may all seek strong speech

31 MB-0090. ASTM E336-25a.
32 MB-0899. International Organization for Standardization, ISO 717-1:2020.
33 MB-0898. International Organization for Standardization, ISO 717-1:2020.

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privacy, yet they do not share one automatic accreditation regime; the first task is to identify the owner, location, protected information, responsible authority, and date of decision.

Beneath governing authority sit technical standards and specifications. Consensus standards define methods, quantities, classifications, and reporting conventions. Project specifications translate the owner's requirement into contractual obligations; government technical specifications may add construction, inspection, and management provisions. None should be cited outside its scope; ASTM E90 defines a laboratory method for airborne sound transmission loss of specimens and explicitly separates that result from building performance; [34] ASTM E336 defines field measurements in completed buildings, including direct and flanking paths; [35] ASTM E2638 addresses speech privacy for a bounded unaided-listener model. [36] Each is authoritative for its own measurand, not for every question concerning a secure room.

The next level is empirical evidence. Laboratory reports, mock-up tests, field tests, vibration surveys, leakage investigations, and commissioning records describe particular objects and conditions. Their value depends on traceability. The specimen or room must be identified; the configuration and operating state must be recorded; the instrument and calibration history must be known; and the data must be processed in accordance with the cited method. A single-number result without the frequency-band data, test conditions, and limitations may be convenient for procurement but weak for diagnosis or expert review.

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34 MB-0105. ASTM E90-23.
35 MB-0090. ASTM E336-25a.
36 MB-0077. ASTM E2638-24.

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Professional analysis connects the evidence to the decision; the engineer may calculate composite transmission, identify a likely flanking path, estimate the effect of a door gap, or propose a guard band; those steps are not mere opinion when they are based on a transparent model, valid inputs, and stated uncertainty. They remain analysis rather than direct observation. The distinction matters in reports and litigation; a measured level difference is an observation produced by a method; the conclusion that a certain junction caused the result is an inference that should be tested against alternatives.

The final level is acceptance. The client, contracting officer, accrediting official, or other competent authority decides whether the evidence satisfies the governing requirement. That decision may consider technical performance, risk, compensating controls, schedule, mission, waivers, and operational restrictions. It should not be represented as though it emerged automatically from a sound-level meter. Conversely, an authority's decision should not be used to alter the numerical meaning of a measured result.

Table 2.1. Evidence hierarchy for acoustic-security claims.

Evidence class	Principal question answered	Typical source	Common misuse
Law, regulation, and policy	Who has authority and what obligation applies?	Statute, regulation, departmental manual, security policy	Quoted as if it supplied detailed acoustic physics
Programme or project specification	What must this facility or contract achieve?	Government technical specification, project specification, basis of design	Applied outside its jurisdiction or version
Consensus test or rating standard	How is a quantity measured, calculated, or reported?	ASTM, ISO, ANSI/ASA, BSI, CSA standard	Treated as an accreditation or universal adequacy criterion
Laboratory report	How did a defined specimen perform under a defined method?	Accredited laboratory report	Applied to a different assembly or to field performance

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Evidence class	Principal question answered	Typical source	Common misuse
Field measurement	How did the completed room or path perform in the tested state?	Commissioning or diagnostic survey	Generalised beyond tested positions, states, or uncertainty
Professional analysis	What mechanism best explains the evidence and what change is predicted?	Engineering calculation, model, forensic opinion	Presented as direct observation or stripped of assumptions
Acceptance record	Did the competent authority authorise use for a defined purpose?	Certificate, accreditation letter, authority-to-operate record	Treated as a permanent physical property despite later changes

2.2.1 Five Dimensions of Source Fitness

A source may be authentic yet unfit for a particular claim; source fitness should therefore be evaluated along at least five dimensions: authority, currency, applicability, granularity, and reproducibility; authority asks whether the issuer is competent to establish the proposition. Currency asks whether the edition remains operative or is retained only for historical analysis. Applicability asks whether the facility, jurisdiction, contract, or method falls within the source’s scope; granularity asks whether the available text reaches the clause, configuration, or data needed for the claim; reproducibility asks whether another researcher can locate the same source and understand how it was used.

Authority is not a ranking of prestige. An ISO or ASTM standard may be authoritative for a measurement method, while a local accrediting official is authoritative for permission to use a particular facility; a peer-reviewed paper may be authoritative evidence of a physical phenomenon but have no power to waive a government requirement. A manufacturer’s laboratory report may be the best evidence for one specimen, yet it cannot establish

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that a site-built wall matches the specimen; the source class must correspond to the verb of the proposition.

Currency requires more than copying the year printed in an old bibliography. Standards organisations maintain revision histories, amendments, corrigenda, confirmations, withdrawals, and active work items; government manuals may show chapter-level transmittal codes that differ from dates within subordinate sections. A current web page may preserve an older effective date; the source register should record both the cited edition and the verification date; where a new work item exists, it may illuminate future direction but remains distinct from the active standard; the manuscript should not convert proposed language into present doctrine.

Applicability is often the most neglected dimension; a building regulation for dwellings may be useful comparative evidence but not a secure-speech criterion; a United States Intelligence Community standard may apply only through specified authorities and programmes. A United Kingdom page distinguishing secure working areas from secure speech rooms should not be used to define Canadian accreditation; the question is not whether a source is relevant in a broad thematic sense, but whether it governs or informs the precise decision under discussion.

Granularity controls the strength of the claim. Public metadata for a licensed standard may confirm title, edition, scope, and status, but not every normative formula or exception; a government public page may identify a programme and responsible office while withholding technical thresholds; a product data sheet may state a nominal rating without the laboratory report, specimen description, or frequency data. The manuscript may use

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each source only to the depth it actually supports; where clause-level text is unavailable, the claim must remain at metadata or programme level.

Reproducibility requires stable identification and preservation; persistent locators, digital object identifiers, document numbers, exact titles, access dates, and local checksums reduce the risk that a later reader encounters a changed page or ambiguous edition; a source may still disappear, particularly from operational government websites; where lawful, the research archive should retain the accessed file or a contemporaneous record of the page, together with its checksum and access status. The archive should not bypass access controls.

These five dimensions can conflict. A superseded technical manual may offer excellent granularity and reproducibility but lack current authority; a current programme page may have high authority and currency but little technical detail; a laboratory report may be specific and reproducible but narrow in applicability. The claim-to-source matrix should record these trade-offs rather than collapsing them into a single confidence score; numerical scores can create false precision unless their meaning is rigorously defined; this volume therefore uses explicit status language and limitation notes, permitting the reader to see why a source is controlling, corroborative, contextual, historical, or excluded.

2.3 Authority, Applicability, and Jurisdiction

A source is not controlling merely because it is official; applicability depends on the legal and institutional relationship between the issuer, the facility, and the decision; the Department of Defense’s Unified Facilities Criteria programme describes UFC as mandatory across DoD components

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unless a waiver applies, while distinguishing supplements and component-specific documents. [37] That statement gives UFC a defined governmental role; it does not make every UFC a universal building code for private facilities, nor does it permit a private author to declare that a room satisfies a programme whose responsible authority has not reviewed it.

The Department of State's public FAM provisions illustrate layered applicability; 12 FAM 710 implements Department policy for SCI, refers to ICD 705 and related guidance, requires accreditation before operations, and controls modifications to existing Department facilities; [38] overseas physical-security provisions connect additional FAM and FAH materials to facilities abroad. [39] An acoustic engineer working from public material can accurately state that the Department uses a lifecycle and approval structure; the engineer cannot infer every construction value used at a particular post or reproduce criteria contained in controlled standards.

The United Kingdom's public sources are structured differently. NPSA provides protective-security guidance and separates room categories by threat and function. [40] [41] FCDO Services, home to UK NACE, publicly describes secure speech design, construction, testing, TSCM, and monitoring services. [42] [43] These pages establish a national technical-security context and a performance philosophy. They do not publish the full method by which a given room is accepted for a particular government use. An international

37 MB-0442. Department of Defense, "About the UFC Program".
38 MB-1262. U.S. Department of State, 12 FAM 710.
39 MB-1299. U.S. Department of State, 12 FAM 310.
40 MB-1084. National Protective Security Authority, "Secure Working Areas".
41 MB-1082. National Protective Security Authority, "Secure Rooms".
42 MB-0467. FCDO Services, "Secure Speech Environments".
43 MB-0468. FCDO Services, "Technical Surveillance Countermeasures".

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comparison must preserve that difference rather than force UK terminology into an American SCIF framework.

Canada's public Contract Security Manual identifies speech privacy rooms and SCIFs as specialised facilities, requires a Government of Canada sponsor, directs organisations to obtain approval before construction, and states that authority to operate is required before use. [44] The Canadian Cyber Centre separately describes EMSEC policy and programme roles. [45, 46] These public sources support a governance analysis, but they do not justify importing acoustic thresholds from another country or treating electromagnetic controls as equivalent to speech privacy.

A project source register should therefore include an applicability statement. The statement identifies whether the source is binding, incorporated by contract, informative, historical, comparative, or merely a research lead. It also records the geographical and organisational scope. This prevents a common citation error in which a document is technically authentic but legally irrelevant to the project under review.

2.3.1 Incorporation by Reference and the Contractual Chain

Technical obligations often enter a project by incorporation rather than by direct quotation; a contract may require compliance with a departmental manual, a UFC, a national code, an ASTM method, and a project-specific specification; the design team must trace the chain and determine which document controls when provisions differ. A list of references at the front of a specification is not enough; each requirement should identify whether the

44 MB-1131. Public Services and Procurement Canada, Contract Security Manual, sec. 5.5.
45 MB-0398. Canadian Centre for Cyber Security, "Information Leakage".
46 MB-0400. Canadian Centre for Cyber Security, "Canadian Industrial TEMPEST Program".

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cited document is mandatory, informative, or used only to define a test method.

Order-of-precedence clauses deserve particular attention. A project specification may impose a stricter field criterion than a referenced laboratory standard. A government programme may require approval of substitutions even when a civil building code permits them; a later addendum may modify a drawing; if the documents are inconsistent, the contractor should not be left to choose the least expensive interpretation; the responsible design and contracting authorities should resolve the conflict in writing before affected work proceeds.

Incorporation also fixes an edition unless the contract states otherwise; phrases such as latest edition can create uncertainty when a standard changes during design or construction; automatic adoption of a new edition may alter methods, terminology, or cost after tender; conversely, retaining an obsolete edition may conflict with the authority’s current programme. The project should state a base edition and a controlled procedure for evaluating later revisions.

The contractual chain extends into submittals and tests. If a wall is specified by performance, the submittal must demonstrate equivalence to the cited assembly evidence. If final acceptance is based on a field method, the test agency, room condition, frequency range, report content, uncertainty, and retest process should be stated. A reference without these project decisions can shift unresolved technical risk to the end of construction.

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2.4 Consensus Standards and the Limits of Public Metadata

Consensus standards are indispensable because they stabilise terminology and measurement practice; their authority arises from adoption, contract, regulation, professional acceptance, or the need for comparability, not from their mere existence; a standard's public page usually provides the title, edition, status, scope, and selected significance statements; that information is enough to establish what the standard generally addresses. It is not enough to reproduce normative contours, detailed microphone procedures, mounting conditions, correction limits, or all reporting requirements.

ASTM E413 illustrates the point. Its public description explains that STC is the rating invoked by E90, while E336 invokes NIC, NNIC, and ASTC. It also cautions that single-number ratings correlate generally with familiar building sounds and are not appropriate for sources with substantially different spectra, for which frequency-band analysis is necessary. [47] A scholarly discussion may rely on those public propositions. A worked rating calculation, however, should use the licensed standard or another lawful source that reproduces the method with permission.

ISO 717-1 likewise defines single-number quantities derived from octave or one-third-octave measurements and explains that the ratings simplify requirements while retaining a relationship to source spectra; [48] ISO 16283-1 addresses field measurement between rooms and covers a broad frequency range and room-volume range; [49] these documents support an international comparison of purpose and terminology. The detailed calculation and

47 MB-0288. ASTM International, ASTM E413-22.
48 MB-0943. ISO 717-1:2020., ISO 717-1:2020.
49 MB-0870. International Organization for Standardization, ISO 16283-1:2014.

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method must still be checked against the full text; a source note should not imply that the author has reproduced proprietary tables from an abstract.

Licensed standards also change. The active ASTM pages show that E336 was updated in 2026 and that E2964's current title concerns the normalised insertion loss of doors. A prior manuscript's title or edition may therefore be wrong even when the number looks familiar. The source register should record the verification date and retain the prior value in a conflict note so that the correction is auditable. Silently replacing the edition erases useful editorial evidence.

2.4.1 Copyright, Licensed Standards, and Lawful Technical Use

Many of the most important acoustic standards are copyrighted and distributed under licence. A scholarly author may cite the standard, describe its scope, discuss quantities, and use lawfully obtained methods, but should not reproduce protected tables, contours, or extensive normative text without permission. This is not a mere publishing courtesy. Unauthorised copying can detach the material from its edition and corrections, while a proper citation directs the reader to the controlled source.

The practical drafting rule is to separate public metadata from licensed content; public ASTM and ISO pages establish the active designation, title, status, broad scope, and selected significance statements; clause-level procedures, tolerances, correction limits, and calculation details should be checked against the licensed document; the source register records which level of access supported the claim. A statement based only on an abstract should not be written as though every normative exception had been reviewed.

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Figures and tables derived from standards require equal care. An original explanatory diagram may illustrate the relationship among laboratory, field, and speech assessments without copying a proprietary figure. A calculated example may apply a lawfully used equation while defining variables and assumptions in the author's own form. Where a contour or reference table is indispensable, permission or a lawful citation to the standard should replace reproduction.

This discipline improves technical accuracy. It forces the writer to identify the actual proposition needed rather than importing pages of standard language. It also makes edition control easier because the manuscript cites a stable designation and pinpoints the relevant clause, while the project archive preserves the licensed copy used for review.

2.5 Government Material, Controlled Criteria, and Responsible Silence

Public government material often contains explicit boundaries. The Canadian Cyber Centre's page for ITSG-11A identifies a March 2025 update and a Protected A distribution level; [50] the responsible use of that page is to record the existence, date, subject, and access limitation of the guidance; it is not to infer the protected technical requirements from older secondary accounts. The same principle applies whenever a public page names a controlled standard or a government service describes capabilities without publishing acceptance values.

Responsible silence is an affirmative scholarly practice; it means stating that a source gap exists, explaining why the missing information matters, and limiting the conclusion accordingly. It does not mean omitting the topic;

50 MB-0397. Canadian Centre for Cyber Security, ITSG-11A public metadata.

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for example, public sources may demonstrate that an authority performs secure-speech testing and that maximum vocal effort is considered, while the numerical criterion remains unavailable; the correct conclusion is that the public performance philosophy is known but the controlled decision rule is not. [51]

This approach protects both security and accuracy. Invented thresholds can create false confidence, cause a project to underperform, or mislead a contractor into believing that a public design automatically meets government criteria. Excessive vagueness can be equally harmful if it conceals what public material does establish. A careful text differentiates the known public proposition, the unavailable detail, and the practical consequence: consult the competent authority before design is frozen or construction begins.

Historical and declassified sources require a related discipline. They may illuminate the origin of sound groups, construction practices, or counter-eavesdropping programmes. They should be labelled by date and status. A historical criterion should not be presented as current merely because it remains technically interesting. The source register should separate historical authority from present applicability and record any modern document that supersedes or reframes it.

2.5.1 The Evidentiary Meaning of an Unavailable Standard

The absence of public access to a technical standard is itself a fact, but it is not a licence to invent the standard's content. Secure-facility programmes frequently operate through controlled documents, project-specific

51 MB-0467. FCDO Services, "Secure Speech Environments".

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directions, licensed standards, or criteria disclosed only to authorised participants. Public sources may identify the document number, responsible authority, general purpose, or access classification. Those facts can be cited. The undisclosed thresholds, test protocols, construction details, and waiver practices cannot be reconstructed merely because a knowledgeable reader can imagine what they might contain.

Three forms of responsible silence should be distinguished; the first concerns copyright and licensing; a consensus standard may be commercially available but not lawfully reproducible in full; its public metadata, scope, edition, and selected short passages may support analysis, while the project team must obtain the licensed text for normative use. The second concerns restricted governmental distribution. The public record may confirm that guidance exists while expressly limiting access; the third concerns project-specific security information, where even a generally public method may be applied through non-public threat assumptions, locations, details, or acceptance criteria.

A scholarly monograph should mark the boundary in a way that remains useful; it should identify what the public source establishes, explain which technical question remains unanswered, and direct authorised practitioners to the competent authority or acquisition route; it should not fill the gap with unmarked professional custom. A statement such as “the controlled standard is believed to require” is unacceptable unless supported by a citable public source and clearly labelled as secondary reporting; even then, it should not be used as a design requirement.

Public-source gaps also affect comparative analysis. Two jurisdictions may disclose different portions of their systems; one may publish

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construction criteria but not accreditation thresholds; another may publish programme terminology and service descriptions but little normative detail; the greater volume of public text does not necessarily indicate a more demanding or less demanding system. It indicates a different disclosure surface; comparative tables should therefore include a column for public evidentiary depth and should avoid ranking regimes on unavailable criteria.

The Canadian public metadata for ITSG-11A illustrates the method. The public page can establish the document's title, updated date, and Protected A distribution. [52] It cannot support a reconstructed list of EMSEC thresholds. Likewise, the State Department's public FAM can identify secure-room and treated-conference-room terminology and the organisational route for technical countermeasures, but detailed OSPB and other criteria may remain outside the public text. [53] [54] [55] The correct conclusion is bounded: the programme exists, certain responsibilities and definitions are public, and authorised project teams must obtain applicable criteria through official channels.

Responsible silence should not become an excuse for thin analysis. The physical principles of sound transmission, public test methods, building-service pathways, material behaviour, uncertainty, and general construction quality can be treated deeply without disclosing controlled criteria; the monograph can show how to formulate a requirement, inspect a boundary, validate a method, preserve evidence, and distinguish ratings from accreditation. It can also identify where authority-specific direction must

52 MB-0397. Canadian Centre for Cyber Security, ITSG-11A public metadata.
53 MB-1258. U.S. Department of State, 12 FAM 010.
54 MB-1259. U.S. Department of State, 12 FAM 310.
55 MB-1296. U.S. Department of State, "1 FAM 262.1-2(A)(1), Emanations Countermeasures Branch".

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enter the workflow; what it must not do is present a plausible public synthesis as though it were the missing government standard.

The source register should classify unavailable documents separately from unresolved sources. An unavailable but verified document has a known identity and access limitation. An unresolved source has not yet been confirmed sufficiently to support even that statement. This distinction prevents the research queue from being mistaken for evidence. It also allows later authorised work to update the project without rewriting the intellectual structure of the volume.

2.6 The Claim-to-Source Matrix

A long technical volume benefits from a claim-to-source matrix because ordinary footnotes do not reveal the complete evidentiary structure. Each material proposition receives an identifier, a chapter and section, a concise statement, a source identifier, a pinpoint reference, a source class, a verification status, and any limiting or contrary authority. The matrix is not published as a substitute for readable notes. It is an editorial control that permits systematic review before release.

The claim should be stated at the level at which it can be verified. “STC proves sound security” is too broad and is false. “ASTM E413 assigns the name STC to the single-number rating derived when E90 invokes the classification” is specific and verifiable. [56] “A laboratory STC is an upper bound on field isolation” is a useful shorthand, but it should be qualified because field configurations and metrics differ; e90’s public significance section

56 MB-0094. ASTM E413-22.

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explains that laboratory ratings do not directly relate to building isolation and generally represent an upper limit under the standard's assumptions. [57]

Pinpoint citation is essential. A 200-page government manual cited at the chapter level leaves the reader unable to locate the controlling statement. Section, paragraph, clause, annex, table, or page should be supplied where available. Web material should include the page title, issuing body, revision identifier or publication date, stable locator, and access date. When a public page changes, the archived local copy and checksum preserve the version used in the analysis.

Contrary authority belongs in the same matrix. If a manufacturer's report predicts high performance while a field test shows a lower result, both records should be retained. If two standards use similar names for different quantities, the difference should be explicit. If a government page uses a room label that resembles a consensus acoustic term but carries a different institutional meaning, the matrix should prevent accidental merger.

The matrix also helps control repetition. Once a proposition has been fully established in one chapter, later chapters can cite and apply it rather than restating several paragraphs of background. Cross-reference is not merely an editorial convenience. It preserves a single authoritative treatment and reduces the risk that later paraphrases drift into inconsistency.

2.6.1 Confidence Levels for Source Use

The source register should assign a confidence and use status that is more informative than verified or unverified. A source may be authentic but

57 MB-0105. ASTM E90-23.

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unsuitable for the proposed claim; a government web page may be authoritative for organisational responsibility but not for a numerical design value; a laboratory report may be authentic for one specimen but inapplicable to the proposed wall; verification therefore has at least three dimensions: identity, applicability, and sufficiency.

Identity asks whether the source is what it purports to be. The issuer, title, date, edition, and locator are checked. Applicability asks whether the source governs or meaningfully informs the facility, jurisdiction, date, assembly, and quantity. Sufficiency asks whether the source contains enough detail to support the precise proposition. A public abstract may pass identity and broad applicability but fail sufficiency for a worked calculation.

A useful internal scale is: controlling, supporting, contextual, historical, discovery lead, and excluded; controlling sources govern the decision or method. Supporting sources corroborate or explain. Contextual sources provide background without deciding the claim. Historical sources illuminate development. Discovery leads point to material requiring verification; excluded sources are retained in the audit trail but not cited as support; the scale should be accompanied by reasons, not assigned mechanically.

The same source can occupy different statuses for different propositions. The FCDO Services secure-speech page is controlling evidence that the service publicly describes maximum-vocal-effort assessment and non-zero-decibel design philosophy. [58] It is not sufficient evidence for a concealed numerical acceptance threshold. The Canadian ITSG-11A metadata page is

58 MB-0467. FCDO Services, “Secure Speech Environments”.

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controlling evidence of title, update, and restricted distribution, but not of technical content. [59] Such proposition-specific classification prevents overreach.

2.7 Manufacturer Reports and Assembly Evidence

Manufacturer data can be valuable, particularly for proprietary door sets, glazing systems, isolation clips, damping products, modular rooms, and tested wall assemblies. Its evidentiary strength depends on the test report, not the brochure headline. The report should identify the laboratory, method, date, specimen dimensions, materials, fastener pattern, framing, cavity treatment, seals, mounting, and any deviations. A rating without this information cannot be confidently transferred to the proposed assembly.

Substitution is a major source of error; two boards of the same nominal thickness may differ in surface density and bending stiffness; a different steel stud gauge, spacing, or flange width can change coupling; mineral wool density and placement may differ; sealants can harden or shrink. Door hardware can alter compression. A project that specifies “or equal” without defining the acoustic equivalence risks accepting a product that matches dimensions but not the tested mechanism.

Test reports also represent a specimen, not a guarantee of field workmanship. The laboratory may construct the assembly with close supervision and ideal continuity. Field installations include junctions, service penetrations, tolerances, sequencing, and trade interfaces. The report should therefore inform design and submittal review, while field acceptance

59 MB-0397. Canadian Centre for Cyber Security, ITSG-11A public metadata.

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remains dependent on the completed room and applicable method. ASTM E90's separation from E336 is again instructive. [60, 61]

A scholarly source register should distinguish manufacturer-authored claims, independent laboratory reports, and third-party certifications. It should record whether the test report itself was reviewed or only a summary sheet. If the report is confidential, the published manuscript should state the evidence class and limitation without disclosing protected commercial information.

2.7.1 Peer-Reviewed Literature, Textbooks, and Triangulation

Government and standards sources define authority and method, but they do not always explain the physics in sufficient depth for design. Peer-reviewed research and recognised textbooks provide derivations, experimental comparisons, material behaviour, and critiques of simplified models. Their role is analytical rather than regulatory. A journal article may show how stud coupling changes transmission, but it does not become a project requirement unless adopted by the design or authority.

Literature review should be systematic enough to expose disagreement. Search terms, databases, date ranges, inclusion criteria, and subject categories can be recorded for major technical questions. Studies should be compared by specimen, boundary conditions, frequency range, and measurement method. A result from a small laboratory panel may not transfer to a full-height wall. A numerical model validated against one material may not support another.

60 MB-0105. ASTM E90-23.
61 MB-0090. ASTM E336-25a.

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Triangulation is strongest when different source classes converge. A standard defines the measurand, a textbook explains the physical model, a peer-reviewed experiment tests the mechanism, and a field case demonstrates practical consequences. No single source is forced to perform every function. Where they diverge, the differences guide further testing or identify the limits of generalisation.

Textbooks require edition control and critical reading. A classic treatment may remain physically sound while its standards references are obsolete. A new handbook may summarise current practice but omit derivation. The manuscript should cite the source for the proposition actually used and should not decorate a paragraph with unrelated authorities. Citation quantity is a poor substitute for source fit.

2.7.2 Specimen Identity, Substitution, and Manufacturer Reports

Manufacturer evidence is indispensable in many acoustic projects, but its probative value depends on specimen identity; a report does not support a product family in the abstract; it supports the tested configuration, subject to the laboratory method, tolerances, mounting, size, materials, accessories, seals, and any stated limitations. Marketing literature often compresses this complexity into a headline rating; the design and submittal process must recover the underlying report before relying on the number.

The identity problem is acute for multi-component assemblies. A door result depends on leaf construction, dimensions, frame, glazing, hinges, latch pressure, perimeter seals, threshold, automatic bottom, and installation; a gypsum partition result depends on board type, thickness, surface density, stud material, stud depth and spacing, fastening, cavity

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depth, insulation, joint treatment, specimen dimensions, and perimeter mounting. A silencer result depends on size, airflow, pressure loss, lining, internal geometry, test direction, and duct termination; substituting one component can change the mechanism even when the product description appears equivalent.

A responsible submittal review creates a test-to-proposed-assembly crosswalk; each report attribute is compared with the proposed construction and classified as identical, conservatively bounded, materially different, or unknown; a difference is not automatically disqualifying. A larger door may perform differently because of panel modes and seal length; a smaller door is not automatically better if hardware or edge construction changes; a denser board may add mass but alter bending stiffness and coincidence behaviour; a different insulation may change flow resistivity and cavity damping. Engineering judgement must identify the mechanism and the evidence needed.

Field substitution also interacts with fire, structural, accessibility, and operational requirements; a heavier door can exceed hinge or closer capacity. A threshold that improves the acoustic seal can create an accessibility conflict or maintenance problem; additional gypsum layers can alter fire-listed details, deflection capacity, and support loading; acoustic approval should therefore be integrated with the complete code and performance review rather than issued as an isolated product comparison.

The report’s laboratory status should be verified. Accreditation scope, test method, report number, date, specimen drawings, deviations, and signatures should be recorded; a report marked preliminary, engineering estimate, or calculation should not be represented as a completed

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accredited test; where a manufacturer supplies only a summary, the project should request the full report or treat the claim as unverified. ASTM E90's method and ASTM E413's classification are tied to the tested specimen and frequency-band data. [62, 63] Their public descriptions do not support transfer to an undocumented variant.

Older reports may remain technically useful, particularly for durable products whose construction has not changed. They require lineage evidence. The manufacturer should confirm whether materials, suppliers, tooling, seals, hardware, and production methods remain materially identical. Corporate acquisition or model-number continuity does not prove construction continuity. Where lineage cannot be established, a new test, engineering analysis, or conservative design alternative may be necessary.

Manufacturer reports should also be used diagnostically rather than ceremonially; the frequency curve can reveal resonance, coincidence, seal leakage, or other limitations that a single number hides. Comparing the proposed source spectrum with the curve may show that a highly rated product is poorly suited to the mission; conversely, a modest headline rating may conceal strong performance in the bands most relevant to a bounded application; the decision should be documented in terms of spectrum, mechanism, and complete-envelope contribution.

This volume therefore treats manufacturer data as configuration-specific empirical evidence. It is neither dismissed as marketing nor elevated to universal authority. Its proper role is to support a defined design

62 MB-0105. ASTM E90-23.
63 MB-0094. ASTM E413-22.

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proposition within an auditable chain that continues through procurement, installation, field measurement, and acceptance.

2.8 Measurement Evidence and Uncertainty

Measurement is often treated as the highest evidence because it appears numerical; a number is persuasive only when the measurand, method, configuration, and uncertainty are known. The measurand is the particular quantity intended to be measured, not a general idea such as privacy; ASTM E336 offers several quantities and ratings for field isolation, each with conditions and meanings; [64] selecting ASTC when the room geometry does not permit it, or treating NIC as though it were an assembly property, changes the proposition being reported.

NIST Technical Note 1297 separates uncertainty components evaluated by statistical methods from those evaluated by other information and combines them through a measurement model. [65] JCGM 100 provides the broader international framework. [66] Acoustic field tests may contain Type A contributions from repeated spatial samples and Type B contributions from calibration, instrument specifications, room-volume estimates, background corrections, and method implementation. Correlations matter when several results share the same instrument or calibration.

Uncertainty is not the same as error, tolerance, or observed variation; it characterises the dispersion of values reasonably attributable to the measurand under the model; a result near an acceptance limit should therefore be judged with a declared decision rule. A guard band may reduce

64 MB-0090. ASTM E336-25a.
65 MB-1175. Taylor and Kuyatt, NIST Technical Note 1297.
66 MB-0965. JCGM 100:2008., JCGM 100:2008.

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the probability of false acceptance by requiring the measured result to exceed the nominal criterion by a margin related to uncertainty; the choice of risk belongs to the contract or competent authority, not to an unrecorded assumption by the tester.

Diagnostic measurements have a different purpose from acceptance tests; temporarily sealing a grille, blocking a door gap, or isolating a duct can identify a dominant path. ASTM E336 permits diagnostic use but requires modified conditions to be clearly labelled; [67] the report should retain both baseline and modified results and explain the inference; the improved number after a temporary intervention is not the accepted room performance; it is evidence that the altered path was influential.

2.8.1 Decision Risk and the Consequences of Error

Measurement uncertainty becomes operationally significant when a decision is made; a false acceptance occurs when the reported evidence leads to approval although the true performance does not meet the requirement; a false rejection occurs when a satisfactory room is rejected; the relative consequences are rarely equal; in a high-consequence protected environment, the authority may prefer a conservative guard band and additional investigation near the limit. In a routine commercial privacy project, the balance may differ.

Decision risk cannot be managed by rounding alone; the test method, uncertainty budget, acceptance limit, and guard band should be agreed before final measurement. Otherwise, the team may select a favourable interpretation after seeing the result; a value exactly at the nominal

67 MB-0090. ASTM E336-25a.

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threshold is not automatically a confident pass when expanded uncertainty overlaps the failure region; conversely, an unexplained demand that every result exceed the criterion by an arbitrary number may create unnecessary cost.

The uncertainty model should reflect correlated inputs; several rooms tested with the same calibrator share part of the calibration uncertainty. Repeated microphone positions are not independent if the source drifts; a room-volume estimate can affect several bands or derived quantities; treating correlated contributions as independent can understate or overstate uncertainty; JCGM 100 and NIST TN 1297 provide the general framework, while method-specific studies and professional judgement identify the acoustic inputs. [68, 69]

The report should express the decision rule in plain language. It should state whether the criterion applies to the measured value, a lower confidence bound, a guard-banded limit, or another approved rule. It should also identify who selected the risk policy. That transparency separates technical measurement from institutional risk acceptance.

2.9 Reconciling Conflicts and Contradictions

Conflicting evidence should not be smoothed away. It may arise from edition changes, different metrics, different configurations, statistical variation, workmanship, or genuinely inconsistent sources. The first step is to normalise the question. Are the documents measuring the same quantity, frequency range, specimen, receiver condition, and operating state? Many apparent contradictions disappear when the measurands are separated.

68 MB-1175. Taylor and Kuyatt, NIST Technical Note 1297.
69 MB-0965. JCGM 100:2008., JCGM 100:2008.

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Where the conflict remains, the record should preserve both sides. A laboratory wall report and a lower field result may be entirely compatible because the building introduces flanking and workmanship effects; a civil building-regulation requirement and a secure-speech criterion may both be valid but serve different purposes; england's Approved Document E addresses resistance to the passage of sound in building regulation. [70] It should not be presented as a secure-speech approval standard.

Date and status can resolve other conflicts. A superseded edition may have governed an older facility but not a new project. An archived criterion may remain relevant to maintenance of an existing installation. A new edition may change terminology without invalidating all prior data. The source-conflict memorandum should state the old position, verified current position, chapters affected, and required correction.

When no resolution is possible, the uncertainty belongs in the conclusion. The designer may recommend a conservative assumption, a mock-up, a field investigation, or consultation with the authority. The worst response is to select whichever source supports the preferred design and omit the other. Scholarly restraint is visible in the treatment of inconvenient evidence.

2.9.1 Current, Superseded, and Legacy Requirements

A facility can legitimately remain governed by a document that is no longer current for new construction. An older standard may be incorporated into the original contract or accreditation basis. A later edition may be used for diagnostic comparison without retroactively changing the original

70 MB-1302. UK Government, Approved Document E: Resistance to the Passage of Sound, published 4 March 2015.

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obligation. The source register must therefore distinguish current authority for new work from legacy applicability to an existing room.

The distinction affects forensic conclusions. If a 2012 room was built under a 2010 programme specification, the engineer should first determine whether it complied with that accepted basis. The engineer may then compare the room with modern practice and recommend upgrades. Declaring the original room defective solely because a later edition changed terminology or method would be historically unsound. Equally, continuing to design new rooms to a superseded criterion merely because it appears in an old template is unacceptable.

Supersession is not always simple. A document may be withdrawn and replaced, archived without replacement, incorporated into another publication, or retained for existing projects. Agency websites may show both current and historical copies. The source-conflict memorandum should record the transition and the chapters affected. Procurement templates and standard details should be searched for obsolete references before release.

The same care applies to common language. Terms such as field sound transmission class may appear in legacy reports even though current ASTM practice uses other field metrics. The manuscript should explain the historical term when reviewing old evidence, then use the current designation for new work. This approach preserves intelligibility without perpetuating obsolete nomenclature.

2.10 Records, Archives, and Reproducibility

The source archive should preserve the exact version used. Public web pages can change without a formal new edition. A local PDF or web capture,

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access date, and checksum provide an evidentiary anchor. Paid standards should be stored and used in accordance with licence terms. Bibliographic metadata should identify the lawful source without reproducing copyrighted tables beyond permitted use.

File naming should be intelligible outside the project team. A robust name includes source identifier, issuer, document number, short title, edition or date, and file type. The archive should separate current controlling sources, superseded sources, historical sources, research leads, and unresolved items. A manifest records file size, checksum, provenance, and review status.

Editorial records should be equally clear. The chapter evidence map identifies planned claims and sources; the reconstruction register records which concepts were retained from the predecessor manuscript and which text was independently rewritten; the table register states the source and purpose of each table; the equation register records derivation and validation; these records do not belong in the published narrative, but they protect the intellectual integrity of the work.

Reproducibility has limits. A later reader may not have access to a controlled document, proprietary report, or test site. The publication should distinguish reproducible public reasoning from project-specific protected evidence. It should never imply that a reader can independently accredit a government room from public pages alone. What can be reproduced is the logical structure: the question, source class, public proposition, limitation, measurement, inference, and decision boundary.

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2.10.1 Digital Fixity, Versioning, and the Reproducible Archive

A research archive is reproducible only when the retained object can be shown to be the object that was reviewed. File names are not sufficient. A later download may bear the same name but contain a revised document, a corrected scan, or a different web export. Digital fixity is established by a cryptographic checksum calculated over the retained bytes. The checksum does not prove that the document is authentic or correct, but it permits later detection of unintended change within the archive.

Each archived source should have a manifest record containing the source identifier, issuer, exact title, edition or revision, publication date, access date, original locator, local file name, file size, media type, and checksum. Where a document is extracted from a larger compilation, the record should identify the parent file, page range, and extraction method. Where optical character recognition has been used, the image original should be preserved and the OCR text treated as a derivative with its own checksum and quality note.

Versioning must distinguish source evolution from editorial evolution. A government standard may issue a new change, while the manuscript may also move from draft to draft. The source register should record which source version supported which manuscript proposition. If a source changes after drafting, the claim-to-source matrix allows targeted review. Without that mapping, a project may update the bibliography while leaving old technical claims in the body.

Web pages present special problems. They can change without a visible version number. The archive should preserve a lawful contemporaneous representation where permitted, or at least a dated capture record

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containing the page title, relevant text, access date, and locator; dynamic pages may display content assembled from several systems; the record should state whether the citation was verified against the rendered page, a downloadable document, or metadata only. A screenshot can document appearance but is not a substitute for searchable text and source context.

Access-controlled and licensed sources require additional care. The archive must not redistribute content beyond licence or authority. It may retain metadata, notes, and a record that an authorised reviewer consulted the source. The claim matrix should identify the clause or page without reproducing excessive protected text. This approach preserves the audit trail while respecting copyright and security controls.

The manuscript itself also requires fixity at release; the final DOCX, authoritative PDF, source registers, and QA reports should receive checksums and be placed in a manifest; the PDF used to validate page locators must be tied to the exact DOCX version from which it was rendered. If a later edit changes pagination, the index and checksum set become stale and must be regenerated; a checksum cannot make a defective document correct, but it can prevent an unrecorded alteration from being mistaken for the reviewed edition.

Reproducibility extends to analytical processing. Calculation workbooks, scripts, settings, raw measurements, and exported figures should be archived with version information and input dependencies. Where proprietary software is used, the report should identify the software and version and preserve sufficient intermediate data to permit independent checking. Automated processing should not become a black box that

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converts raw acoustic observations into ratings without a recoverable method.

The archive is ultimately an institutional memory system. Its purpose is to allow a competent person, years later and without the original team, to determine what evidence existed, what version was used, what calculations were performed, what limitations were known, and why a decision was made. That objective is aligned with the traceability principles of measurement science. [71, 72, 73] It is also indispensable to lifecycle assurance, because later modifications can be judged only against a trusted and recoverable baseline.

2.11 Editorial and Ethical Rules

Technical writing about protected facilities carries two obligations; it must be sufficiently precise to avoid misleading designers, and sufficiently restrained to avoid fabricating or disclosing criteria that are not lawfully available. The balance is achieved by disciplined sourcing, not by vague prose; a public document can explain why a method matters, what it measures, how its results differ from another method, and what evidence a project should retain; it can also state plainly where the competent authority must supply project-specific direction.

Attribution must remain accurate. A paraphrase should not enlarge the source; a quotation should be brief, exact, and necessary; manufacturer claims should be identified as such. Historical accounts should not be allowed to masquerade as current policy; internal project volumes may

71 MB-1175. Taylor and Kuyatt, NIST Technical Note 1297.
72 MB-0965. JCGM 100:2008., JCGM 100:2008.
73 MB-1057. National Institute of Standards and Technology, “Calibration Policies”.

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assist discovery, but they should not become sole authorities for external facts; self-reference is appropriate only where the earlier work contains original analysis that is itself relevant and adequately supported.

The published volume should disclose material limitations. Public-source doctrine is incomplete by design in some fields; licensed standards are not fully reproduced; composite case studies are instructional, not reports of actual accredited facilities; structured internal review is not external peer review; these statements strengthen rather than weaken the work because they define the proper scope of reliance.

Finally, the source apparatus should be usable. Notes should lead the reader to the exact authority. Registers should be sorted and searchable. Acronyms should be controlled. Cross-references should replace repeated background passages. A scholarly monograph is not merely a long text with many citations. It is an organised evidentiary system in which the reader can see why each proposition is present and how firmly it is supported.

Chapter 2 Glossary

Acceptance record. A document by which a competent authority records that stated evidence satisfies a defined requirement, subject to any limitations or conditions.

Applicability. The legal, contractual, organisational, geographical, and temporal relationship that determines whether a source governs a particular project.

Claim-to-source matrix. An editorial register linking each material proposition to a verified source, pinpoint citation, source class, limitations, and contrary authority.

Consensus standard. A technical document developed through an established standards process. Its project authority depends on adoption, contract, regulation, or professional use.

Controlling authority. The person or organisation empowered to define, approve, waive, or accept requirements for the facility and protected use.

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Controlled criterion. A requirement whose detailed content is not available for unrestricted public distribution. Its existence may be public while its values or methods remain restricted.

Decision rule. The documented rule by which a measurement result and its uncertainty are compared with an acceptance limit.

Diagnostic measurement. A measurement performed to identify a mechanism or path, often with controlled temporary modifications. It must not be confused with ordinary operational performance.

Evidence class. A category describing the nature and authority of a source, such as law, policy, standard, laboratory report, field measurement, analysis, or acceptance record.

Expanded uncertainty. A stated interval obtained by multiplying combined standard uncertainty by a coverage factor, subject to the assumptions of the measurement model.

Historical source. A document valuable for chronology or prior practice but not presumed to govern current work.

Manufacturer report. Product or assembly evidence issued by a manufacturer or its laboratory. The exact specimen and test conditions determine its applicability.

Measurand. The particular quantity intended to be measured, defined sufficiently to distinguish it from related quantities.

Normative provision. A requirement within a standard or specification that forms part of the prescribed method or obligation.

Pinpoint citation. A reference to the specific page, clause, section, table, figure, or paragraph supporting a proposition.

Primary source. An original official, technical, experimental, or contemporaneous record rather than a later summary of it.

Public-source boundary. The point beyond which public material does not disclose the detailed criteria, threat assumptions, or methods used by a controlled programme.

Research lead. A source or reference that identifies a potentially relevant document but is not itself verified or sufficient for a controlling claim.

Source-conflict memorandum. A register preserving inconsistent or superseded source positions, their resolution, and the resulting editorial correction.

Standard uncertainty. Uncertainty expressed as an estimated standard deviation.

Type A evaluation. Evaluation of an uncertainty component by statistical analysis of observations.

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Type B evaluation. Evaluation of an uncertainty component using information other than statistical analysis of repeated observations, such as calibration data or specifications.

Verification status. The recorded condition of a source after checking title, issuer, edition, date, status, access, and scope.

Applicability statement. A source-register entry that records the jurisdiction, facility, contract, object, method, date, and decision to which the cited authority applies.

Digital fixity. Evidence, ordinarily a cryptographic checksum, that retained file bytes have not changed since the value was calculated.

Granularity. The depth at which a source supports a claim, ranging from public metadata to clause-level technical detail and configuration-specific data.

Source fitness. The combined suitability of a source in authority, currency, applicability, granularity, and reproducibility for a particular proposition.

Specimen crosswalk. A comparison between every material test-report attribute and the proposed assembly, classifying each attribute as identical, bounded, different, or unknown.

Unavailable verified source. A source whose identity, role, and access restriction are confirmed, but whose controlled or licensed content is not available for unrestricted analysis.

Unresolved source. A putative source whose identity, edition, status, or content has not been confirmed sufficiently to support a claim.

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Chapter 3. Terminology and the Four-Proposition Model

3.1 Why Four Propositions Are Necessary

Secure-room projects repeatedly fail in language before they fail in construction; a laboratory test result is described as though it were a property of every field installation; a field isolation value is described as though it proved that no words can be understood outside; a speech-privacy result is described as though it constituted governmental accreditation. Each statement removes a necessary condition from the argument; the four-proposition model restores those conditions by separating specimen performance, installed performance, occupied speech performance, and formal authority.

The model is not merely an editorial taxonomy. It determines what evidence must be collected and what corrective action follows a failure; if a laboratory specimen does not meet its specified rating, the assembly concept, materials, dimensions, or test evidence may be defective; if a field result is lower than the laboratory expectation, flanking, workmanship, geometry, or services may govern. If field isolation is substantial but speech remains intelligible, the source condition, background sound, receiving position, or frequency distribution may be different from the assumed condition; if all technical evidence is favourable but the room lacks approval, operations must still not begin where the governing programme requires accreditation.

Each proposition has its own subject, verb, and object; a specimen achieved a laboratory result under a method; a completed building achieved a field result in a tested configuration; an occupied room provided a stated probability or degree of speech privacy under declared source and receiving

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conditions. A competent authority authorised use for a defined purpose; precision in grammar reflects precision in engineering.

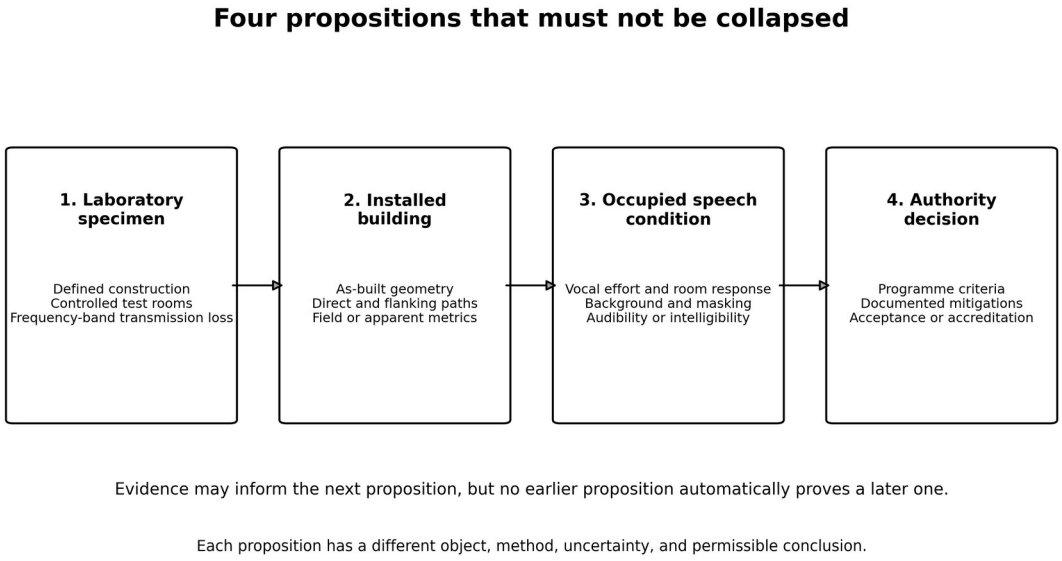

Figure 3.1. Four propositions in the evidentiary chain. Evidence may flow from left to right, but no earlier proposition automatically proves a later one.

3.2 Proposition One: Laboratory Specimen Performance

The first proposition concerns a defined specimen installed between laboratory test rooms; ASTM E90 measures airborne sound transmission loss of building partitions and elements under conditions intended to make the specimen the principal transmission path and to approximate diffuse sound fields; [74] the result is frequency-dependent transmission loss. When ASTM E413 is invoked, those band values can be reduced to a single-number sound transmission class; [75] the test establishes how that specimen performed under that method; it does not establish the performance of a differently built wall, a complete room, or an occupied security condition.

74 MB-0105. ASTM E90-23.
75 MB-0094. ASTM E413-22.

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The specimen identity is therefore inseparable from the result. A useful report describes surface densities, board types, number of layers, stud material and spacing, cavity depth, insulation, fasteners, joint treatment, dimensions, perimeter mounting, and any doors or services included. A nominal label such as double-stud wall is insufficient. Two assemblies bearing that label may differ in leaf mass, structural coupling, cavity resonance, workmanship, and critical-frequency behaviour.

Laboratory control is both strength and limitation; the controlled rooms reduce uncertainty from unrelated paths and permit comparison among specimens; that is precisely why the result may exceed field performance. The laboratory does not ordinarily reproduce every slab junction, façade return, duct, conduit, ceiling plenum, door frame, or trade tolerance found in the building; e90's public significance statement says that laboratory ratings do not relate directly to building isolation and generally represent an upper limit relative to field testing. [76]

The first proposition may be expressed as follows: the specified specimen achieved the reported frequency-band transmission loss and associated rating under the cited laboratory method. The statement should not be shortened to the wall is STC 60 unless the reader can recover which wall, which report, which method, which date, and which configuration. The rating is an evidentiary record, not a transferable badge detached from the specimen.

76 MB-0105. ASTM E90-23.

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3.2.1 Specimen Identity, Tolerances, and Transferability

Laboratory evidence becomes misleading when the specimen is treated as a generic member of a product category. The specimen is a constructed physical system with dimensions, boundary conditions, material batches, joints, fasteners, accessories, and workmanship. Its test result belongs to that system. Transfer to a proposed assembly is an engineering inference that must be justified, not a clerical act performed by matching a short description.

Dimensional tolerance can affect performance through several mechanisms; panel width and height change modal frequencies. Stud spacing changes bending spans and coupling density. Cavity depth changes mass-air-mass resonance. Fastener spacing and perimeter restraint change effective stiffness and damping; door size changes leaf modes and seal length; glazing dimensions change coincidence and frame behaviour; a proposed assembly that is nominally similar may therefore differ in precisely the region that controls the security-relevant spectrum.

Material identity is equally important. Gypsum boards of the same thickness can differ in surface density, core formulation, facing, stiffness, and loss factor; concrete units can differ in density, web geometry, moisture, and grouting. Seal materials can differ in compression set and temperature response; mineral-fibre products can differ in density and airflow resistivity; the test report should be examined for actual material descriptions rather than relying solely on trade names, particularly when products have been reformulated after the test date.

Mounting conditions determine whether the laboratory specimen reproduces the intended field boundary. A wall installed between massive

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test-room frames may have perimeter conditions unlike a wall connected to a lightweight façade, a flanking slab, or a suspended ceiling; a door tested in a rigid laboratory opening may not reproduce frame movement in the building; e90 deliberately seeks to make the specimen the principal transmission path. [77] The field assembly contains the supporting construction that the laboratory suppresses or controls; transferability therefore weakens as the project boundary departs from the specimen boundary.

The evidence package should classify each difference according to physical significance; identical means supported by drawings and product records, not merely by a schedule description. Conservatively bounded means that a defensible physical model shows the proposed difference cannot reduce performance in the relevant range, with uncertainty considered; materially different means that the mechanism or configuration changes enough to prevent direct use of the result; unknown means that the information required for classification has not been supplied. Unknown differences should not be silently treated as equivalent.

Statistical production variation is another limitation. A single specimen does not describe the complete distribution of manufacturing and installation outcomes. Laboratory accreditation and method control reduce measurement uncertainty, but they do not eliminate product variability or field workmanship. Where the decision consequence is high, the design should include margin, quality controls, mock-ups, or multiple evidence sources rather than relying on the best available single report.

77 MB-0105. ASTM E90-23.

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The first proposition should consequently be written with exact nouns. “The tested specimen described in Report X achieved the stated band transmission losses and STC under ASTM E90-23 and ASTM E413-22” is defensible. “This wall type is STC 60” is not, unless the type is defined so precisely that the proposition remains true and the transfer is justified. The language disciplines the design team to preserve specimen identity through submittal, procurement, installation, and final comparison.

3.3 Transmission Loss and Sound Transmission Class

Transmission loss is an energy-ratio quantity expressed by frequency. If incident acoustic power on a specimen is W_i and transmitted acoustic power is W_t, the power transmission coefficient is tau = W_t/W_i; the corresponding transmission loss is TL = -10 log10(tau) decibels; a transmission loss of 40 dB corresponds to a transmitted power fraction of 10^-4 under the definition. This relation does not itself predict a wall’s behaviour; it converts an energy ratio into a logarithmic quantity and must be applied to a defined test configuration.

STC is a classification derived from a set of one-third-octave transmission-loss values under ASTM E413 when invoked by E90. [78] Its utility is comparison and specification for familiar building sources. Its weakness is compression. Different frequency-response shapes can receive the same STC. A partition with a pronounced low-frequency resonance and another with a high-frequency coincidence dip may share a rating while performing differently for male speech, amplified programme audio, mechanical noise, or particular consonantal bands.

78 MB-0094. ASTM E413-22.

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The public ASTM description expressly limits the generality of the single-number rating. It notes that the classification correlates generally with familiar sources such as speech, radio, and television, but is not appropriate for sources with substantially different spectra, for which frequency-band analysis is required. [79] Secure-room engineering should adopt the same caution even for speech. Vocal effort, room reinforcement, loudspeakers, and the need to protect consonantal information may make the full spectrum more informative than the headline value.

STC is also not a field adjective. The current E413 classification names STC for E90 laboratory results, while E336 field procedures produce NIC, NNIC, and ASTC under their respective conditions. [80, 81] Informal expressions such as field STC persist in conversation and older records, but a current report should use the term required by the method and explain any historical terminology encountered in legacy documents.

3.3.1 Worked Interpretation: Equal Ratings, Unequal Spectra

Consider two laboratory partitions that both receive the same single-number rating. Partition A has relatively smooth transmission loss through the principal speech bands but a marked deficiency near its mass-air-mass resonance. Partition B performs strongly at lower frequencies but exhibits a coincidence dip in a higher band important to consonantal detail. The rating process may compress both spectra to the same number, yet their security relevance differs with vocal effort, room reinforcement, and listener background.

79 MB-0094. ASTM E413-22.
80 MB-0090. ASTM E336-25a.
81 MB-0094. ASTM E413-22.

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Suppose a protected discussion contains amplified presentation audio with substantial low-frequency energy. Partition A may deliver more received energy than its rating suggests because the source excites the resonant deficiency; if the discussion is unamplified but the receiving corridor is quiet, Partition B's higher-frequency weakness may preserve consonantal cues that improve word recognition; neither conclusion can be drawn from the rating alone. The one-third-octave data and source spectrum are needed.

This example does not make single-number ratings useless. They remain efficient tools for comparison, procurement, and code language. The correct conclusion is narrower: the rating answers a classification question under its prescribed method. A security question may require additional band criteria or a speech-based assessment. ASTM E413's caution concerning sources with materially different spectra supports that approach. [82]

The same interpretive rule applies to field ratings. Two rooms with the same NIC may have different background spectra, receiving-room absorption, door leakage, and spatial variance. One may provide adequate privacy at ordinary corridor positions while failing near a grille. The field number is an entry point to analysis, not the end of it.

3.4 Proposition Two: Installed Field Performance

The second proposition concerns the completed building. ASTM E336 measures airborne sound attenuation between rooms and explicitly recognises the combination of direct transmission through the separating partition and indirect flanking paths. [83] Depending on room conditions and

82 MB-0094. ASTM E413-22.
83 MB-0090. ASTM E336-25a.

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the selected quantity, the method may yield noise reduction, normalised noise reduction, or apparent transmission loss, with corresponding ratings such as NIC, NNIC, or ASTC. These values are related but not interchangeable because they normalise different aspects of the receiving condition.

Noise reduction is the difference between source-room and receiving-room sound-pressure levels under the tested furnishing and absorption condition. NIC is a single-number rating derived from that reduction; normalised noise reduction adjusts the result toward a reference receiving-room absorption condition, producing NNIC; apparent transmission loss uses the receiving-room absorption area and separating area to characterise the apparent insulation of the construction, including flanking, and may produce ASTC when conditions permit. The exact formulae and restrictions must be taken from the current licensed method; the conceptual difference is that some metrics describe isolation between locations, while ASTC is framed as an apparent property of the separation and supporting structure.

Field measurement is sensitive to geometry; room volume, absorption, modal behaviour, source position, microphone sampling, partition area, and proximity to surfaces affect the result. E336 imposes restrictions on which metrics may be reported under particular conditions; [84] a competent report should state not only the value but why the chosen metric was valid for the rooms; reporting ASTC where the method's room requirements are not met is not a harmless labelling error. It changes the claimed measurand.

84 MB-0090. ASTM E336-25a.

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The installed condition should be ordinary and unmodified for acceptance. Diagnostic changes may be valuable, but they create a different proposition; if temporarily sealing a door gap improves the receiving level difference by 12 dB in certain bands, the test supports an inference that the gap is influential; it does not prove that the unmodified room meets the criterion. Baseline, diagnostic, repaired, and final states should be separately identified.

The second proposition may therefore be stated: the completed boundary between specified rooms achieved the reported field metric, under the cited method, room conditions, operating state, and uncertainty. It does not yet say whether words are understandable at all relevant locations, and it does not say whether a government authority has approved the room.

3.4.1 Selecting the Field Metric

Metric selection should occur during the test plan, not after the data are collected; the project begins by asking what proposition is required. If the owner wants to know the isolation between two occupied rooms in their present furnished state, NIC may be appropriate; if comparison across different receiving-room absorption conditions is important, a normalised quantity may be preferred; if the aim is to characterise the apparent insulation of the separating construction and the rooms satisfy the method's conditions, ASTC may be appropriate. [85]

The decision should also consider room size and geometry. Small or irregular rooms can exhibit strong modal variation. Large spaces can show

85 MB-0090. ASTM E336-25a.

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pronounced level gradients with distance from the separating partition. A single microphone position is unlikely to represent the room; the current method provides procedures and restrictions that must be followed, and the report should explain why the selected quantity was valid.

Door and mixed-element conditions require care. A complete separation containing a door can be measured as a whole, but the performance of the door alone may not be recoverable from an unmodified room test. ASTM E336 directs evaluation of smaller doors to ASTM E2964 within its scope. [86] A contractor should not subtract an assumed wall contribution from a room result and label the remainder a door rating without a valid method.

For security work, the metric should be supplemented by path-specific observations. Frequency-band maps near door edges, grilles, ceiling junctions, and service penetrations can explain a low result. Those diagnostic measurements need not become separate acceptance ratings, but they should be preserved as evidence of mechanism and remediation.

3.5 International Field and Rating Quantities

International practice uses a related but distinct vocabulary. ISO 16283-1 specifies field measurement of airborne sound insulation between rooms, while ISO 717-1 provides single-number ratings derived from frequency-band results. [87] [88] Quantities such as D_nT,w or R'_w may appear in building regulations, project specifications, and international reports. Their names, normalisations, and frequency treatment should not be casually translated into ASTM terms.

86 MB-0090. ASTM E336-25a.
87 MB-0943. ISO 717-1:2020., ISO 717-1:2020.
88 MB-0932. ISO 16283-1:2014 with Amendment 1:2017., ISO 16283-1:2014.

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R_w is generally associated with laboratory sound reduction under the ISO framework; r'_w denotes an apparent field sound reduction index that includes the influence of flanking; and D_nT,w describes a standardised level difference related to reverberation time. The precise definitions belong to the current standards. The editorial rule is that similar numerical values do not prove equivalence. A project crosswalk should state the underlying band data, normalisation, frequency range, contour method, and reporting context.

ISO 717-1 recognises that single-number quantities simplify requirements and incorporates spectrum adaptation for different source spectra. [89] That feature underscores the larger point: the same construction may be judged differently when the source spectrum changes. A secure-room specification should therefore retain the band requirements or adaptation terms relevant to the threat rather than relying solely on a familiar rating label.

Cross-jurisdictional work requires special caution. A British project may cite BS EN ISO 717-1, an American project may cite ASTM E413, and a Canadian project may use a programme-specific requirement alongside national or international standards. The design team should not substitute one system without approval merely because an informal conversion suggests a similar number. The authority and project specification determine which evidence is acceptable.

89 MB-0943. ISO 717-1:2020., ISO 717-1:2020.

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3.5.1 ASTM and ISO Quantities Are Related, Not Interchangeable

The ASTM and ISO frameworks address overlapping physical phenomena but use different quantities, normalisations, rating contours, frequency ranges, and reporting conventions. A crosswalk is therefore a translation aid, not an equivalence table. The correct comparison begins with the underlying band data and measurement conditions, then identifies which rating procedure has been applied. Converting a headline number by adding or subtracting a customary constant is not technically defensible.

In the ASTM laboratory chain, E90 produces frequency-dependent transmission loss and E413 may assign STC. [90, 91] In the ISO laboratory chain, ISO 10140-2 produces the sound reduction index by frequency and ISO 717-1 assigns R_w and spectrum adaptation terms. ISO 717-1 expressly bases its single-number quantities on octave or one-third-octave results and uses them to simplify expression of requirements, while preserving the role of the underlying bands. [92, 93] STC and R_w often lie near one another for conventional partitions, but their contour rules and frequency treatment differ. Agreement for one assembly does not establish a universal numerical conversion.

Field quantities require even greater care. ASTM E336 distinguishes noise reduction, normalised noise reduction, and apparent transmission loss, with NIC, NNIC, and ASTC as corresponding ratings when method conditions permit; [94] ISO 16283-1 provides field procedures from which quantities such as the apparent sound reduction index, standardised level difference, and

90 MB-0105. ASTM E90-23.
91 MB-0094. ASTM E413-22.
92 MB-0943. ISO 717-1:2020., ISO 717-1:2020.
93 MB-0942. ISO 717-1:2020 lifecycle record., ISO 717-1:2020.
94 MB-0090. ASTM E336-25a.

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normalised level difference may be derived, with weighted values assigned under ISO 717-1. [95] These quantities do not all answer the same question; some describe level differences between rooms under a stated receiving condition; others normalise to reverberation time or absorption area; apparent quantities attribute direct and flanking transmission to the separation under the method's model.

Area and room correction terms matter; the apparent sound reduction index and apparent transmission loss use relationships involving separating area and receiving-room absorption, but their detailed definitions and reference conditions are governed by their respective standards; standardised level difference uses reverberation-time normalisation; normalised level difference uses a reference absorption area. NIC remains tied to the measured receiving condition rather than an ISO reference time; a report that lists the numbers in one column headed "field STC equivalents" erases these differences.

Frequency ranges also affect comparison. The principal rating range and any extended low- or high-frequency treatment should be stated. A secure-room decision may depend on bands outside the principal single-number contour or on a source spectrum that weights the bands differently. Spectrum adaptation terms in the ISO framework may provide additional information for stated source spectra, but they do not transform R_w into a speech-security criterion. Likewise, ASTC incorporates the apparent field behaviour of the separation and supporting construction, but does not by itself establish that speech is unintelligible at every accessible receiver.

95 MB-0932. ISO 16283-1:2014 with Amendment 1:2017., ISO 16283-1:2014.

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A defensible crosswalk contains columns for test method, band quantity, normalisation, rating method, room constraints, treatment of flanking, principal use, and prohibited inference; it should also identify legacy terminology. Earlier ASTM field practice used field-prefixed terms that were later removed or reframed; the current E336 public description explains that NIC, NNIC, and ASTC are distinct and not interchangeable; [96] legacy reports should be interpreted in the edition under which they were produced rather than relabelled retrospectively.

When a project spans jurisdictions, the specification should select one controlling method for contractual acceptance and identify any supplementary measurements needed for comparison. Testing the same room under multiple frameworks may be justified, but the results should be reported separately. The purpose of comparison is to understand the physical and procedural relationship, not to manufacture a false equivalence between national systems.

3.6 Proposition Three: Occupied Speech Privacy or Speech Security

The third proposition asks whether protected speech remains usefully available outside the room under stated operating conditions. It is not answered completely by a wall rating or even by a field isolation rating. The source level and spectrum must be defined; the room’s reverberation and directivity influence the energy incident on each boundary; receiving positions must reflect credible access; and background sound or masking affects detection and understanding.

96 MB-0090. ASTM E336-25a.

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ASTM E2638 supplies a method for objective measurement of speech privacy provided by a closed room for unaided listeners not touching the boundary; it combines isolation and external background sound and permits estimates of speech audibility or intelligibility probability; [97] the method's limitations should appear wherever its result is used. It does not model contact listening, electronically aided collection, or every deliberate eavesdropping condition; a room that satisfies an E2638-derived criterion may still require TSCM, glazing assessment, equipment controls, or other security measures.

Vocal effort is a major uncertainty if it is not controlled. Normal conversation, raised speech, loud speech, and maximum credible effort produce different source levels and spectral balances; the public FCDO Services approach explicitly tests secure conference rooms against maximum vocal effort in the surrounding environment; [98] a commercial privacy test based only on normal conversation should not be presented as equivalent. The project requirement should state the source condition and the method of generating or representing it.

Background sound can improve privacy by reducing signal-to-noise ratio at the receiving position, but it is not a permanent substitute for construction; mechanical noise varies with operating mode. An electronic masking system may be switched off, altered, poorly calibrated, or uneven; excessive masking can impair comfort, concentration, accessibility, and communications inside or outside the room; the accepted condition should

97 MB-0077. ASTM E2638-24.
98 MB-0467. FCDO Services, "Secure Speech Environments".

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specify the required spectrum, spatial uniformity, level range, control access, alarm behaviour, and monitoring.

The receiving position is equally important; a corridor centreline may not be the most favourable location. Door perimeters, grilles, ceiling voids, adjoining cupboards, exterior façades, or structural contact points may produce higher information recovery; the threat model should identify positions that are both physically favourable and plausibly accessible; if a location is excluded because access is controlled, that control becomes part of the security case and must be preserved operationally.

The third proposition may therefore be stated: under the defined speech-source condition, room configuration, background or masking condition, receiving positions, listener model, and measurement method, the room provided the reported degree or probability of speech privacy. That proposition remains distinct from formal permission to conduct classified discussions.

3.6.1 Listener Models and Levels of Adversarial Effort

A listener model should distinguish at least four levels of effort; the first is incidental perception by an ordinary occupant who does not seek the conversation; the second is deliberate unaided listening from an accessible position; the third uses physical contact or a simple acoustic aid; the fourth uses specialised electronic, optical, or signal-processing equipment. Each level changes the measurement method, the receiving positions, and the permissible conclusion.

Ordinary privacy standards often address the first or second levels. ASTM E2638 addresses an unaided listener outside the room who is not touching

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the boundary; [99] it is therefore inappropriate to use the result as proof against contact microphones or remote optical collection; conversely, testing every commercial consultation room against the most sophisticated conceivable state threat may be disproportionate. The threat model must be tied to the protected asset and access.

Observation time should be included. A brief transient leak may be insignificant for incidental privacy yet valuable to a determined listener over a long meeting. Repetition, context, and speaker familiarity can improve recovery. The receiving condition should specify whether the criterion applies to a snapshot, a statistical period, or the duration of a representative meeting.

Listener capability also varies. Hearing acuity, language proficiency, knowledge of the subject, and training affect intelligibility. Objective methods reduce dependence on one test listener, but their interpretation still embodies assumptions about speech distribution and probability. The authority should select a criterion that is conservative enough for the mission without pretending that human perception has one fixed threshold.

3.7 Speech Privacy, Speech Security, and Ordinary Confidentiality

Speech privacy is used in several professional senses. In open offices it may describe freedom from distraction or the difficulty of understanding nearby conversations; in healthcare it may concern compliance, dignity, and protection from incidental overhearing; in legal practice it may concern privilege and client confidence; in secure-government work the term may be

99 MB-0077. ASTM E2638-24.

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attached to a specialised facility and accreditation process. The same words can therefore carry materially different consequences.

A responsible text states the listener model and consequence; incidental privacy usually concerns an ordinary occupant engaged in normal activity; speech security may concern intentional listening at favourable positions. Secure technical practice may add sensors, physical contact, standoff access, or hostile equipment; ASTM's current work programme itself distinguishes secure-speech assessment from non-secure privacy categories, confirming that the interpretive context matters even when measurement techniques are related; the active standard at the time of project design must be checked rather than inferred from a work item.

The term confidential room should be avoided unless accompanied by measurable conditions. Confidentiality is a legal or organisational property of information and conduct, not a material property of gypsum or concrete. Construction can support confidentiality by reducing transmission; procedures can support it by controlling access and devices; law can impose duties; but no wall independently creates privilege or secrecy.

The same caution applies to security labels; a room may be private in ordinary commercial use but unsuitable for classified discussion. A government secure room may be designed primarily for storage rather than speech; a secure speech room may be intended for discussions but not open storage; NPSA's public distinction among secure working areas, secure rooms, and secure speech rooms illustrates the need to retain functional categories. [100, 101]

100 MB-1084. National Protective Security Authority, "Secure Working Areas".
101 MB-1082. National Protective Security Authority, "Secure Rooms".

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3.7.1 Privacy, Confidentiality, and Security as Different Decision Domains

Privacy, confidentiality, and security overlap but are not synonymous. Privacy often concerns freedom from incidental or routine overhearing in a social, medical, legal, or commercial setting; confidentiality concerns the obligation to protect information from unauthorised disclosure, regardless of whether the disclosure route is acoustic, documentary, digital, or human; speech security concerns deliberate recovery under a defined threat and access model. The design consequence depends on which domain governs.

An ordinary office may require conversational privacy from adjacent occupants. The likely listener is incidental, observation time is limited, and the consequence may be discomfort or breach of workplace expectation; a legal consultation room may protect privilege and client confidence, with a greater consequence and possible deliberate interest; a diplomatic or intelligence facility may face persistent and technically capable collection. The same field isolation value cannot be interpreted identically across these settings because source conditions, listener effort, access, background, and acceptable probability differ.

ASTM E2638 provides a bounded method for objective measurement of speech privacy outside a closed room and assumes unaided listeners who are not touching the boundary. [102] Its value lies partly in the clarity of that listener model. A project can state that the method addresses deliberate unaided listening at defined points while separately assessing more capable threats. The result should not be described generically as proof against eavesdropping without retaining the method’s exclusions.

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102 MB-0077. ASTM E2638-24.

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FCDO Services' public secure-speech description adopts maximum vocal effort and external unintelligibility as a functional objective, while withholding the controlled details of the assessment. [103] The Canadian Contract Security Manual identifies speech privacy rooms as specialised secure facilities requiring accreditation and authority to operate. [104] These examples demonstrate that institutional terminology carries programme consequences beyond ordinary building acoustics. A commercial consultant should not borrow the label while omitting the corresponding authority and lifecycle controls.

The listener model should specify access posture. A receiver in a public corridor, a locked service void, an adjacent tenant space, a roof, a shared riser, and a contact point on glazing present different opportunities. It should specify whether the listener may remain for the whole meeting, select favourable times, use linguistic context, or employ equipment. It should also identify whether secondary information, such as occupancy, speaker identity, cadence, or emotional state, is protected.

The decision criterion should match the protected attribute; if the objective is incidental privacy, occasional faint audibility may be acceptable while intelligibility is controlled. If the objective is privilege, even intermittent recovery of names or legal strategy may be unacceptable; if the objective is classified speech security, the competent authority may require measures and thresholds not available in public sources; the public engineer can define and test the physical propositions but cannot declare accreditation.

103 MB-0467. FCDO Services, "Secure Speech Environments".
104 MB-1131. Public Services and Procurement Canada, Contract Security Manual, sec. 5.5.

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Operational measures also vary by domain; a medical room may rely on scheduling, sound masking, and corridor management. A high-threat secure-speech room may require controlled adjoining spaces, technical inspection, equipment restrictions, and continuing configuration management; acoustic construction remains important in both, but the complete system and burden of proof differ; using precise domain language prevents a design suited to ordinary privacy from being represented as a security solution.

3.8 Proposition Four: Formal Acceptance, Certification, or Accreditation

The fourth proposition is institutional. The competent authority reviews the applicable requirements and evidence and decides whether the facility may be used for a stated purpose. The decision can include conditions, waivers, compensating controls, expiration, periodic review, or restrictions on information, equipment, occupancy, and operations. It is not reducible to a sound-isolation number.

The Department of State's public SCI policy states that operations may not begin until accreditation is granted and describes continued evaluation, modification approval, and records. [105] Canada's Contract Security Manual similarly requires prior approval for construction of specialised facilities and authority to operate before use. [106] These examples show why the timing of the authority decision matters. Building first and seeking approval later can produce expensive rework or an unusable room.

105 MB-1262. U.S. Department of State, 12 FAM 710.
106 MB-1131. Public Services and Procurement Canada, Contract Security Manual, sec. 5.5.

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An accrediting authority may accept a design that uses layers of security, controlled adjoining space, operational restrictions, or approved mitigations. A public engineering monograph should not guess the decision calculus. It can, however, explain the evidence that enables a reasoned decision: verified drawings, construction records, inspection results, equipment approvals, field tests, uncertainty, deviations, and corrective actions.

Accreditation is also configuration-specific. A later wall penetration, equipment change, door replacement, or use change may trigger review. The accepted room is not a permanent abstraction. It is a physical and operational state under a continuing governance regime. A certificate that cannot be linked to the present configuration has diminished evidentiary value.

The fourth proposition may be stated: the identified authority authorised the identified facility for the stated protected use, subject to recorded conditions, on a given date. The proposition should be supported by the actual acceptance record, not inferred from the room's measured performance or from a contractor's statement of compliance.

3.9 As Designed, As Built, As Tested, and As Operated

The four-proposition model intersects with four project states; as designed describes the drawings, specifications, models, schedules, and approved requirements; as built describes the physical construction and installed equipment; as tested describes the configuration and operating conditions during measurement; as operated describes the condition during

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real use. These states may diverge, and the divergences frequently explain failure.

A design may show a slab-to-slab partition while the contractor stops the board at a suspended ceiling. A tested room may have a closed damper that is normally open; a door may pass commissioning with new seals and later be operated with a floor wedge; a masking system may be accepted at one level and subsequently reduced after complaints; the security claim must identify the state to which it applies.

The as-built record should not be presumed correct because it bears that label. It should be supported by inspections, photographs, submittals, nonconformance records, and selective verification. Concealed work is especially important. Once a second board layer, ceiling, or chase is closed, the continuity of seals and cavity treatment may be difficult to confirm without destructive opening.

The as-tested record should include every condition capable of affecting the result. Door positions, latch state, mechanical modes, masking, furniture, source and microphone locations, background sound, room temperature where relevant, and temporary diagnostic measures belong in the report. If the test condition differs from ordinary operation, both should be stated.

The as-operated state requires lifecycle controls. User training, maintenance procedures, equipment approval, access control, and change management preserve the relationship between acceptance and daily use. The most rigorous commissioning exercise can be undone by an undocumented alteration. Conversely, a well-governed room can remain

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reliable through planned change when each modification is reviewed and retested proportionately.

3.9.1 Lifecycle Transitions and the Expiry of Evidence

Evidence does not remain valid merely because the file remains available. Its applicability can expire when the physical object, operating state, governing source, threat assumption, or authority changes. Lifecycle assurance therefore requires defined transition points at which earlier conclusions must be reviewed.

The first transition occurs between design and construction. Approved drawings describe an intended configuration. Submittals, substitutions, field conditions, tolerances, and trade coordination determine what is built. A design calculation based on a double-stud wall cannot be carried forward if the installed framing is bridged by unreviewed backing or services. The evidence must follow the as-built condition.

The second transition occurs between construction and testing. The room may be incomplete, temporarily sealed, unfurnished, or operated at a non-representative mechanical state. A diagnostic test can inform repair but does not necessarily support acceptance. The as-tested state should be compared systematically with the intended as-operated state. Any temporary measure, disabled service, unusual door adjustment, or altered masking condition must be declared.

The third transition occurs at acceptance. The competent authority may impose restrictions, compensating controls, inspection intervals, or change triggers. The technical file should incorporate those conditions. Acceptance of one use does not authorise a different information category, occupant

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load, source level, or equipment suite. The authority decision is purpose-specific.

The fourth transition occurs during operation; wear, maintenance, damage, and alterations can invalidate previous measurements. Door seals compress, closers drift, floor finishes change, duct components are replaced, and penetrations accumulate; the State Department's public SCI policy treats accreditation as a lifecycle of monitoring and requires coordination for physical and equipment changes; [107] the DOE public TSCM material similarly situates inspection within continuing technical-security practice. [108] These sources support the need for review triggers even where the precise programme procedures differ.

The fifth transition is doctrinal. A test standard may be revised, a government instruction superseded, or an authority restructured. A room does not physically change because a document changes, but the adequacy and reporting of its evidence may need review. A legacy result should remain identified under the method and edition used. Retesting may be required where the new method addresses a material deficiency, where continuing accreditation demands it, or where the old record cannot support present decisions.

A lifecycle register should therefore link each evidence item to validity conditions. The register records the configuration, operating state, source edition, decision, restrictions, and events that trigger re-evaluation. Triggers may include structural work, new penetrations, door or glazing replacement, HVAC modification, audiovisual change, new networked

107 MB-1262. U.S. Department of State, 12 FAM 710.
108 MB-1256. U.S. Department of Energy, Technical Surveillance Countermeasures.

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equipment, changed adjoining-space access, water or fire damage, change of protected information, or an incident suggesting compromise.

The expiry principle is not intended to create needless retesting. It permits proportionate review. A documented change with no credible acoustic or technical effect may be closed by inspection and record update. A path-altering change may require targeted measurement. A major reconstruction or mission change may require full recommissioning and authority review. The decision should be made before the room returns to protected use.

3.10 The Proof Matrix

The four propositions can be organised as a proof matrix. Each row identifies the object, measurand or decision, primary evidence, principal confounders, and permissible conclusion. The matrix prevents an engineer, contractor, or author from skipping a logical step.

Table 3.1. Four propositions, their evidence, confounders, and permissible conclusions.

Proposition	Object	Primary evidence	Principal confounders	Permissible conclusion
Laboratory specimen performance	Defined test specimen	Frequency-band transmission loss and applicable laboratory rating	Specimen differences, mounting, test-room conditions, report completeness	The tested specimen achieved the reported result under the stated method
Installed field performance	Completed rooms and building paths	NR, NNR, ATL and valid single-number field ratings; inspection records	Flanking, room geometry, absorption, operational state, workmanship	The tested completed condition achieved the reported field result

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Proposition	Object	Primary evidence	Principal confounders	Permissible conclusion
Occupied speech performance	Protected speech event and receiving conditions	Speech privacy or security measurements, vocal-effort definition, background or masking records	Listener model, source variability, receiving access, observation time, technical aids	The room provided the stated degree or probability of privacy under declared conditions
Formal acceptance or accreditation	Facility and protected mission	Authority decision, accepted deviations, conditions, expiry and lifecycle records	Jurisdiction, programme, waiver, later changes, use outside scope	The authority permitted the defined use subject to recorded conditions

A related metric matrix is useful because the same acronym may be misapplied to another proposition.

Table 3.2. Principal laboratory, field, speech, and authority quantities and their limits.

Quantity or rating	Typical framework	What it principally describes	What it does not prove
Transmission loss, TL	ASTM E90 or ISO laboratory methods	Frequency-dependent reduction in transmitted acoustic power through a defined specimen	Field room isolation, speech intelligibility, or accreditation
Sound Transmission Class, STC	ASTM E413 invoked by E90	Single-number classification of laboratory transmission-loss data	The performance of an untested field assembly or complete room
Noise Isolation Class, NIC	ASTM E413 invoked by ASTM E336	Single-number field isolation between locations in the tested receiving condition	An intrinsic wall property or universal speech-security criterion
Normalised Noise Isolation Class, NNIC	ASTM E336 and E413	Field isolation adjusted toward a reference receiving absorption condition	Accreditation or protection against aided listening
Apparent Sound Transmission Class, ASTC	ASTM E336 and E413	Apparent field insulation of a separation including direct and flanking transmission under permitted conditions	Performance of individual small elements without modification, or occupied speech security by itself

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Quantity or rating	Typical framework	What it principally describes	What it does not prove
Weighted Sound Reduction Index, Rw	ISO 717-1 with laboratory data	Single-number laboratory rating under ISO framework	Automatic equivalence to STC or field performance
Apparent Weighted Sound Reduction Index, R'w	ISO 717-1 with field data	Apparent field rating including building transmission paths	A government acceptance decision
Speech privacy result	ASTM E2638 or another defined method	Audibility or intelligibility likelihood under a stated listener and source model	Protection against every technical collection method
Accreditation or authority to operate	Applicable government or institutional programme	Permission for a defined protected use	A timeless physical property immune to later alteration

The matrix should appear in design reviews, specifications, commissioning plans, and reports. A requirement can then state which proposition must be proved and by which evidence. For example, a wall-type submittal may require laboratory transmission-loss data, while final room acceptance requires field isolation, speech-security testing, and authority review. One value cannot discharge all four obligations.

3.10.1 From Vague Aspiration to Testable Requirement

A vague requirement might read: “Provide an STC 60 secure conference room.” It leaves unanswered whether the rating applies to each wall, the complete enclosure, doors, glazing, or field performance; which edition of the standard applies; whether the source condition includes amplified speech; which receiving positions matter; how uncertainty is treated; and who accepts the room. It also confuses a laboratory classification with secure use.

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A testable requirement separates the propositions; it might require specified wall, door, glazing, ceiling, and silencer submittals supported by current laboratory reports for configurations materially identical to those proposed. It might require field measurement of the completed room under a cited method and stated operating condition, retention of frequency-band data, and valid reporting of NIC, NNIC, ASTC, or another approved quantity; it might then require speech-privacy assessment at defined accessible positions using a declared vocal-effort model and background condition. Finally, it would state that use may begin only after the responsible authority has reviewed the complete evidence and issued written acceptance.

The requirement should include failure and retest procedures. If an initial field result fails, diagnostic modifications may be used to isolate paths, but the final acceptance test must represent the repaired ordinary state. Substitutions should require equivalence evidence at the assembly level. Changes after acceptance should be screened against defined triggers.

This syntax is longer than a one-line rating, but it is not bureaucratic excess. It converts an ambiguous aspiration into an auditable sequence of proof. It also allocates responsibility. Designers define the system, contractors build and document it, testers measure it, and the authority decides whether the evidence satisfies the mission.

3.11 Practical Consequences for Design and Commissioning

The four-proposition model changes procurement language. Instead of requiring an STC 60 secure room, the specification identifies the laboratory evidence required for each assembly, the field metrics and frequency bands required for the completed room, the speech-source and receiving

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conditions for privacy testing, and the authority responsible for acceptance. It also states how uncertainty, substitutions, deviations, and diagnostic modifications will be handled.

The model changes submittal review. A laboratory report is checked against the proposed assembly rather than accepted by rating alone; door reports are checked against leaf, frame, seals, hardware, dimensions, and mounting; duct silencers are checked in relation to airflow, regenerated noise, pressure drop, and cross-talk; glazing is checked for make-up, area, frame, and coincidence behaviour. Each item supports one portion of the complete path network.

The model changes commissioning. Field isolation is measured in the ordinary operational state. Receiving positions reflect credible access. Speech privacy is tested under the required vocal effort and background conditions. Diagnostic changes are separately labelled. The report distinguishes observations, calculations, inferences, and authority decisions.

The model changes maintenance. The facility record identifies which physical and operational features supported acceptance. Alterations can then be screened against those dependencies. A new penetration may require inspection and local testing. A door replacement may require full boundary retesting. A changed use may require a new threat assessment even if the construction is untouched.

Most importantly, the model changes scholarly language. It removes the temptation to use secure, compliant, certified, and soundproof as loose adjectives. Each conclusion becomes a complete proposition with a subject,

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condition, evidence, uncertainty, and authority. That precision is the foundation on which the remaining technical chapters will build.

3.11.1 Narrow Conclusions, Decision Consequences, and Guarded Language

A technically mature report states the narrowest conclusion that the evidence can sustain. This restraint is not timidity. It is the means by which measurements remain useful when reviewed by another engineer, an accrediting authority, a court, or a later project team. Overstatement converts a valid observation into an indefensible proposition.

Suppose a field survey produces an ASTC value for a separating construction under valid room conditions. The defensible conclusion is that the apparent sound insulation of that separation, including supporting flanking paths as treated by the method, achieved the reported value in the tested configuration. The result does not prove that every receiver around the room has equal isolation, that speech is unintelligible, that determined technical collection is defeated, or that the facility is accredited. Each additional claim requires additional evidence.

Language should preserve measurement uncertainty and spatial limitation; “no speech was detected” may mean that received levels were below the instrument or background under one source condition; it does not prove absence of transmitted energy; “the wall passed” may conceal that the measured object included doors and flanking. “The room is secure” is ordinarily too broad for an acoustical report; better language identifies the source, receiver, method, state, measured quantity, uncertainty, criterion, and untested threats.

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Decision consequences determine how conservative the conclusion and acceptance rule should be. A false acceptance may expose protected information and create a difficult-to-detect compromise; a false rejection may impose cost, delay, or operational restriction; measurement science does not choose the acceptable balance, but it makes the balance visible; NIST and JCGM uncertainty guidance provides the framework for identifying and combining uncertainty components. [109, 110, 111] The owner or authority then selects a decision rule suited to the consequence.

Guard bands are one means of controlling decision risk. If the required minimum is close to the measured value, a rule may require additional margin so that uncertainty does not create an excessive probability of false acceptance; the exact rule must be declared in advance and should not be improvised after seeing the result; where the standard or authority prescribes a rule, that rule controls. Where it does not, the project should document the rationale and obtain approval.

Conflicting observations should remain visible. A high average isolation value does not erase a local intelligible leak; a successful retest after repair does not justify deletion of the original failure. The sequence demonstrates mechanism, corrective action, and final condition; likewise, an unexplained anomaly should not be converted into an accusation of surveillance; the report should state what was observed, what benign and adverse mechanisms remain plausible, what tests discriminated among them, and what uncertainty remains.

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109 MB-1175. Taylor and Kuyatt, NIST Technical Note 1297.
110 MB-0965. JCGM 100:2008., JCGM 100:2008.
111 MB-1058. National Institute of Standards and Technology, “Calibration Policies”.

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The final decision belongs to the competent authority, but engineering language shapes the decision. A clear report separates measured fact, calculation, inference, criterion, and authority action. It prevents a favourable technical result from being mistaken for permission and prevents a cautious limitation from being misunderstood as technical failure. That separation is the practical culmination of the four-proposition model.

Chapter 3 Glossary

Apparent Sound Transmission Class, ASTC. A single-number field rating derived under ASTM E336 and ASTM E413 from apparent transmission loss under permitted room conditions. It includes direct and flanking transmission through the supporting construction.

Apparent sound reduction index, R'. A field quantity under the ISO framework that includes the influence of building transmission paths. Its weighted single-number form is commonly written R'w.

As-built condition. The physical construction and equipment actually installed, supported by inspection and verification rather than by drawing title alone.

As-designed condition. The configuration represented in approved drawings, specifications, schedules, calculations, and submittals.

As-operated condition. The room’s ordinary use state, including doors, mechanical systems, masking, equipment, furnishings, access, and user behaviour.

As-tested condition. The exact configuration and operating state during measurement, including any temporary diagnostic change.

Field performance. Measured sound isolation or apparent insulation of the completed building condition, including direct and flanking paths as defined by the selected method.

Formal acceptance. The competent authority’s documented decision that the facility may be used for a stated purpose, subject to conditions.

Four-proposition model. The analytical separation of laboratory specimen performance, installed field performance, occupied speech performance, and formal acceptance or accreditation.

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Laboratory specimen. The exact partition, element, or assembly installed and measured in a controlled test facility.

Noise Isolation Class, NIC. A single-number rating of field noise reduction under the tested receiving-room condition, derived when ASTM E336 invokes ASTM E413.

Normalised Noise Isolation Class, NNIC. A single-number field rating based on normalised noise reduction under ASTM E336 and ASTM E413.

Occupied speech performance. The degree or probability of speech audibility or intelligibility outside a room under declared source, room, background, receiving, and listener conditions.

Power transmission coefficient, tau. The ratio of transmitted acoustic power to incident acoustic power for a defined specimen or system.

R_w. Weighted sound reduction index derived from laboratory data under ISO 717-1. It is not automatically equivalent to STC.

Sound Transmission Class, STC. The single-number classification assigned under ASTM E413 to laboratory transmission-loss data obtained by a method such as ASTM E90.

Speech privacy. A context-dependent degree of protection against speech being heard or understood. The listener model and consequence must be stated.

Speech privacy room, SPR. A Canadian specialised-facility term used in the public Contract Security Manual. It carries accreditation and authority-to-operate implications within that programme.

Speech security. Protection against intentional recovery of protected speech under a defined threat and listener model. It is generally more demanding than ordinary incidental privacy.

Standardised level difference, D_nT. A field level difference normalised to a reference reverberation time under the ISO framework. The weighted form is D_nT,w.

Transmission loss, TL. Ten times the negative common logarithm of the acoustic power transmission coefficient, expressed by frequency for a defined specimen and method.

Weighted rating. A single-number classification derived from frequency-band data by a prescribed contour or weighting procedure. It does not replace the underlying spectrum.

Decision consequence. The harm associated with false acceptance, false rejection, or delayed decision, used to select an appropriate acceptance rule and evidentiary margin.

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Evidence expiry. Loss of applicability caused by change in configuration, operation, threat, source edition, method, or authority rather than by disappearance of the original record.

Metric crosswalk. A structured comparison of quantities and rating systems that preserves different methods, normalisations, frequency ranges, and permissible inferences.

Transferability. The justified extent to which evidence from a tested specimen can support a different proposed or installed assembly.

Listener domain. The defined combination of listener capability, access, position, observation time, linguistic context, and use or non-use of technical aids.

Narrow conclusion. The most specific proposition supported by the stated evidence without importing untested conditions or authority decisions.

Guard band. A deliberate margin between a measured result and a specification limit used to control decision risk in view of uncertainty.

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PART II. ACOUSTIC AND STRUCTURAL PHYSICS

Part II develops the physical and metrological foundations required for every later construction, privacy, commissioning, and forensic conclusion in this volume. It treats acoustic quantities, transmission through single and multiple elements, structural vibration and flanking, room response, and human speech as distinct but coupled domains. The analysis remains governed by the separation among laboratory assembly performance, installed field performance, occupied speech-security performance, and formal acceptance by the competent authority.

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Chapter 4. Sound Fields, Pressure, Intensity, Power, and Impedance

4.1 Acoustic quantities and the definition of the measurand

Acoustic-security engineering begins by defining what is to be measured. Terms such as “quiet”, “soundproof”, and “speech secure” do not identify a physical quantity, location, bandwidth, time interval, or uncertainty. Sound pressure, particle velocity, intensity, and power describe related but distinct aspects of an acoustic field. Pressure is a scalar state variable at a point. Particle velocity is a vector. Intensity describes directional energy flow per unit area. Sound power describes the rate at which a source emits acoustic energy. A microphone level cannot be converted into source power or directional intensity unless the field model supports that conversion.[112]

The measurand should be written before instruments are selected; a field sound-insulation test may require spatially averaged source- and receiving-room pressure levels, receiving-room decay, and background correction; a leakage investigation may require local active intensity normal to a boundary. A loudspeaker-characterisation task may require band sound power or directivity; a speech-security assessment adds a source spectrum, listener-access positions, receiving background, and a defined intelligibility or privacy metric. Each proposition demands different evidence.

A measurement model states the relation between inputs and the reported result; it identifies reference planes, coordinates, calibration factors, environmental state, processing, and assumptions; the model also defines what remains outside scope; this discipline prevents a high laboratory rating

112 MB-0990. JCGM 100:2008.

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from being presented as proof of occupied speech security or formal accreditation.

4.2 Sound pressure and logarithmic level

Instantaneous acoustic pressure $p(t)$ is the departure from static pressure. For an observation interval T, root-mean-square pressure is

Equation 4.1

$$p_{rms} = \sqrt{\frac{1}{T}\int_{0}^{T} p^{2}(t)\,dt}.$$

Sound-pressure level is

Equation 4.2

$$L_{p} = 20\log_{10}\left(\frac{p_{rms}}{p_{0}}\right),$$

where $p_{0} = 20\,\mu Pa$ is the conventional reference pressure in air. The factor 20 follows from the square relationship between pressure and energy in a progressive wave. The level must be accompanied by frequency band, weighting, detector, averaging interval, and position when those details affect meaning.[113]

Decibels represent logarithmic ratios. Independent levels add in the energy domain:

Equation 4.3

$$L_{sum} = 10\log_{10}\left(\sum_{i} 10^{L_{i}/10}\right).$$

113 MB-1004. Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens, and James V. Sanders, Fundamentals of Acoustics.

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Two uncorrelated 60 dB sources combine to 63 dB, not 120 dB; coherent tonal sources require complex pressure addition because phase controls reinforcement and cancellation; the distinction matters when test signals coexist with masking, ventilation tones, and electrical hum.

Worked example 4.1. Combining and subtracting levels

Three independent sources produce 58, 61, and 64 dB at a receiver. Equation 4.3 gives

$$L_{sum} = 10 \log_{10}\left(10^{5.8} + 10^{6.1} + 10^{6.4}\right) = 66.4\,dB.$$

If the total source-on level is 31 dB and background is 29 dB, the corrected source contribution is

$$L_s = 10 \log_{10}\left(10^{31/10} - 10^{29/10}\right) = 26.7\,dB.$$

The 2 dB source-on excess produces a large correction and high sensitivity. A small error in either input changes the result materially. The governing method’s background limitations and uncertainty rule must therefore be applied.

4.3 Particle velocity and characteristic impedance

Particle velocity $u(t)$ describes oscillatory motion of the medium. It is not steady airflow. For a plane progressive wave in a lossless fluid, pressure and velocity are in phase and

Equation 4.4

$$p = \rho_0 c\, u,$$

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where ρ_0 is ambient air density and c is sound speed. The product $Z_0 = \rho_0 c$ is characteristic acoustic impedance. Near room temperature, Z_0 is about $410\,Pa\,s/m$, subject to environmental state.[114]

The plane-wave relation is not universal. Near sources and boundaries, pressure and velocity can be out of phase; standing waves can produce pressure maxima near velocity minima; a pressure reading close to a wall or grille may therefore overstate or understate net energy flow. Direct velocity or intensity measurement, or a validated field model, is needed when reactive behaviour matters.

Vector velocity measurements can help distinguish air motion through an opening from pressure build-up caused by reflection; their calibration, orientation, flow sensitivity, and usable band should be recorded; a probe placed inside a narrow gap can perturb the field and should be treated as a diagnostic configuration.

4.4 Acoustic intensity and active power flow

Instantaneous intensity is $I(t) = p(t)u(t)$. Active intensity is its time average. For complex rms quantities, normal active intensity is

Equation 4.5

$$I_n = \Re\{p u_n^{*}\}.$$

Positive and negative signs depend upon probe orientation and the stated convention. Reactive intensity represents stored energy exchange. Active intensity represents net transport. Intensity is measured in watts per square metre.[115]

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114 MB-1004. Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens, and James V. Sanders, Fundamentals of Acoustics.
115 MB-1006. Leo L. Beranek and Tim Mellow, Acoustics: Sound Fields and Transducers.

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Integrating normal active intensity over a surface estimates acoustic power:

Equation 4.6

$$W = \int_S I_n \, dS.$$

A scan of a door or access panel can rank leaf, frame, perimeter, and threshold contributions; the scan grid must resolve local variation, and the probe's phase match and pressure-intensity capability must be suitable; reflections and unrelated sources can invalidate the estimate. Field indicators and repeat scans should be retained.

Worked example 4.2. Surface-power estimate

A 0.60 m by 0.90 m panel is divided into six equal cells; their outward band intensities are 0.40, 0.55, 0.65, 0.50, 0.45, and 0.70 mW/m², mean intensity is 0.542 mW/m² and area is 0.54 m². Estimated power is

$$W = \left(0.542 \times 10^{-3}\right)\left(0.54\right) = 2.93 \times 10^{-4} \, W.$$

The result assumes the cells represent the whole panel and intensity is normal to the scan surface. It estimates power through that surface, not room privacy.

4.5 Sound power and source descriptors

Sound power W is the rate of acoustic energy emission. Sound-power level is

Equation 4.7

$$L_W = 10 \log_{10}\left(\frac{W}{W_0}\right),$$

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where $W_0 = 10^{-12}$ W. Sound power is intended to describe the source under a defined method rather than one receiver position. It remains dependent on operating state, mounting, and test conditions.[116]

Mechanical equipment may require both airborne sound power and structure-borne blocked force; a conference loudspeaker may be characterised by power, spectrum, directivity, and limiting behaviour; catalogue data should not be transferred to an installed source without configuration comparison. Fan speed, duct connection, enclosure, equalisation, and support all matter.

Sound-power methods include reverberation-room, free-field or hemi-anechoic, comparison, and intensity methods. The report should identify the method and uncertainty. A single nearby microphone level is not a sound-power measurement.

4.6 Impedance, reflection, absorption, and transmission

Specific acoustic impedance is the complex ratio $Z = p/u$ at a point and direction. For a normally incident plane wave meeting a locally reacting surface of impedance Z_s, the pressure-reflection coefficient is

Equation 4.8

$$R_p = \frac{Z_s - Z_0}{Z_s + Z_0}.$$

Normal-incidence absorption is

Equation 4.9

$$\alpha_n = 1 - \left| R_p \right)^2$$

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when transmission through the backing is absent from the energy balance. A perfectly matched surface with $Z_s = Z_0$ has no reflection in the ideal model. A rigid surface with very large impedance approaches full reflection.[117]

Absorption and transmission are different. A porous finish can reduce reverberation while the supporting wall remains weak; a heavy wall can provide strong transmission loss while reflecting most incident sound into the source room; the design should not use an absorption coefficient as though it were a partition rating.

Worked example 4.3. Resistive surface

If $Z_s = 2\,Z_0$, then $R_p = (2\,Z_0 - Z_0)/(2\,Z_0 + Z_0) = 1/3$. The ideal normal-incidence absorption is $1 - (1/3)^2 = 0.889$. The result assumes a real, local, infinite surface and no transmission. It is an illustration of impedance matching, not a field rating for a product.

4.7 Free, near, reverberant, and diffuse fields

A free field is dominated by direct propagation without significant reflection. A near field lies close enough to a source that reactive components, source geometry, and non-spherical behaviour matter. A reverberant field contains many reflections. A diffuse field is an ideal statistical condition in which energy density is spatially uniform and directions are random. Real rooms approximate these conditions over limited bands and regions.[118]

Laboratory sound-insulation methods seek sufficiently diffuse source and receiving fields to support spatial averages; small rooms, low frequencies, strongly absorptive surfaces, and directional sources reduce the

117 MB-1004. Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens, and James V. Sanders, Fundamentals of Acoustics.
118 MB-0274. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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approximation; field rooms are usually less controlled; the report should not call a field diffuse without evidence.

Security diagnostics use several field types. Close scans locate openings but are not room averages. Room averages support level difference. Exterior positions may be free-field or façade-reflected; ceiling voids can be modal and non-diffuse; the measurement model should identify the applicable field and correction.

4.8 Frequency, wavelength, phase, and sampling

Frequency f, sound speed c, and wavelength λ are related by

Equation 4.10

$$\lambda = \frac{c}{f}.$$

At 100 Hz with $c = 343$ m/s, wavelength is 3.43 m. At 4 kHz it is 0.0858 m. Low-frequency control therefore involves dimensions comparable with rooms and structural spans, while high-frequency leakage can be concentrated at small gaps.[119]

Phase controls coherent addition and cancellation. Room reflections create spatial maxima and minima; microphone positions should be separated and distributed according to the method; array spacing must satisfy the analysed wavelength and steering geometry; a single point can fall in a null and understate a path.

Temporal sampling requires a sample rate above the useful bandwidth with adequate anti-alias filtering. Frequency resolution is $\Delta f = f_s / N$ for an N-

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sample rectangular record, while windowing broadens effective resolution. Record length and stationarity must match the question.

Worked example 4.4. Digital record

For $f_s = 48,000$ Hz and $N = 65,536$, record duration is 1.365 s and FFT line spacing is 0.732 Hz. Nyquist frequency is 24 kHz, but the calibrated microphone and analogue filter may limit usable bandwidth. A Hann window reduces leakage but broadens the response.

4.9 Environmental state and sound speed

For an ideal gas,

Equation 4.11

$$c = \sqrt{\frac{\gamma R T}{M}},$$

where γ is heat-capacity ratio, R is the universal gas constant, T is absolute temperature, and M is molar mass. A practical approximation for dry air near room temperature is $c \approx 331.3 + 0.606\,\theta$ m/s, with θ in degrees Celsius.[120]

Humidity, pressure, and composition also affect density, impedance, and atmospheric absorption; over ordinary room distances, configuration changes often dominate, but environmental records are necessary for phase, array, ultrasonic, and long-duration comparability; temperature also correlates with HVAC state and building operation.

4.10 Instrument chain, calibration, and dynamic range

The complete chain includes microphone, preamplifier, conditioner, cable, digitiser, clock, software, and processing. Each channel requires identity and

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calibration. Pretest and post-test field checks establish short-term stability. Periodic calibration provides traceability. Neither replaces the other.[121]

Dynamic range is bounded by self-noise and overload; receiving-room tests can approach the noise floor, while source-room levels can overload the same range; dual ranges or separate instruments may be needed; automatic gain control should be disabled or documented. Clipping, overload flags, and noise spectra should be retained.

Phase calibration is required for intensity, arrays, and transfer functions; a common clock is necessary for synchronous channels; channel latency, resampling, and wireless codecs can corrupt phase; the instrument register should preserve firmware and processing versions.

4.11 Measurement uncertainty and decision relevance

Uncertainty includes calibration, repeatability, spatial sampling, source stability, background correction, environmental state, and model form. For $y = f(x_1, \ldots, x_n)$, first-order propagation with covariance is

Equation 4.12

$$u_c^2(y) = \sum_i \left(\frac{\partial y}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i<j} \frac{\partial y}{\partial x_i} \frac{\partial y}{\partial x_j} u(x_i, x_j).$$

Correlations should be retained. A common microphone calibration affects source-on and source-off readings similarly and may cancel partly in a difference. Treating every input as independent can overstate or understate uncertainty.[122]

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Uncertainty should be related to the decision; if a measured result exceeds a criterion by 15 dB, a 1 dB uncertainty may not change the conclusion; if the margin is 0.5 dB, decision risk is material. The authority or contract should define conformity rules before testing.

4.12 Source-path-receiver evidence chain

Every acoustic-security observation can be organised into source, path, and receiver. The source includes level, spectrum, directivity, position, and time state. The path includes boundaries, junctions, openings, services, and structural coupling. The receiver includes position, room response, background, access, and metric.[123]

This organisation prevents category errors. Added source-room absorption can reduce boundary excitation but does not increase wall transmission loss; added receiving masking can improve privacy but does not improve passive isolation; a better door can improve the installed relationship without changing the laboratory wall specimen. Formal accreditation remains a fourth institutional proposition.

4.13 Reporting requirements

A defensible report states authority, scope, measurand, methods, instruments, calibration, source state, coordinates, environmental and service state, raw and processed data, uncertainty, limitations, and conclusions. Frequency-resolved results should be retained beneath any rating or summary.[124]

Figures require scales, units, bands, source conditions, and processing; tables should distinguish measured, calculated, specified, and assumed

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values; diagnostic positions should be separated from standardised averages; background-limited results should be reported as bounds where appropriate.

The conclusion should identify what the data establish and what they do not. Acoustic measurement supports design, diagnosis, and privacy analysis. It does not by itself confer authority to discuss classified information.

4.14 Spatial sampling, averaging, and the geometry of evidence

A room-average sound-pressure level is an estimator constructed from a finite set of spatial observations. It is not a direct reading from one privileged microphone position. The underlying field may contain deterministic interference, low-frequency modal maxima and minima, near-boundary pressure build-up, and local contributions from doors, ducts, penetrations, and equipment. Sampling geometry therefore affects the reported result as surely as instrument calibration. The positions, heights, exclusion distances, source locations, movement procedure, and averaging rule must be part of the measurement definition.[125]

Energy averaging of levels requires conversion from decibels to linear mean-square quantities. If $L_{p,j}$ is the level at position j, an equal-weight spatial average is

Equation 4.13

$$\overline{L_p} = 10 \log_{10} \left(\frac{1}{N} \sum_{j=1}^{N} 10^{L_{p,j}/10} \right).$$

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Arithmetic averaging of decibel values gives a geometric, not energetic, mean and can bias the result when spatial variation is appreciable; equal weighting is itself an assumption; a continuous microphone traverse represents a path average whose speed, dwell, trajectory, and exclusion zones must be controlled. Fixed-position measurements allow local variance to be retained, but they may require more positions to characterise a strongly non-uniform room.

Low-frequency sampling is especially consequential because there may be only a few modes within a band; repeating the same nominal microphone arrangement by shifting every point a few centimetres can expose whether the estimate is robust or dominated by a local null. For diagnostic work, the variance is not merely nuisance; a sharp local maximum near a junction can identify a path; for conformity work, however, the method's prescribed spatial average must be followed, and diagnostic observations should be reported separately.

Worked example 4.5. Energetic spatial average

Four receiving-room positions return 24, 27, 31, and 25 dB in one band. The energetic average is

$$10\log_{10}\left(\frac{10^{2.4}+10^{2.7}+10^{3.1}+10^{2.5}}{4}\right)=27.6\,dB.$$

The arithmetic mean of the four decibel values is 26.8 dB; the 0.9 dB difference is caused by the disproportionate contribution of the 31 dB position; the higher position should not be discarded merely because it is inconvenient. Its physical location and repeatability should be investigated; the result does not establish that every accessible listener position experiences 27.6 dB. It describes the stated averaging procedure.

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4.15 Cross-spectral quantities and path discrimination

Two-channel measurements can distinguish coincident level changes from dynamically related behaviour. The auto-spectral density $G_{xx}(f)$ describes the distribution of mean-square quantity x with frequency. The cross-spectral density $G_{xy}(f)$ retains relative phase and amplitude between channels. A frequency-response estimate may be written

Equation 4.14

$$H_1(f)=\frac{G_{xy}(f)}{G_{xx}(f)},$$

where x is treated as the input and y as the output. The magnitude-squared coherence is

Equation 4.15

$$\gamma_{xy}^2(f)=\frac{\left|G_{xy}(f)\right)^2}{G_{xx}(f)G_{yy}(f)}.$$

It ranges from zero to one under the usual estimator. High coherence can support a stable linear relationship within the analysed records, but it does not prove that x is the sole cause of y. Common forcing, shared clocks, electrical crosstalk, saturation, and insufficient averaging can also produce high values. Low coherence can arise from unrelated noise, time variance, nonlinear response, or inadequate signal-to-noise ratio.[126]

In a structural-acoustic investigation, one channel might measure wall velocity and another receiving-room pressure; a coherent peak near a suspected panel mode strengthens the hypothesis that panel radiation contributes; a simultaneous measurement on a duct or slab can reveal

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competing paths. Controlled interventions, such as temporarily sealing a gap or changing source position, provide stronger causal evidence than coherence alone; the analysis should retain estimator type, block length, window, overlap, number of averages, confidence limits, and channel phase calibration.

4.16 Source directivity, orientation, and boundary excitation

A source is rarely an omnidirectional point. Human speech, loudspeakers, machinery openings, and duct terminations radiate differently with angle and frequency. The field incident upon a particular wall or door therefore depends upon source orientation and position. A room-average source level can coexist with substantially higher local exposure of one boundary. For secure-room analysis, the source schedule should include credible seats, standing positions, installed loudspeakers, teleconference devices, and orientations towards weak elements.[127]

Directivity can be represented by a directional factor Q or directivity index $DI = 10 \log_{10} Q$ under defined conditions. These descriptors are useful only when the reference field and angular averaging are stated. In a reflective room, directivity dominates the early field near the source, while the later reverberant field reduces angular contrast. At low frequencies, the source may be nearly omnidirectional; at higher frequencies, speech and loudspeakers often become increasingly directional.

The effect should be treated as a sensitivity problem rather than a single correction; rotate the source, move it nearer to the suspect boundary, and compare frequency-resolved results; if a door becomes governing only

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when the source faces it from an adjacent seat, that is a legitimate operational condition, not an outlier. The design response may involve relocation, absorption, door improvement, or an operational restriction, depending upon the authority and use case.

4.17 Background-limited observations and bounded reporting

A receiving-room observation can approach the background so closely that subtraction becomes unstable or prohibited by the governing method. The correct response is not to invent a lower transmitted level. It is to report a bound, increase source level within linear and safe limits, reduce unrelated background, extend averaging, use a more sensitive chain, or change the test configuration. Each intervention changes the evidence and must be documented.[128]

Suppose source-on level is L_{on} and background is L_b. The estimated source contribution is

Equation 4.16

$$L_s = 10\log_{10}\left(10^{L_{on}/10} - 10^{L_b/10}\right).$$

The derivative of this function becomes large as the two levels approach; consequently, even well-calibrated inputs can produce a highly uncertain difference; a statement such as “at least 52 dB isolation in this band” may be more defensible than an exact 54.7 dB value calculated from nearly equal measurements. Censoring should remain visible in plots and rating calculations.

Background is often non-stationary. Ventilation cycles, lifts, traffic, wind, footsteps, and electrical tones can change within minutes; time histories and

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band percentiles help distinguish persistent from intermittent limitation; turning building systems off may improve measurement range but can create a non-representative acceptance state. Both operating and diagnostic states may be needed.

4.18 Digital provenance and reproducible signal processing

Raw waveform files are evidence only when their identities and processing histories are preserved. The record should contain file hashes, channel map, time base, sample rate, bit depth, full-scale calibration, preamplifier range, clock source, synchronisation method, trigger, anti-alias filter, and acquisition software version. If files are converted, resampled, trimmed, or normalised, the derivative should receive a new identifier and the transformation should be recorded.[129]

Processing parameters determine results. Window type, overlap, averaging mode, spectral scaling, one-sided or two-sided convention, frequency weighting, band integration, smoothing, background correction, and outlier treatment should be recoverable; a screenshot without the underlying data and settings is an illustration, not a complete measurement record. The audit trail should permit an independent analyst to reproduce the numerical result without relying on undocumented operator memory.

Clock integrity matters whenever phase, delay, or cross-channel relationships are used. Separate unsynchronised recorders drift. Networked or wireless systems can introduce buffering and variable latency; a common start time does not prove a common sample clock; synchronisation should

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be demonstrated with a known event or reference signal, and residual timing uncertainty should be incorporated into the interpretation.

4.19 From physical quantity to security conclusion

The purpose of acoustic measurement is not to accumulate levels, spectra, and images. It is to test a bounded proposition. The sequence begins with a defined source and operating state, proceeds through a specified path and receiving geometry, uses instruments whose range and calibration suit the measurand, and ends with an inference that respects uncertainty and method scope. The same data can support different conclusions only when the additional assumptions are made explicit.[130]

A laboratory transmission-loss curve describes a specimen; a field level difference describes an installed relationship under stated rooms and conditions; a local intensity scan ranks outward power through a surface; an intelligibility metric estimates a listener-related outcome under a defined source and background. None of these, by itself, grants authority for classified discussion. The engineering report should state the strongest conclusion supported by the evidence and the observations that would overturn it.

4.19.1 Microphone sensitivity and traceable level reconstruction

A digital count becomes acoustic pressure only through the complete sensitivity chain. If a microphone produces voltage V_m for pressure p, its sensitivity is $M = V_m / p$, commonly expressed in volts per pascal. With preamplifier and digitiser gain G, the reconstructed pressure is $p = V_d / (G M)$, subject to frequency response and calibration convention.[131]

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A field calibrator provides a known pressure at a stated frequency under specified environmental limits; it verifies the installed channel before and after measurement; it does not establish microphone frequency response across the full band, phase match between channels, or low-noise performance. Laboratory calibration supplies those additional data. The report should retain calibration certificate, field-check level, environmental correction, date, and observed drift.

Worked example 4.6. Sensitivity correction

A microphone nominally has sensitivity 50 mV/Pa, but calibration gives 47.5 mV/Pa. If analysis uses the nominal value, reconstructed pressure is low by the ratio $47.5/50=0.95$. The level error is

$$20\log_{10}(0.95)=-0.446\,dB.$$

The correction is modest for one channel, but mismatched channels can bias level differences, intensity phase, and transfer functions. Whether the uncertainty cancels depends upon the same chain being used for both quantities.

4.19.2 Spatial covariance and effective sample size

Additional microphone positions do not provide independent information when the field is strongly correlated. If adjacent positions move together because of a broad mode, the effective sample size is smaller than the count. Conversely, positions separated across nodal regions can reveal genuine spatial variance.[132]

A practical survey can examine the covariance matrix of band levels or complex pressure; high correlation suggests redundancy; low correlation

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may indicate adequate coverage or unstable conditions; sampling should not be optimised solely to minimise variance; required boundary regions and accessible listener positions must remain represented even if they differ from the room average.

The uncertainty of a spatial mean should include between-position variance and repeatability; repeating the traverse after moving source position provides a stronger estimate than repeating identical readings without changing geometry; the final report should show both mean and distribution when local exposure matters.

4.19.3 Detection limits and reporting of non-detections

A non-detection is not a measured zero. It means the observation fell below a method- and state-dependent detection capability. The detection limit depends upon background, self-noise, averaging, leakage from the measurement chain, and the decision rule.[133]

For a tonal search, coherent averaging can lower random noise but will not remove coherent interference at the same frequency; for broadband speech, longer averaging may reduce statistical variance while erasing short information-bearing peaks; a detection statement should therefore name signal class and processing.

When a path is not detected, report the upper bound supported by the data; that bound can be propagated into the path budget; a lower bound on isolation may be sufficient for design acceptance, but it should not be presented as an exact value. Later changes in background or instrumentation can alter the bound without any change in the room.

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4.19.4 Stationarity, confidence, and repeated states

Spectral averaging assumes that the statistical properties of the signal remain sufficiently stable over the analysed records. A fan cycling between stages, a masking controller changing level, or a talker moving between seats violates that assumption. Averaging incompatible states can create a spectrum that never existed at any one time.[134]

Stationarity should be examined through time histories, block spectra, running level, and operating logs; stable segments can be analysed separately; confidence intervals for spectral estimates depend upon the number of effectively independent averages and the window overlap. More nominal averages do not guarantee proportionate confidence when records are correlated.

Repeated measurements should include purposeful reconfiguration. Replacing the source or microphone in the same marks tests setup repeatability; moving to alternate valid positions tests spatial sensitivity; returning on another day tests state reproducibility; these components should not be merged into one undifferentiated standard deviation.

4.19.5 Multi-channel synchronisation and phase closure

Synchronous channels are essential for intensity, beamforming, transfer functions, and time-of-arrival analysis. Shared hardware usually provides a common sample clock, but channel filters and analogue paths can still create differential phase. Separate recorders require an explicit synchronisation method and drift estimate.[135]

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A phase-closure test can route one reference signal to every channel and compare amplitude and phase across frequency; the test should be repeated after cable or range changes; a single impulse aligns start time but may not reveal long-record clock drift. Pilot tones or periodic references can quantify drift.

For a 10 kHz component, a timing error of 1 microsecond corresponds to 3.6 degrees of phase; intensity probes and compact arrays can be sensitive to errors of that order; the uncertainty budget should convert timing and phase mismatch into the reported quantity rather than treating synchronisation as a binary condition.

4.19.6 Acoustic energy density and room power balance

Acoustic energy density combines potential energy associated with pressure and kinetic energy associated with particle velocity. In a plane progressive wave, the time-averaged contributions are equal. In a standing or reactive field, their local balance changes. Pressure-only measurements can therefore misrepresent stored and transported energy near boundaries or sources.[136]

For a diffuse steady field, room power balance relates source power, absorption, and mean energy density; the relation supports reverberation-room sound-power methods and statistical sound-insulation theory; it should not be applied uncritically in small modal rooms; the assumptions of uniform energy, random incidence, and steady state need evidence.

Energy balance is also a diagnostic audit; if a calculated receiving-room power exceeds credible incident power after all paths and corrections,

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areas, absorption, or reference quantities are inconsistent; conversely, an apparently missing balance can indicate unmeasured flanking or background. Such checks expose unit and model errors before they become conclusions.

4.19.7 Coordinate control and survey repeatability

Acoustic positions should be tied to a recoverable coordinate system. Room sketches, laser survey, fixed monuments, photographs, and labelled grids allow a later team to reproduce source and receiver geometry. Descriptions such as “near the door” are inadequate when centimetres affect a standing-wave result.[137]

Coordinate uncertainty should match wavelength and decision; a 100 mm positioning error is minor for some low-frequency room averages but substantial for a compact array at several kilohertz; heights, boundary distances, microphone orientation, and source acoustic centre should be recorded. Temporary furnishings and open doors should appear in the same survey.

Repeatability improves when fixtures and marks are used, but fixtures themselves can reflect or transmit sound; non-conductive, low-scattering supports may be appropriate for some measurements; the report should identify any fixture remaining within the field.

The following sections deepen the practical consequences of this framework through microphone phase integrity, spatial statistics, cross-spectral discrimination, source directivity, time variance, arrays, intensity diagnostics, background censoring, digital provenance, uncertainty prioritisation, and

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controlled perturbation. These are not ancillary refinements. They determine whether an apparently precise result actually represents the room and decision at issue.

4.20 Microphone systems, traceable sensitivity, and phase integrity

A microphone is not merely a device that returns a number labelled in decibels. It is the first transducer in a measurement chain whose amplitude, phase, self-noise, directional response, environmental sensitivity, and mechanical mounting determine what the later numerical record can legitimately mean. For ordinary level surveys, a sound calibrator before and after the measurement may establish satisfactory control of sensitivity at one frequency. Acoustic-security work often asks more. Leakage localisation, intensity measurement, array processing, cross-spectral analysis, and low-level receiving-room tests can be governed by phase mismatch, channel latency, cable motion, preamplifier noise, or the interaction between the microphone body and a confined field. The instrument register should therefore identify capsule type, nominal diameter, polarisation method, preamplifier, conditioner, analyser channel, cable, firmware, calibration history, and any individual correction data applied. A generic entry such as “Class 1 meter” does not preserve enough information to reconstruct the measurement.[138]

The distinction between pressure-field, free-field, and random-incidence response is practical rather than taxonomic; a microphone calibrated for one incidence condition can show a systematic high-frequency departure

138 MB-0430. David A. Bies, Colin H. Hansen, and Carl H. Howard, Engineering Noise Control: Theory and Practice, 6th ed.

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when used in another; that departure may be immaterial for a broad environmental survey but consequential where a narrow band carries a large share of speech intelligibility or where several channels are compared to infer direction. Windscreens, nose cones, protective grids, probe spacers, and extension tubes alter the local field; their use should be included in the configuration record and, where relevant, in the calibration or correction model. A microphone pushed into a door undercut or duct grille can perturb the very field it is meant to observe. Close-proximity results should therefore be treated as local diagnostic evidence, not automatically as room-average levels.

Phase integrity requires a common time base or a demonstrably stable relation among channels; even small interchannel delay can corrupt active-intensity estimates at high frequency because the pressure-gradient estimate depends upon phase; the same defect can rotate an array steering vector, shift an apparent source, or reduce measured coherence. A multichannel system used for such work should be checked with a common electrical or acoustical signal before deployment; a pistonphone or calibrator verifies sensitivity at the microphone, while an electrical loopback can expose channel delay and gain mismatch downstream. Neither alone proves the complete chain. The metrological record should state what was tested, at which frequency and level, and what uncertainty remains outside the check.

For very low receiving levels, microphone self-noise and preamplifier noise may become part of the background; the relevant limit is not the catalogue’s single A-weighted self-noise figure alone; one-third-octave noise, overload margin, environmental stability, and the analyser’s input range matter. A

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system that is quiet in total A-weighted terms can contain tonal electronics or elevated low-frequency noise; the verification programme should include an acoustically quiet termination or sealed-coupler check where feasible, followed by an in-situ background record with the source off. This separates the instrument floor from the room background and prevents a beautifully smooth spectrum from being mistaken for transmitted sound.

4.21 Spatial averaging as an estimator of a field, not a ritual

A room-average sound-pressure level is an estimator. Its reliability depends upon the spatial distribution being sampled, the correlation among positions, the number and geometry of observations, and the purpose for which the average is used. In a diffuse laboratory room, prescribed microphone paths and source positions are intended to reduce the influence of local standing waves and specimen directivity. In a small office, ceiling void, service cupboard, stair enclosure, or narrow corridor, the field may be strongly non-diffuse. A nominally compliant traverse can then produce an average that is numerically repeatable yet poorly representative of the listener locations that govern security. The test plan should distinguish the standardised field estimate from threat-informed supplemental positions.[139]

Energy averaging is performed in the linear domain. If levels $L_{p,i}$ represent equivalent mean-square pressure at N positions, the spatial average is

Equation 4.17

$$\overline{L_p} = 10 \log_{10} \left(\frac{1}{N} \sum_{i=1}^{N} 10^{L_{p,i}/10} \right).$$

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Arithmetic averaging of decibels is only an approximation, and the error grows with spatial variance; consider four positions at 22, 22, 22, and 34 dB; their arithmetic mean is 25 dB, while the energy mean is approximately 28.7 dB. The outlying position represents a physically important concentration of energy, perhaps beside a door jamb or duct; a security assessment should not hide that concentration inside a room average. The report should preserve individual band spectra, identify maxima, and state whether the acceptance decision is based on average, worst accessible position, percentile, or some combination.

Spatial sampling uncertainty is not identical to microphone calibration uncertainty; it arises because the selected positions are one realisation of a spatially varying field; repeat traverses, randomised positions, or bootstrap methods can estimate its magnitude; the effective number of independent observations may be lower than the number of logged points because nearby positions are correlated, particularly at low frequency. The common practice of adding more closely spaced microphones without considering correlation can create false confidence. The sampling design should be related to wavelength, room dimensions, likely path locations, and the expected modal density.

A protected-room investigation often benefits from a two-tier spatial plan; the first tier follows the governing laboratory or field method and supports comparison with the stated metric. The second tier is diagnostic. It includes door perimeters, glazing frames, ceiling junctions, service penetrations, return-air grilles, raised-floor boundaries, and adjoining spaces available to a listener; diagnostic points are not silently folded into the standardised average unless the method permits it; instead, they are reported as a

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separate map of susceptibility. This preserves both comparability and operational relevance.

4.22 Cross-spectra, coherence, and causal discrimination

A level spectrum shows how much energy is present. It does not by itself show where that energy came from. Cross-spectral methods compare two simultaneously measured signals and can help distinguish energy associated with the controlled source from unrelated background. The cross-power spectral density $G_{xy}(f)$ retains amplitude and phase relations between channels, while the magnitude-squared coherence

Equation 4.18

$$\gamma_{xy}^2(f) = \frac{\left|G_{xy}(f)\right|^2}{G_{xx}(f)G_{yy}(f)}$$

lies between zero and one under conventional estimation. High coherence between a source-room reference signal and a receiving microphone supports a causal connection at the analysed frequency, provided that both channels have adequate signal-to-noise ratio and the estimator is not dominated by leakage, common clocks, or deterministic tonal background. Low coherence does not prove absence of transmission. Time variance, nonlinear response, multiple independent source components, poor reference placement, insufficient averaging, or background contamination can all reduce it.[140]

The method is especially useful when ordinary background correction becomes unstable; a pseudorandom or deterministic test sequence can be reproduced through the source system while a reference channel records

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the actual drive or source-room field; synchronous averaging and transfer-function estimation can extract the component correlated with the excitation even when uncorrelated background is comparable in level. That advantage comes with obligations. The excitation must not overload the room or apparatus; the source must remain in its linear operating region. Clock synchronisation and record alignment must be verified. Windowing, overlap, block length, averaging method, and rejection of transients must be recorded because each changes spectral bias and variance.

Coherence can also expose a misleading inference; suppose a receiving-room tone at 250 Hz rises whenever the test source operates; if its phase and amplitude remain coherent with a source-room reference, transmission is plausible; if coherence is low and the tone tracks ventilation fan speed instead, a mechanical source may be responsible. A controlled source on-off sequence, fan-speed change, microphone relocation, and structural accelerometer channel can discriminate the hypotheses. The correct analytical attitude is experimental. Each proposed path should predict a change under a controlled perturbation.

Transfer functions require explicit reference planes. A loudspeaker electrical input, an acoustic reference microphone near the source, and a spatially averaged source-room level are not interchangeable denominators; the electrical reference includes loudspeaker response and room coupling inside the measured transfer function; a local acoustic reference may be dominated by near-field behaviour. A room-average reference is harder to synchronise but more closely reflects the standardised excitation field; the report should name the chosen reference and explain what mechanisms remain inside or outside the estimated function.

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4.23 Source directivity and orientation uncertainty

The acoustic field exciting a boundary depends upon source directivity. Human speech becomes increasingly forward-biased with frequency because the mouth, head, and torso are no longer acoustically small compared with wavelength. Loudspeakers impose their own frequency-dependent pattern, which changes with baffle dimensions, driver spacing, crossover design, and mounting. A source aimed towards a door leaf can raise the incident level at that element while the room-average level changes little. Conversely, a dodecahedral source intended to produce a diffuse test field does not reproduce the local directional exposure created by a seated talker or conference loudspeaker. These are different source models and should not be conflated.[141]

Orientation uncertainty can be treated experimentally. For a representative talker position, measurements may be repeated with the source facing the door, glazing, principal wall, and room centre; the resulting spread is not an inconvenience to be averaged away. It describes operational sensitivity. If a receiving location becomes intelligibility-limited only when the talker faces a particular weak element, the design response may be local reinforcement, seating control, relocation of a lectern, or improvement of the weak path; a report that uses only the most favourable orientation can miss the governing condition.

Where a directional loudspeaker is used as a surrogate, its polar response should be documented over the speech-relevant bands; on-axis equalisation does not guarantee correct off-axis energy; a source with narrow high-

141 MB-0766. Frank Fahy and Paolo Gardonio, Sound and Structural Vibration: Radiation, Transmission and Response, 2nd ed.

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frequency directivity may under-excite lateral walls and over-excite a door in front of it. A source with broad radiation may overstate diffuse exposure compared with a talker; the correct choice follows the proposition. Standard sound-insulation measurement seeks a controlled room field. Operational speech assessment seeks a defensible representation of actual or bounding use.

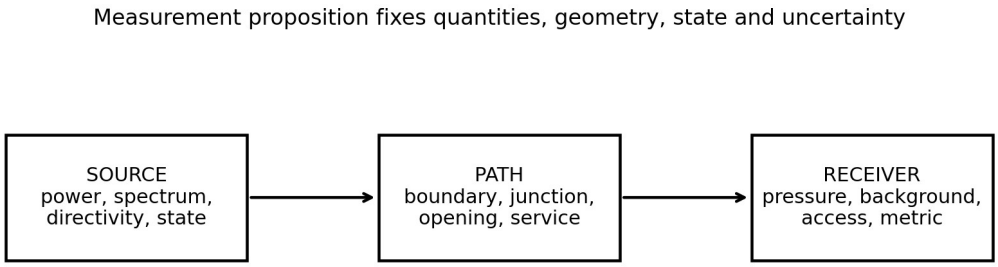

Figure 4-1. Source, path, and receiver evidence chain. Author's original diagram.

The source-path-receiver model also clarifies uncertainty allocation; source power, spectrum, directivity, location, and temporal state belong to the source; boundary construction, openings, junctions, and services belong to the path; receiver position, background, room response, listener access, and metric belong to the receiver. Some variables interact, but the classification prevents a change in one domain from being misreported as a property of another. For example, adding absorption to the source room can reduce the incident field for a given source power. It does not increase the intrinsic transmission loss of the wall.

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4.24 Coherent and incoherent summation in multi-path rooms

Secure rooms contain multiple transmission paths. Direct airborne leakage through a door, flanking through a ceiling plenum, structural radiation from a slab, and duct-borne sound may arrive at a receiving position with different phases and degrees of coherence. Broadband engineering estimates usually combine independent path powers, but narrowband components can interfere constructively or destructively. A single-point measurement can therefore show a deep cancellation that disappears a short distance away. The safer practice is to retain spatial and spectral data, avoid interpreting a local null as robust attenuation, and use energy-based path models for broader predictions unless phase relations are demonstrably stable.[142]

For uncorrelated paths with levels L_i, the combined level follows logarithmic power addition. If the paths are coherent, complex pressure must be summed:

Equation 4.19

$$p_{tot}(f)=\sum_i p_i(f)e^{j\phi_i(f)}, L_p=20\log_{10}\left(\frac{|p_{tot})}{p_0}\right).$$

The phase ϕ_i depends upon path length, impedance, modal response, and source state. It can drift with temperature, door position, fan speed, or occupancy. A cancellation observed during one test may therefore be an unstable condition rather than a design margin. The report should resist presenting it as permanent protection.

142 MB-1005. Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens, and James V. Sanders, Fundamentals of Acoustics, 4th ed.

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Path substitution tests can separate contributions. Temporarily sealing a door perimeter with a reversible, documented treatment, stopping a fan, closing a damper, adding mass to a vibrating panel, or decoupling a service can alter one path more than others; the difference spectrum indicates the path's contribution, subject to the intervention not changing the rest of the field. Repeating the test at multiple receiving positions helps distinguish genuine power reduction from spatial redistribution.

The same reasoning applies to masking. Masking sound and transmitted speech are normally treated as incoherent, so their energies do not cancel predictably; a phase-controlled antiphase system cannot be relied upon across a room and broad speech spectrum; active control may reduce low-frequency sound in a limited zone, but it is not a general substitute for passive containment. The governing evidence for speech security remains the receiving signal relative to credible background under the full operating state.

4.25 Time weighting, temporal statistics, and short information-bearing events

Speech is non-stationary. Vowels carry sustained energy, while plosives, fricatives, and word onsets can be brief and spectrally concentrated. A long equivalent-continuous level may describe total exposure yet conceal momentary events that remain audible or intelligible. A maximum detector can preserve those events but may also capture an unrelated impact or chair movement. Percentile levels describe distribution but not linguistic sequence. The measurement design should therefore use temporal

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descriptors matched to the proposition rather than applying one familiar setting to every question.[143]

Equivalent-continuous level over interval T is

Equation 4.20

$$L_{eq,T} = 10 \log_{10} \left[\frac{1}{T} \int_0^T \frac{p^2(t)}{p_0^2} dt \right).$$

The expression gives equal weight to equal acoustic energy, regardless of when that energy occurs; it is useful for stable test noise and for comparing average operating states. It does not preserve modulation. For speech-related analysis, short-time spectra, modulation transfer, or calibrated recordings may be needed; the record should retain raw or losslessly encoded time data when authority and information-handling controls permit it; if actual speech is not necessary, speech-shaped noise or standardised test signals reduce privacy risk and improve repeatability.

Temporal synchronisation matters in intervention tests. If the source is switched on and off according to a known sequence, receiving data can be aligned to estimate source-correlated response; clocks should be referenced or drift measured; consumer recorders that begin at nominally the same time can drift enough to impair cross-channel analysis over long records. Buffering, automatic gain control, noise reduction, and wireless codec delay must be disabled or documented; a system that modifies the waveform may be acceptable for listening but unsuitable for quantitative metrology.

143 MB-0430. David A. Bies, Colin H. Hansen, and Carl H. Howard, Engineering Noise Control: Theory and Practice, 6th ed.

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The quietest credible interval may govern security; daytime averages can be reassuring while short night-time periods reveal the path; a ventilation system may cycle, a lift may stop, or exterior traffic may fall; long-term monitoring should therefore record operational states and identify low-background windows. The final conclusion should not be based exclusively on the noisiest period unless that state is guaranteed by design and monitored through lifecycle control.

4.26 Arrays, beamforming, and the danger of impressive images

Microphone arrays can help localise leakage by exploiting differences in phase and arrival time across sensors. Delay-and-sum beamforming, frequency-domain steering, near-field holography, and more advanced inverse methods can produce maps that appear intuitively authoritative. Their resolution and bias, however, depend upon aperture, sensor spacing, frequency, steering model, environmental assumptions, and the number and coherence of sources. A map is an estimator, not a photograph of sound.[144]

Spatial aliasing occurs when sensor spacing is too large for the wavelength. For a linear array with spacing d, a conservative no-aliasing condition for broadside plane-wave analysis is

Equation 4.21

$$d \leq \frac{\lambda_{min}}{2} = \frac{c}{2 f_{max}}.$$

144 MB-0271. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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At 8 kHz in air with $c = 343\,m/s$, half-wavelength spacing is about 21 mm. Many practical building arrays use wider spacing and therefore rely upon restricted steering angles, lower analysis bands, sparse-array processing, or interpretation of grating lobes. The report should state the usable band and not display unsupported high-frequency localisation merely because software can compute it.

Near-field sources require a spherical or otherwise appropriate steering model; a plane-wave model can misplace a source close to the array; reflections create virtual sources and sidelobes; a strong door leak may illuminate a wall and produce a secondary maximum that is not an independent opening. Validation should use a known test source at representative distances and frequencies, plus physical perturbation of suspected paths. The map should be compared with point spectra, inspection findings, and source-on/source-off controls.

Array output must also preserve scale. Automatic normalisation can make weak patterns look as prominent as strong ones; each map should show absolute or referenced levels, dynamic range, frequency band, averaging interval, array geometry, steering distance, and processing method; a security report should include the underlying numerical data and a statement of localisation uncertainty. A colourful image without those controls is useful for illustration but weak as evidence.

4.27 Sound intensity probes and field indicators

Two-microphone sound-intensity probes estimate particle velocity from the pressure gradient between closely spaced microphones and combine it with mean pressure. Their useful band is bounded at low frequency by phase

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mismatch and at high frequency by finite spacing and field non-uniformity. Different spacers change the compromise. The operator should select spacer length according to the intended band, apply the associated calibration, and document residual-intensity performance. A probe suitable for a loud machine may not possess enough pressure-intensity index for a high-isolation wall with a strong reactive field.[145]

Field indicators compare pressure and intensity quantities to assess whether the measurement is likely to be valid; large differences can signal reactive energy, background contamination, or insufficient dynamic capability; the indicators do not automatically correct the result. They tell the practitioner when the assumptions of the method are strained; scanning speed and path density also matter. A rapid hand scan may miss a narrow leak or bias the average towards areas where the operator slowed. A gridded scan with logged position, dwell time, and repeat pass provides stronger evidence.

Intensity can be integrated over a surface to estimate transmitted sound power; this is valuable where receiving-room reverberation is unsuitable for conventional transmission-loss measurement or where one wishes to rank local contributions; the integration surface should enclose or intercept the relevant energy flow without crossing unrelated sources. Background sources behind the scan surface can reverse local intensity or corrupt the estimate; the sign convention, surface geometry, cell area, probe orientation, and excluded regions must be recorded.

For a door assembly, separate scans of leaf, perimeter, threshold, vision panel, and frame-wall junction can reveal which subcomponent dominates;

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yet the surface power is not necessarily the listener exposure; radiation directivity and receiving-room response still connect the surface to a particular position. Intensity data should therefore support path diagnosis and power ranking, while pressure measurements support occupied receiving conditions.

4.28 Low-level measurement, background limitation, and censoring

High-isolation rooms challenge the measurement system because the transmitted signal can approach the combined background and instrument floor. This is not merely a nuisance to be corrected by subtracting two decibel values. As the source-on and source-off levels converge, the corrected estimate becomes highly sensitive to small errors. Standards may prescribe correction limits or permit lower-bound reporting. The security report should retain the uncensored bands, corrected bands, and background-limited bands separately.[146]

A lower-bound result can still be valuable; if the receiving level is indistinguishable from background while the source-room level is high and stable, the test may establish that apparent isolation exceeds a stated value under the measured conditions. It does not reveal the true higher value; reporting an exact number beyond the dynamic capability invents precision; the correct notation is a bound, accompanied by the source level, background, integration time, and correction rule.

Source power can sometimes be increased to improve margin, but only within the linear and safe range of the loudspeaker, room elements, and

146 MB-0766. Frank Fahy and Paolo Gardonio, Sound and Structural Vibration: Radiation, Transmission and Response, 2nd ed.

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test method; excessive low-frequency excitation can drive rattles, door hardware, ceiling tiles, or flexible panels into nonlinear behaviour that would not occur during speech. Excessive high-frequency level can provoke protective limiting in amplifiers or cause audible leakage into uncontrolled areas; a pretest should establish linearity by comparing receiving response at two or more source levels; if a 6 dB source increase produces approximately 6 dB receiving increase in each relevant band, linear transmission is supported. Deviations require investigation.

Censoring rules should be decided before reviewing results; selecting only favourable quiet periods or excluding maxima after the fact introduces bias; transient events can be marked and excluded if they are demonstrably unrelated and the rule is consistent. The raw chronology, exclusions, and reason codes should remain available; for unattended monitoring, tamper evidence, clock control, channel health, and storage integrity become part of the measurement model.

4.29 Digital acquisition, anti-aliasing, and processing provenance

Digital recording converts a continuous electrical signal into a sequence of samples. The sample rate, analogue anti-alias filter, converter resolution, input range, clock stability, channel synchrony, and numerical format jointly define the record. A nominal 48 kHz file does not prove that useful response extends to 24 kHz. The analogue front end may roll off earlier, and anti-alias filters introduce amplitude and phase behaviour near the band edge. Conversely, ultrasonic energy can fold into the audio band if filtering is inadequate. Where a secure-room investigation includes ultrasonic sensing,

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modulated carriers, or nonlinear demodulation hypotheses, the acquisition chain must be characterised beyond its nominal audio setting.[147]

Converter bit depth controls ideal quantisation range, but effective number of bits is reduced by analogue noise and distortion; the correct operating range places the signal well above the converter noise without clipping peaks; automatic range switching and automatic gain control should be avoided unless their behaviour is recorded and validated. A clipped waveform can still produce a plausible spectrum, but harmonic products and flattened peaks corrupt quantitative interpretation; peak flags, overload counts, and input-range settings should be preserved with the data.

Spectral estimates depend upon block length, window, overlap, averaging, and scaling; a Hann window reduces leakage from components not periodic in the record but broadens spectral lines and changes amplitude correction; flat-top windows improve amplitude estimates for isolated tones at the expense of frequency resolution and noise bandwidth. Exponential averaging tracks change differently from linear ensemble averaging; power spectral density, power spectrum, and narrowband level are not interchangeable labels. The report should identify the estimator and units, including whether values are per hertz, per FFT line, or integrated into fractional-octave bands.

Processing provenance should be sufficiently complete for an independent analyst to reproduce the published figure from raw data; minimum records include original file checksum, channel map, calibration factor, time-zone and clock basis, software and version, script or processing recipe, excluded

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intervals, window and overlap, frequency weighting, band-integration method, background correction, and rounding. A screenshot cannot carry this burden. It is a visual derivative whose underlying numerical record must remain available.

4.30 Environmental state, air properties, and long-duration comparability

Temperature, humidity, and static pressure affect sound speed, air density, characteristic impedance, and atmospheric absorption. Within ordinary occupied buildings these changes are modest, but they can matter when phase, time of flight, or high-frequency attenuation is used diagnostically. More importantly, environmental state correlates with building operation. A change in temperature can bring different fan speeds, damper positions, door use, or façade pressure. The environmental log is therefore both a physical correction record and a marker of configuration.[148]

Sound speed determines wavelength and array steering; a 3 per cent error in sound speed produces a corresponding error in inferred range or phase relation; for metre-scale localisation this may be visible; humidity strongly influences molecular absorption at higher audio and ultrasonic frequencies. A test conducted in a dry, cold unconditioned building can differ from one conducted after occupancy and humidification. The significance should be assessed rather than assumed. In most room-to-room speech work, boundary and background changes dominate atmospheric absorption, but a complete record allows that judgement to be defended.

148 MB-0430. David A. Bies, Colin H. Hansen, and Carl H. Howard, Engineering Noise Control: Theory and Practice, 6th ed.

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Long-duration monitoring should log operational state with enough granularity to explain clusters; HVAC mode, occupancy, door status, masking level, exterior wind, precipitation, and nearby equipment can be more informative than a single average temperature; automated building-system logs may assist, but their timestamps and sensor calibration should be checked. A fan command does not prove actual speed; a damper percentage does not prove airflow; where the operation matters, a local measurement or status verification is stronger.

Comparability requires a state matrix. Each survey run should be assigned values for source configuration, room furnishing, door and window state, services, masking, occupancy, and environmental variables; before-and-after remediation tests should match the matrix or disclose differences; a 4 dB improvement measured with a quieter source room, louder receiving background, and different door latch condition is not attributable to the repair without further analysis.

4.31 Frequency weighting, band reduction, and preservation of speech evidence

A-weighted and C-weighted levels are useful summaries for certain human-response and environmental applications. They are not universal measures of speech leakage. A-weighting reduces the contribution of low-frequency bands and can conceal bass-rich amplified speech, structural rumble, and resonant double-leaf weaknesses. C-weighting retains more low-frequency energy but still collapses the spectrum. Secure-room evidence should preserve one-third-octave or finer data over the relevant range, with any weighted value presented as a secondary descriptor.[149]

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Band reduction is an irreversible operation if the underlying narrowband data are discarded; fractional-octave integration combines FFT bins according to defined band edges and weighting; the analyst should retain sufficient frequency resolution to identify tones, comb filtering, resonances, and narrow leaks before reduction. A narrowband line from a fan or electronic device can dominate a fractional-octave band and falsely appear as source-correlated transmission; coherence, source-off data, and line inspection help separate it.

Speech evidence is carried unevenly across frequency; low bands contribute voicing and prosody, middle bands contribute much vowel and consonant energy, and higher bands contribute articulation cues; the exact importance depends upon language, vocal effort, listener, background, and metric. A broadband level difference that looks substantial can coexist with weak isolation in a small set of important bands; conversely, a low-frequency weakness may be conspicuous to instruments but contribute little to intelligibility under a particular speech spectrum. The report should avoid both errors by preserving the band data and applying a stated speech model.

A rating contour or weighted index is useful for comparison and specification, but it does not replace the spectrum; the design review should examine adverse deviations, extended low-frequency bands where relevant, and path-specific features; the publication should show both the single-number result and the underlying curve, with axes, reference conditions, and source identified. This is especially important when comparing American STC-based language with ISO weighted sound-reduction indices or when interpreting field metrics that include flanking.

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4.32 Inverse source and path estimation

In an inverse problem, measured responses are used to infer the source or transmission path that produced them. Acoustic leakage localisation, sound-power estimation, and structural source identification are all inverse problems. They can be ill-conditioned because different source distributions produce similar fields, particularly with limited sensors and strong reflections. Regularisation, prior assumptions, and model choice therefore influence the answer. A result should not be described as uniquely determined unless uniqueness and stability have been demonstrated.[150]

A simple path-ranking model may represent measured receiving pressure as a linear combination of candidate path contributions. If matrix H contains predicted transfer functions from each path to each receiver, vector q contains unknown source strengths, and p contains measured complex pressures, then

Equation 4.22

$$p = H\,q + \varepsilon\,,$$

where ε represents measurement error and model discrepancy. Direct least squares can amplify noise when columns of H are similar. Regularised solutions constrain magnitude or smoothness, but the constraint imports assumptions. The analyst should test sensitivity to regularisation strength, sensor selection, and omitted paths.

Physical intervention remains the strongest validation. If the model identifies a return-air grille as dominant, a reversible and safe treatment should reduce the predicted bands while other paths remain stable; if the

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response does not change, the model or intervention assumptions are wrong. This experimental loop prevents mathematical sophistication from replacing physical proof.

Inverse methods can also estimate equivalent source power on a vibrating surface; near-field measurements, boundary-element models, or operational transfer paths may be used. The result is configuration-specific. Changes in room absorption, surface boundary condition, or sensor position can alter the inversion; reports should preserve the forward model, mesh, boundary conditions, regularisation, residual, and uncertainty rather than presenting only a reconstructed source image.

4.33 Sensitivity analysis and uncertainty priorities

An uncertainty budget lists input uncertainties, but sensitivity analysis shows which inputs materially control the result. For measurand $y=f\left(x_1,\ldots,x_n\right)$, local sensitivity coefficients $c_i=\partial y/\partial x_i$ quantify first-order influence. A large input uncertainty can be unimportant if the measurand is insensitive to it, while a small uncertainty can dominate near a singular correction or threshold. Background subtraction is the classic example: sensitivity grows sharply as source-on level approaches background.[151]

Sensitivity analysis should precede expensive data collection; if spatial variation dominates a receiving-room estimate, adding a higher-grade calibrator may not change the conclusion; more independent positions or a better field model will; if phase mismatch dominates intensity uncertainty at low frequency, longer averaging does not cure it. If door-latch force changes

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the perimeter gap, repeated acoustic measurements without mechanical state control only quantify variability, not cause.

A practical security decision also has threshold sensitivity; suppose an acceptance rule requires a result above a specified limit; measurements close to the limit should be evaluated with a decision rule that accounts for uncertainty and the consequences of false acceptance or false rejection. A guard band may require the measured value minus an expanded uncertainty to exceed the limit; the applicable authority or contract must define the rule. The engineer should not invent a favourable convention after seeing the result.

Global sensitivity methods, including Monte Carlo sampling, can address nonlinear models and correlated inputs; they are useful for composite transmission, uncertain leakage area, variable speech source level, and time-varying background; their output should be a distribution or decision probability, not a false extra decimal place. Input distributions must be justified from measurements, tolerances, or conservative bounds.

4.34 Measurement state matrix and release controls

A protected-room measurement should be linked to a state matrix that records the conditions under which the result is valid. At minimum, the matrix should include source equipment and setting, source position and orientation, room geometry and furnishings, door and window status, service-system mode, masking state, occupancy, receiving access points, microphone positions, environmental conditions, and any temporary treatments. Photographs and sketches should show the reference

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coordinate system. Each later change can then be assessed against the baseline rather than relying upon memory.[152]

The matrix separates permanent construction from operational controls; a room may meet its speech-security objective only with a masking system operating and a sound-lock door closed; that is a legitimate system condition if it is designed, monitored, maintained, and required by procedure. It is not equivalent to the passive isolation of the boundary; the report should identify dependencies and failure states. Power loss, controller fault, door misalignment, disabled fan, or changed furniture may alter the outcome.

Release controls govern how raw and derived data are handled; floor plans, weak-path locations, acoustic spectra, photographs of penetrations, and descriptions of adjoining access can themselves be security-sensitive even when the governing standards are public; the project should classify or protect records according to competent authority, minimise unnecessary detail in broadly distributed reports, and maintain a controlled technical annex where appropriate. Public-source scholarship must not be mistaken for authority to publish site-specific vulnerabilities.

The final technical conclusion should be bounded in time and configuration; it should state the rooms and boundaries tested, date, method, source state, receiving conditions, uncertainty, limitations, and conditions that trigger retest; it should distinguish measured facts, engineering interpretation, and institutional decision. Such discipline is not bureaucratic decoration. It is what permits a later reviewer to determine whether the

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evidence still applies after a door replacement, cable installation, HVAC alteration, or change in room use.

4.35 Reference microphones and source-field control

A reference microphone is used to monitor the source field or excitation stability during a test. Its location and function should be defined. A microphone close to a loudspeaker can track electrical and mechanical drift while remaining dominated by the direct field. It does not necessarily represent the room-average source level. A microphone fixed in a room can track temporal stability but may sit in a modal maximum or minimum. Several references or a repeated spatial survey may be required where the room field itself changes.[153]

The reference channel should be acquired synchronously with receiving channels when transfer functions, coherence, or source-normalised levels are computed. Calibration and phase response matter. If the source is moved among positions, the reference geometry should be reproduced or the change recorded; a source-level control loop can improve stability, but it may interact with room modes or automatic loudspeaker protection; the control algorithm and reference point become part of the source system.

A reference microphone also detects failures. A disconnected driver, amplifier limiting, changed equalisation, or obstruction can alter the source spectrum; a test that assumes the source remained constant because the electrical input file was unchanged can be invalid; the acoustic reference records the delivered field. Source verification before, during, and after each run should be linked to the data file.

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For a human talker, a head-worn or nearby reference microphone can estimate source level but changes geometry and may capture breath or proximity effects; a room microphone array may provide a less intrusive average; the choice depends upon whether the objective is individual vocal effort, room excitation, or operational field. The record should avoid presenting one as another.

4.36 Sound-power measurement and installed source characterisation

Sound power characterises the rate of acoustic energy emitted by a source under defined mounting and operating conditions. It is independent of distance in the ideal sense, but its measurement requires a method that accounts for the surrounding field. Reverberation-room, free-field, and intensity methods use different assumptions. Catalogue sound-power data for equipment cannot be transferred automatically to an installed condition with different speed, duct connection, enclosure, or mounting.[154]

For an installed conference loudspeaker, sound power may be less important than the room field it produces, yet it can support prediction across several rooms or configurations; for mechanical equipment, octave-band sound power and structural blocked force are complementary source descriptors. One addresses airborne emission, the other structure-borne input. Both may be needed.

A substitution method compares the unknown source with a calibrated reference source in the same environment; it can reduce room uncertainty but requires stable conditions and an appropriate reference; intensity integration can estimate source power in situ if the scan surface and field

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indicators are satisfactory. Reverberation methods require a suitable room and absorption determination; the report should cite the method rather than stating merely that “sound power was measured.”

Operating state is decisive. Fan speed, flow, load, control mode, filter condition, and duty cycle affect emission; a variable-speed device should be measured at credible modes, including transitions if they matter; a loudspeaker should be measured below limiting and at the maximum approved setting. The source record becomes an input to path and receiving calculations.

4.37 Monte Carlo propagation for nonlinear acoustic calculations

First-order uncertainty propagation is efficient when the model is smooth and input uncertainties are small. Acoustic-security calculations often contain logarithms, subtractions near background, maxima across positions, and threshold decisions. These operations can create asymmetric or truncated distributions. Monte Carlo propagation samples input distributions, evaluates the model repeatedly, and estimates the output distribution without relying upon local linearisation.[155]

Consider background correction using Equation 4.16. If source-on and background levels are normally distributed with small standard deviations but separated by only 2 dB, some sampled pairs may have background equal to or above source-on level. The corrected signal is then undefined under the simple subtraction model. The simulation exposes a substantial probability of non-resolvable measurement, which a symmetric standard uncertainty around one corrected value conceals.

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Input distributions should be justified. Calibration errors may be normal or rectangular depending upon information. Position variability may be empirical. Source level and background may be correlated through shared operating state; correlation should be included rather than sampling independently by convenience; sensitivity indices or regression across simulations can identify dominant inputs.

The output should be summarised by median, credible interval, decision probability, and unresolved fraction where appropriate; a million simulations do not compensate for a poor physical model; model-form uncertainty, omitted paths, and nonrepresentative states remain outside the numerical distribution unless explicitly represented.

4.38 Instrument drift, field checks, and control charts

Measurement instruments can drift between formal calibrations. Microphone sensitivity changes with contamination, humidity, damage, and ageing. Cables and connectors develop intermittent faults. Battery condition and temperature affect electronics. Pretest and post-test field calibration checks provide evidence of short-term stability, while periodic laboratory calibration provides traceability under controlled conditions.[156]

A field-check difference should be evaluated against a predefined tolerance; if the post-test result departs materially, the affected data require review; simply adjusting all results by the difference assumes linear drift over time and frequency, which may not be justified. The instrument may have been damaged during the survey; intermediate checks can bound the interval.

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Long programmes benefit from control charts of calibrator readings, microphone sensitivity, channel noise, and phase checks; trends can reveal gradual drift before a failure threshold; the chart should distinguish instrument changes from calibrator changes; a reference microphone or redundant channel can help.

Field calibrators also require calibration and environmental correction where significant; coupler fit, microphone adaptor, static pressure, and warm-up can affect readings; the check should be performed with the same configuration used in measurement, including any extension or preamplifier where practicable. The result should be stored as numerical data, not merely a tick in a form.

4.39 Controlled perturbation as the foundation of path proof

An acoustic anomaly becomes a path finding when a controlled change produces the predicted response. Perturbations can alter source level, frequency, orientation, door compression, seal condition, service operation, structural loading, or receiving absorption. The intervention should be safe, authorised, reversible where possible, and narrowly targeted. Before data are taken, the expected spectral and spatial change should be written down.[157]

A temporary perimeter seal that reduces high-frequency leakage supports a gap hypothesis; added local mass that shifts a panel resonance supports a structural mechanism; closing a duct damper that changes only certain bands supports a duct path, though pressure and background changes

157 MB-1005. Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens, and James V. Sanders, Fundamentals of Acoustics, 4th ed.

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must be checked. Turning off masking can reveal passive transmission but also alters occupant behaviour if human sources are used.

Controls are essential. Apply the same temporary material to a non-suspect area or repeat the measurement without changing the path; confirm that the source and background remain stable. Repeat the intervention. If the result is not reproducible, the conclusion should remain tentative.

Perturbations can redistribute energy. Sealing one leak may increase pressure elsewhere or make another path visible; this does not mean the repair failed; the complete room should be retested, and local diagnostics should verify the new path balance; the final remediation should address the system, not only the first identified maximum.

4.40 Acoustic maps, scale integrity, and evidentiary graphics

A technical figure should permit the reader to understand the measurand, configuration, and scale without relying upon oral explanation. Acoustic maps require coordinates, units, frequency band, averaging interval, source state, processing method, dynamic range, and colour scale. Relative maps should state the reference. Smoothing and interpolation should be disclosed.[158]

Interpolation can create apparent features between sparse measurements; a contour maximum may lie where no sensor was placed; the map should show measurement points or provide an uncertainty statement; logarithmic colour scales can exaggerate small differences, while a wide fixed range can conceal local variation. The scale should serve the engineering question and remain consistent across before-and-after comparisons.

158 MB-0430. David A. Bies, Colin H. Hansen, and Carl H. Howard, Engineering Noise Control: Theory and Practice, 6th ed.

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Photographs and acoustic overlays must be registered to geometry; lens distortion, perspective, and array steering can shift apparent locations; a leak attributed to a door corner may actually lie at the adjacent wall junction. Physical verification remains necessary. The underlying table of values should be retained.

Graphics should avoid decorative three-dimensional surfaces that obscure uncertainty. Simple spectra, path diagrams, and plan maps are often more rigorous. Every published graphic should link to a data identifier and processing record.

4.41 Worked example: background-limited band with correlated calibration

A source-on receiving level is measured as 30.5 dB and the source-off background as 28.5 dB in one-third-octave band; both values use the same microphone and analyser calibration, whose standard uncertainty is 0.4 dB. Short-term repeatability contributes 0.3 dB independently to each state; because the calibration error is common to both measurements, it is correlated and largely cancels in the level difference, while repeatability does not.

Equation 4.16 gives the corrected transmitted level:

$$L_s = 10\log_{10}\left(10^{30.5/10} - 10^{28.5/10}\right) = 26.2\,dB.$$

The correction is 4.3 dB below the source-on level, showing that background is a substantial component. If each input were treated as independent with total standard uncertainty $\sqrt{0.4^2+0.3^2}=0.5$ dB, the corrected uncertainty would be overstated in part because common calibration is counted twice. If

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calibration were different between runs, the correlation would be lower. The covariance structure must follow the actual measurement chain.[159]

Sensitivity is evaluated from the derivatives of the logarithmic subtraction. Near a 2 dB source-on to background difference, small changes in either input produce a large change in L_s. Repeating the run with a higher but still linear source level or a longer synchronous estimate may reduce uncertainty. If the method's background condition is not satisfied, the band should be reported as a bound rather than an exact corrected value.

The example also shows why calibration certificates alone do not determine decision uncertainty; spatial variability, source stability, background non-stationarity, and processing sensitivity may dominate; a complete budget should preserve correlation instead of adding every certificate value as though independent.

4.42 Microphone-port geometry, reference planes, and complex calibration

A pressure microphone does not observe an abstract point in space; it responds through a finite diaphragm, protective grid, nose cone, cavity, and mounting arrangement whose geometry changes the relation between the incident field and the electrical output; the nominal coordinate assigned to the microphone should therefore identify the relevant acoustic reference plane. In free-field calibration this may be related to the diaphragm centre under a specified incidence angle. In a coupler it is governed by the cavity and adaptor. In a flush wall mounting it may be displaced by a protective screen, recess, or boundary-layer opening. An unrecorded shift of only a few

159 MB-0271. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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millimetres can introduce material phase error at high frequency or in a steep spatial gradient.[160]

The distinction is especially important when two channels are combined; sound-intensity probes estimate a pressure-gradient quantity from the difference between closely spaced microphones; a phase mismatch that appears negligible in ordinary level measurement can become the dominant error when the true phase difference is small. The usable frequency range is bounded at the low end by residual phase mismatch and at the high end by finite spacing, spatial averaging, scattering, and departure from the intended plane-wave relation; a probe should therefore carry a documented spacer, orientation, channel pairing, complex residual-intensity correction, and pressure-intensity indicator. Exchanging microphones or cables without repeating the pair calibration changes the measurement system.

A general complex correction can be written as

Equation 4.23

$$H_{c,k}(f)=\frac{H_{ref}(f)}{H_k(f)},$$

where $H_k(f)$ is the measured complex response of channel k to the calibration field and $H_{ref}(f)$ is the adopted reference response. Applying only $\left|H_{c,k}\right)$ corrects amplitude but leaves phase bias. Applying the complex factor requires a common time reference, stable sampling, and a calibration field whose spatial and temporal properties are adequate for the intended correction. The corrected channel is not thereby perfect. Uncertainty remains from calibrator field non-uniformity, adaptor leakage, microphone

160 MB-0274. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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position, repeatability, temperature, pressure, and the difference between calibration and use configurations.

Flush and recessed microphones require particular caution in secure-room surveys; a recessed port can behave as a short tube with resonances and viscous losses; a protective perforated plate can create a distributed acoustic impedance; a microphone mounted behind an architectural grille may measure the grille cavity rather than the room field at the nominal surface. These effects can be useful when the installed sensor is itself the object of examination, but they invalidate an assumption that the reading is directly interchangeable with a free-field microphone at the visible surface. The survey record should include section geometry, aperture dimensions, depth, lining, seal condition, and any correction applied.

Near rigid boundaries, the pressure field contains incident and reflected components. A microphone placed very close to the surface may record a pressure maximum while particle velocity normal to the boundary is small. Moving the microphone by a fraction of a wavelength changes the interference relation. This is not random nuisance. It is evidence about the boundary and source geometry. A field protocol should therefore specify whether the objective is incident level, total pressure, surface pressure, pressure gradient, or radiated intensity. The chosen coordinate and correction must follow that objective.[161]

Channel substitution provides a practical closure test; the same microphone, preamplifier, cable, and input channel can be moved between positions, or two nominally identical chains can exchange positions; if the spatial result

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follows the instrument rather than the coordinate, instrumental bias is indicated. A reciprocity or comparison check can further distinguish microphone sensitivity from channel gain; for low-level work, the closure test should include self-noise, dynamic range, polarisation where relevant, and the effect of any environmental enclosure.

The resulting evidence package should preserve the raw complex calibration data, reference-plane definition, pair assignment, spacer, orientation, correction file, software version, and uncertainty contribution; a scalar calibration certificate alone cannot establish the phase integrity of a multi-channel array or intensity probe. Conversely, a sophisticated complex correction does not compensate for an undefined microphone coordinate or an altered architectural port; the physical reference plane and the digital correction are one measurement chain and should be reviewed together.

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4.43 Chapter 4 glossary

Active intensity. The time-averaged directional flow of acoustic energy per unit area, represented by the real part of the pressure and particle-velocity product.

Coherence. A frequency-dependent statistic describing the linear relation between two measured signals under the chosen averaging model.

Dynamic range. The usable interval between the measurement floor and overload or unacceptable nonlinearity for the complete chain.

Energy average. An average performed after converting logarithmic levels to linear mean-square or power quantities.

Field indicator. A diagnostic quantity used in sound-intensity measurement to assess reactive field, background, or residual-intensity limitations.

Measurement state matrix. A structured record of source, path, receiver, service, environmental, and operational conditions attached to a test result.

Reference plane. The physical or analytical boundary at which input and output quantities are defined.

Spatial aliasing. Ambiguity in array processing caused when sensor spacing is too large for the analysed wavelength and steering geometry.

Transfer function. A complex frequency-domain ratio between a defined response and a defined input under stated linearity and time-invariance assumptions.

Sound pressure, particle velocity, intensity, and power illuminate different parts of the acoustic problem. Their mathematical relations become reliable only after the field, reference planes, bandwidth, averaging,

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instrumentation, and environmental state have been defined. A secure-room investigation should therefore begin with a measurement model and a state matrix, not with a preferred instrument or single-number target.

The strongest evidence combines standardised room measurements with diagnostic methods. Spatial averages support comparison, while local maxima preserve weakest-path information. Coherence and controlled perturbations test causal hypotheses. Intensity and arrays assist localisation when their field indicators, aperture limits, and phase calibration are respected. Raw-data provenance, uncertainty analysis, and explicit release controls allow the result to survive later scrutiny.

No quantity in this chapter proves speech security by itself. Pressure levels must be related to a source and background model. Intensity maps must be connected to listener exposure. Sound power must be connected through the room and paths. Instrument calibration must be supplemented by configuration control. These distinctions prepare the ground for Chapter 5, where the boundary itself is examined as a frequency-dependent mechanical and acoustic system.

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Chapter 5. Transmission Loss, Mass Law, Resonance, and Coincidence

5.1 Transmission as an energy ratio

Sound transmission through a building element is a boundary-value problem involving incident acoustic power, structural response, radiation from the receiving face, and alternative paths around the specimen. The transmission coefficient τ is the ratio of transmitted to incident acoustic power under a defined test configuration. Transmission loss is

Equation 5.1

$$T L = 10 \log_{10} \left(\frac{1}{\tau} \right) d B .$$

A coefficient of 10^{-4} corresponds to 40 dB transmission loss. The logarithm compresses an enormous energy range, but it does not remove the need to state frequency, angle or field condition, specimen area, mounting, and receiving environment.[162]

The apparent simplicity of Equation 5.1 can obscure several distinct quantities. A laboratory specimen may be measured between purpose-built rooms with controlled flanking. A field partition is embedded in floors, façades, ceilings, and services. A door leaf can be rated in one frame and installed in another. A computed value may represent normal incidence, diffuse incidence, or a statistical average. The term transmission loss should therefore remain attached to the exact physical and procedural definition used.

162 MB-0336. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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Energy conservation provides a useful audit. Incident power is partitioned among reflected, absorbed, and transmitted components, subject to any internally generated or externally coupled energy; for a passive specimen under steady conditions, coefficients should not imply more transmitted plus reflected power than incident power. Apparent violations usually signal inconsistent reference areas, levels, or field assumptions.

5.2 The ideal mass law and its domain

For an infinite limp panel of surface density m' separating identical fluids, the normal-incidence transmission coefficient can be derived by balancing acoustic pressures and panel velocity. At sufficiently high frequency relative to panel stiffness and resonance, an approximate transmission loss is

Equation 5.2

$$TL_n \approx 20 \log_{10}\left(\frac{\omega m'}{2\rho_0 c}\right),$$

where $\omega = 2\pi f$, m' is surface density in kilograms per square metre, and $\rho_0 c$ is characteristic acoustic impedance. The relation predicts approximately 6 dB improvement for each doubling of frequency or surface density.[163]

Mass law is a trend, not a universal rating formula; real panels are finite, stiff, damped, framed, penetrated, and mounted at edges. Their response changes with angle. Diffuse-field averaging reduces the ideal normal-incidence value; coincidence can create a pronounced high-frequency weakness, while stiffness and panel modes govern lower bands; seams, fasteners, and supports can transmit energy independently of the field panel.

163 MB-0970. John L. Davy, Predicting the sound insulation of single leaf walls: extension of Cremer's model.

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Worked example 5.1. Ideal normal-incidence mass-law estimate

Take $m' = 24$ kg/m², $f = 500$ Hz, $\rho_0 = 1.20$ kg/m³, and $c = 343$ m/s. Then

$$\omega m' = 2\pi(500)(24) = 75,398\,kg/(m\,s),$$

$$2\rho_0 c = 2(1.20)(343) = 823.2\,kg/(m^2\,s),$$

and

$$TL_n \approx 20\log_{10}(75,398/823.2) = 39.2\,dB.$$

The ratio is dimensionless because $\omega m'$ and $\rho_0 c$ both reduce to mechanical impedance per unit area. The result does not predict an installed wall rating. It omits bending stiffness, incidence distribution, framing, seams, and flanking.

5.3 Stiffness-controlled response and panel modes

At low frequency, a panel does not behave as an infinite limp mass. Bending stiffness, dimensions, edge restraint, and modal damping control velocity. The bending stiffness of an isotropic homogeneous plate is

Equation 5.3

$$D = \frac{E h^3}{12(1-\nu^2)},$$

where E is Young's modulus, h is thickness, and ν is Poisson's ratio. The cubic dependence on thickness means that doubling thickness increases ideal plate stiffness by a factor of eight if material and construction remain comparable.[164]

164 MB-0970. John L. Davy, Predicting the sound insulation of single leaf walls: extension of Cremer's model.

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Building panels are rarely homogeneous plates. Gypsum board contains paper facings and a porous core. Laminated glass contains viscoelastic interlayers. Metal decks are orthotropic. Masonry and concrete contain joints, reinforcement, cracking, and spatially varying boundary conditions; effective stiffness may be frequency-, temperature-, and direction-dependent; material handbook values are therefore inputs to a model, not proof of assembly response.

For a simply supported rectangular isotropic plate with dimensions a and b, modal frequencies can be approximated by

Equation 5.4

$$f_{mn} = \frac{\pi}{2}\sqrt{\frac{D}{m'}}\left[\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2\right].$$

Actual restraint lies between ideal boundary cases. Screws, studs, sealants, and frame flexibility change the modes. Low-order resonances can create local weakness or spatial variation that a single-number rating conceals.

5.4 Bending waves and critical frequency

Bending-wave phase speed in a thin plate increases with frequency; coincidence occurs when the trace wavelength of an incident airborne wave matches a structural bending wave, allowing efficient excitation and radiation; for an isotropic thin plate in air, a commonly used critical-frequency expression is

Equation 5.5

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{m'}{D}}.$$

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The formula follows from equality of acoustic and bending wavenumbers under the ideal plate model. It shows that greater bending stiffness lowers critical frequency, while greater surface density raises it when considered independently.[165]

Near and above coincidence, measured transmission loss can fall below the mass-law trend. Damping moderates the depression. Finite dimensions, orthotropy, framing, and oblique incidence broaden or split the effect; laminates can have complex stiffness and loss; a single quoted critical frequency should therefore be treated as an estimate tied to stated properties.

165 MB-0970. John L. Davy, Predicting the sound insulation of single leaf walls: extension of Cremer's model.

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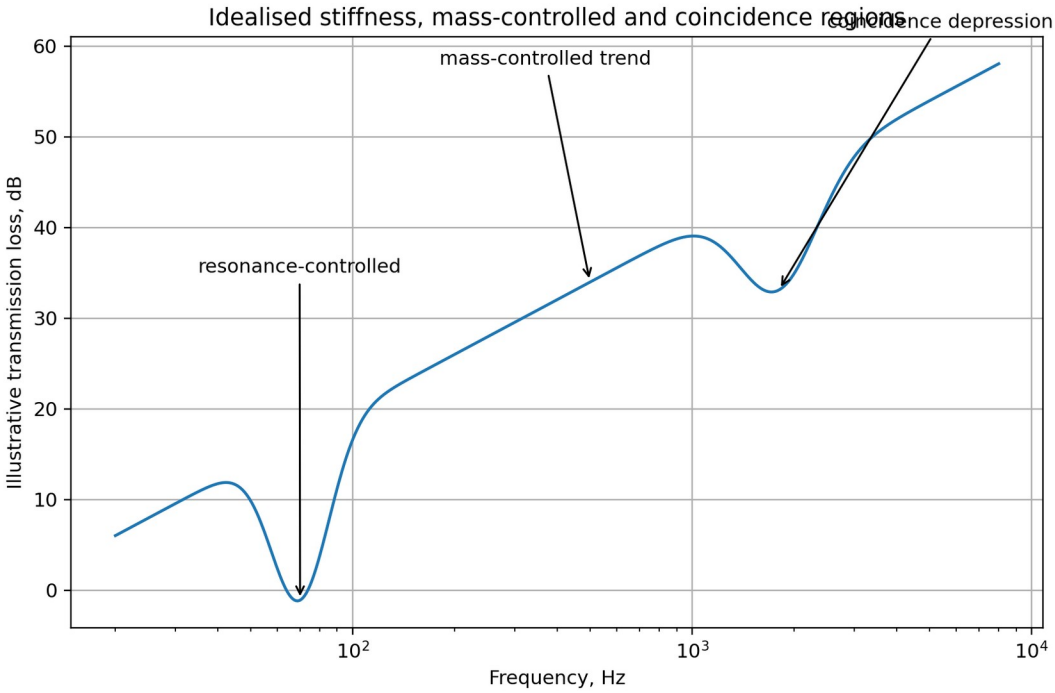

Figure 5-1. Idealised transmission-loss regions showing a resonance weakness, a mass-controlled trend, and a coincidence depression. Values are conceptual rather than product predictions. Author's original plot.

Worked example 5.2. Sensitivity of critical frequency to thickness

For a homogeneous material, $m' = \rho h$ and $D \propto h^3$. Equation 5.5 gives $f_c \propto 1/h$. Increasing thickness from 12.5 mm to 15.9 mm therefore changes the ideal critical frequency by the ratio $12.5/15.9 = 0.786$. A 2.5 kHz estimate would move to about 1.97 kHz. This scaling assumes unchanged material properties and a single homogeneous plate. It is not a substitute for measured gypsum-board data.

5.5 Damping and structural loss

Damping converts organised vibrational energy into heat or other irrecoverable forms. It reduces resonance amplitude and shortens decay. In a lightly damped single-degree system, structural loss factor η is approximately twice damping ratio ζ. For distributed building elements, loss

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is modal, frequency-dependent, and influenced by joints, finishes, air loading, and supports.[166]

Loss can be estimated from resonance bandwidth, decay rate, or complex stiffness. Each method has assumptions. Half-power bandwidth requires isolated modes and adequate signal-to-noise ratio; reverberation-type structural decay assumes a statistical energy regime; material dynamic mechanical analysis may not reproduce the strain, temperature, and boundary conditions of an assembly.

Damping is not equivalent to decoupling. A lossy panel can remain strongly coupled through studs; a resiliently supported lining can be lightly damped; high isolation often requires both reduced coupling and sufficient loss to control resonances; the design should identify which mechanism a treatment is intended to change.

5.6 Double-leaf partitions and cavity stiffness

Two leaves separated by an air cavity form a coupled oscillator. In the ideal low-frequency model, air compressibility acts as a spring. The mass-air-mass resonance is approximately

Equation 5.6

$$f_{mam} = \frac{1}{2\pi}\sqrt{\frac{\rho_0 c^2}{d}\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)},$$

where d is clear cavity depth and m'_1, m'_2 are leaf surface densities.[167]

Below resonance, the leaves tend to move together and the assembly does not realise their combined mass efficiently. Near resonance, transmission

166 MB-0412. Carl Hopkins, Sound Insulation.
167 MB-0412. Carl Hopkins, Sound Insulation.

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increases. Above resonance, substantial improvement is possible if the leaves are mechanically independent and cavity modes, coincidence, framing, and junctions are controlled; cavity absorption reduces standing-wave energy and moderates resonances, but it does not erase rigid bridges.

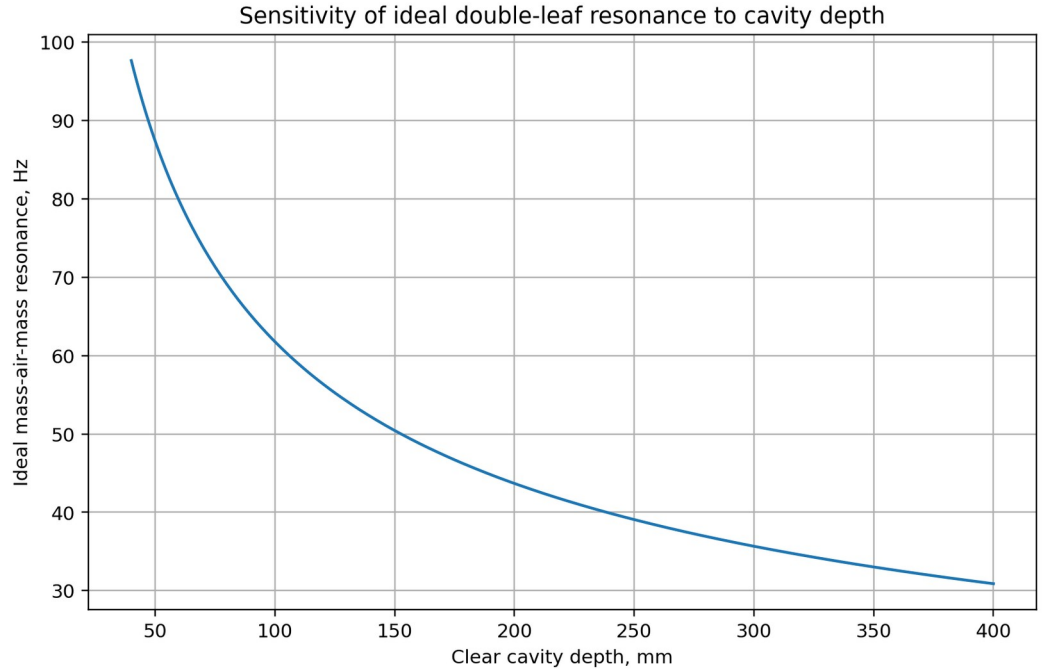

Figure 5-2. Ideal mass-air-mass resonance as a function of cavity depth for leaves of 15 and 25 kg/m². Author's original calculation.

Worked example 5.3. Double-leaf resonance

Let $m'_1 = 15$ kg/m², $m'_2 = 25$ kg/m², $d = 0.10$ m, $\rho_0 = 1.20$ kg/m³, and $c = 343$ m/s.

The cavity stiffness per unit area is

$$\rho_0 c^2 / d = 1.20 (343)^2 / 0.10 = 1.412 \times 10^6 \, N/m^3 .$$

The inverse-mass sum is $1/15 + 1/25 = 0.1067$ m²/kg. Thus

$$f_{mam} = \frac{1}{2\pi} \sqrt{(1.412 \times 10^6)(0.1067)} = 61.8 \, Hz .$$

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The dimensional product reduces to s^{-2}. Doubling cavity depth would reduce the ideal resonance by $1/\sqrt{2}$, to about 43.7 Hz. Stud coupling and finite-panel effects are omitted.

5.7 Cavity modes and absorptive infill

At higher frequency, the cavity supports standing waves. For a simple depth mode, frequencies occur near $f_n = nc/(2d)$. A 100 mm cavity has a first ideal depth mode near 1.72 kHz. Stud bays add lateral dimensions and irregular boundaries. Porous infill reduces cavity energy by viscous and thermal loss, particularly where particle velocity is appreciable.[168]

The material's airflow resistivity, thickness, density, mounting, and degree of compression affect performance; a very low-resistivity material may provide inadequate loss, while an excessively resistive thin layer can reflect rather than absorb efficiently; compression can change both acoustic and mechanical behaviour. Gaps, slumping, and incomplete coverage create non-uniform bays.

Cavity infill should not bridge leaves intended to be independent; a soft fibrous contact is not equivalent to a screw, but dense compression and service packing can create additional coupling; moisture, fire, smoke, and health requirements also constrain selection. Installation photographs and batch records are valuable because the cavity becomes inaccessible after closure.

5.8 Mechanical bridges and framing paths

A double-leaf assembly is only as independent as its connections permit. Shared studs create line coupling. Resilient channels create periodic

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connections whose dynamic stiffness and spacing govern transfer. Screws that penetrate through resilient components, rigid perimeter contact, blocking, door frames, cabinets, and service supports can short-circuit the intended separation.[169]

The effect is frequency-dependent. A bridge can dominate above the mass-air-mass resonance even when the cavity behaves well; periodic spacing can produce wave interactions and pass bands; simplified mass-law calculations cannot represent these features; laboratory evidence should match stud type, spacing, gauge, channel orientation, fastener length, board layers, cavity material, and perimeter details.

Inspection requires more than counting layers. Before closure, verify framing separation, clip loading, channel continuity, screw length, blocking, and services; after closure, controlled tapping, scanning, mobility measurements, or selective opening may locate bridges; the remedy should remove the actual transfer path rather than merely adding more board.

5.9 Angle of incidence and diffuse-field averaging

Transmission through a panel changes with incidence angle because the pressure loading and structural wavenumber change. Normal-incidence mass law is usually more favourable than certain oblique conditions near coincidence. Laboratory rooms seek a diffuse incident field so that many directions contribute. The resulting transmission loss is an angular and spatial average, not a universal response at every angle.[170]

Small test rooms and low frequencies may not approximate diffuse incidence; source position, specimen location, room absorption, and modal

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170 MB-0336. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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structure matter; field rooms can be more directional, especially when a loudspeaker or talker is close to a partition. An assembly that performs well under diffuse laboratory excitation can show a local weakness under directional service conditions.

Prediction methods should state whether they use normal incidence, random incidence, or another distribution; comparing a normal-incidence calculation directly with a diffuse-field test without correction is misleading; when source orientation is important, a sensitivity study with plausible angles and locations is more informative than one nominal rating.

5.10 Finite size, radiation efficiency, and edge restraint

An infinite-panel model omits edges. A finite panel has discrete modes and a radiation efficiency that varies with frequency and mode shape. Below the acoustic coincidence region, some bending modes radiate inefficiently because positive and negative surface velocities cancel in the far field. Edges and discontinuities disturb that cancellation.[171]

Frame stiffness and sealant alter boundary restraint; a nominally clamped panel can behave closer to simply supported if the frame flexes; large glazing panels and doors can have lower modal frequencies than small laboratory samples; conversely, subdivision by mullions can alter modal density and coincidence. Specimen dimensions should therefore be treated as part of the tested configuration.

Edge leakage and structural transmission can occur together; a flexible frame may radiate while a gasket leaks; local vibration and acoustic intensity

171 MB-0411. Carl Hopkins, ISO 10848-1:2017, ISO 12354-1:2017.

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measurements can distinguish these mechanisms; replacing the leaf without addressing frame mobility can leave the dominant path unchanged.

5.11 Orthotropic, ribbed, and layered elements

Corrugated metal, profiled deck, hollow-core slabs, framed boards, and laminated elements are directionally dependent. Their bending stiffness differs along principal axes. Coincidence may occur at different frequencies with direction, and ribs can guide waves towards junctions. An equivalent isotropic plate can be useful for preliminary work but should not conceal directional behaviour.[172]

Layered elements may exhibit shear deformation, interlayer slip, and frequency-dependent complex stiffness; laminated glass is a prominent example; temperature and frequency change the interlayer modulus and loss; composite panels with skins and cores can show local face and global bending modes. Manufacturer data should identify the exact layer build-up, temperature, dimensions, and boundary conditions.

Prediction should progress from the simplest model that can answer the decision; if directional stiffness or interlayer dynamics changes the result materially, a more complete model or test is required; complexity without validated properties merely creates precise-looking uncertainty.

5.12 Openings, gaps, and composite transmission

A small weak area can govern a large strong wall. For elements in parallel under a common incident field, an area-weighted transmission coefficient is

Equation 5.7

172 MB-0411. Carl Hopkins, ISO 10848-1:2017, ISO 12354-1:2017.

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$$\tau_c = \frac{\sum_i S_i \tau_i}{\sum_i S_i}, TL_c = 10 \log_{10}\left(1/\tau_c\right).$$

The relation assumes comparable incident exposure and neglects interaction. It nevertheless demonstrates why a perimeter gap or ordinary door can erase much of a high-rated wall's benefit.[173]

Worked example 5.4. Wall with a weak door

A 30 m² wall has $TL = 60$ dB. A 2 m² door has $TL = 35$ dB. The wall coefficient is 10^{-6} and the door coefficient is 3.162×10^{-4}. Thus

$$\tau_c = \frac{30\left(10^{-6}\right) + 2\left(3.162 \times 10^{-4}\right)}{32} = 2.07 \times 10^{-5},$$

$$TL_c = 46.8\,dB.$$

The 35 dB door reduces the combined result by more than 13 dB relative to the wall. Real frame leakage and flanking can reduce it further.

An open slot can be much worse than a low-rated solid element because its effective transmission coefficient may approach unity within part of the band; seal compression, threshold continuity, frame corners, and service penetrations deserve quantitative attention. Visual closure does not prove acoustic closure.

5.13 Porosity, cracks, and tortuous leakage

Masonry, concrete, stone, plaster, and sealants can contain interconnected pores and cracks. Transmission through a porous path depends on aperture, depth, tortuosity, flow resistivity, and pressure distribution. A long narrow crack can exhibit inertance and viscous loss, while a short open hole

173 MB-0412. Carl Hopkins, Sound Insulation.

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can transmit efficiently. Frequency-dependent behaviour may include resonant effects.[174]

Air leakage tests can identify gross continuity but do not directly measure acoustic transmission; smoke, tracer gas, pressure decay, and thermography can locate paths under suitable conditions. Acoustic probing adds frequency response. The methods should be combined cautiously because pressure differentials can open or close flexible seals differently from ordinary operation.

Cracks may also represent structural discontinuity and vibration coupling; injecting sealant can close an airborne path but stiffen a joint and alter structural transfer; remediation should state which mechanism is being changed and should include before-and-after frequency-resolved verification.

5.14 Doors, frames, and operable assemblies

An acoustic door is a system comprising leaf, internal construction, frame, anchors, hinges, latch, perimeter seals, threshold, automatic bottom, floor condition, and surrounding wall. Laboratory evidence for the leaf alone is insufficient. Operability and repeated use create tolerances that fixed panels do not experience.[175]

Compression seals require uniform contact. Excessive compression can prevent latching or increase operating force; insufficient compression creates leakage; door sag, closer adjustment, warped leaves, damaged seals, debris, carpet, and floor irregularity change performance; magnetic or inflatable seals introduce power, maintenance, and fail-state questions.

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175 MB-0336. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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A vestibule or sound lock can provide serial attenuation if the two doors are sufficiently separated, the intervening surfaces are treated appropriately, and one door is normally closed before the other opens; the benefit is not the arithmetic sum of two laboratory ratings. Frame connections, common walls, ceiling plenums, and operational discipline must be considered.

5.15 Glazing and frame-dominated performance

Glass combines high surface density with bending stiffness and coincidence. Monolithic panes can exhibit a coincidence dip in speech-relevant high-frequency bands; laminated interlayers add damping, subject to temperature and frequency; insulated glazing creates a double-leaf system with a narrow gas cavity and corresponding resonance; unequal panes can reduce coincident weaknesses but do not eliminate frame and seal paths.[176]

Glazing systems should be specified by complete build-up, dimensions, frame, bite, setting blocks, gasket, sealant, and installation; a laboratory result from a small window in a massive test wall may not represent a large façade panel; mullions and transoms can transmit structurally. Operable windows introduce additional seals and hardware.

Secondary glazing can be effective when cavity depth is large, panes are structurally independent, and perimeter continuity is controlled; a small shallow cavity can create a high mass-air-mass resonance or triple-leaf penalty when added to an existing insulated unit. The retrofit should be modelled as the actual layered system.

176 MB-0970. John L. Davy, Predicting the sound insulation of single leaf walls: extension of Cremer’s model.

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5.16 Laboratory specimen mounting and test boundaries

Laboratory transmission-loss testing seeks to suppress flanking so that the specimen controls. Mounting details nevertheless influence the result. Edge restraint, filler construction, specimen dimensions, curing, environmental state, and installation workmanship are part of the test article. Reproducibility depends upon documenting them.[177]

A test opening can be smaller or stiffer than a field bay; sealants can be installed by specialists under ideal access; services and junctions may be absent; a result should therefore be used as evidence for the tested system and close variants supported by engineering judgement, not as a generic property of a material name.

Comparisons across reports require common frequency bands, rating method, specimen size, laboratory qualification, and uncertainty; a higher single-number rating can conceal an adverse dip important to speech security; the full curve and report notes should be retained in the submittal record.

5.17 Field apparent insulation and flanking

Field tests measure an installed relationship that includes direct and flanking transmission unless the method isolates paths. The apparent result can be lower than laboratory performance because energy travels through slabs, walls, façades, ceilings, ducts, and junctions. It can also differ because rooms have different volumes, absorption, and modal fields.[178]

A discrepancy should not be described simply as a “field penalty”; the engineering task is to identify the path; compare level differences, surface

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velocities, intensity maps, junction attenuation, and controlled interventions; a continuous slab can transmit beneath an excellent wall. A shared plenum can bypass it. A door can dominate. Adding mass to the wall field will not correct those mechanisms.

The as-designed, as-built, and as-tested records should remain separate. Drawings show intent. Concealed-work evidence and inspection show implementation. Field measurements show response under stated conditions. Conformity requires a decision rule connecting all three.

5.18 Prediction hierarchy and model choice

Prediction can range from hand calculations to transfer matrices, finite elements, boundary elements, statistical energy analysis, and hybrid models. The appropriate level depends upon frequency, geometry, material knowledge, and decision consequence. Hand calculations are valuable for scaling and screening. Detailed numerical models require verified properties, boundary conditions, mesh convergence, and validation.[179]

A model should name its output. Predicted panel transmission loss is not predicted room privacy; a direct-path model is not an apparent field model; a deterministic low-frequency model should not be extrapolated into a high-modal-density regime without justification; conversely, statistical models can obscure discrete low-frequency resonances.

Sensitivity analysis identifies which uncertain inputs control the decision; if a result is dominated by an unknown seal gap, refining concrete modulus to three significant figures adds no value; modelling should direct investigation and design, not replace evidence.

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5.19 Uncertainty in transmission-loss results

Transmission-loss uncertainty includes source and receiving levels, reverberation or absorption correction, specimen area, background, spatial sampling, source stability, and method repeatability. Because the calculation contains logarithms and subtraction, uncertainty can be nonlinear near the noise floor.[180]

Correlated calibration effects may cancel in level differences when the same chain is used, while independent spatial variability does not; interlaboratory reproducibility can exceed within-test repeatability; a product report's stated uncertainty may not include construction variability or field workmanship.

Conformity should use a declared rule. A measured rating exactly equal to a contractual minimum does not necessarily mean the probability of conformity is acceptable; guard bands, repeat testing, or band-specific requirements may be appropriate; the rule should be agreed before results are known.

5.20 Frequency-resolved evidence and rating curves

Single-number ratings compare a measured curve with a reference contour according to a standard procedure. They are useful for classification and procurement, but they compress spectral information. Two assemblies with the same rating can have different low-frequency, coincidence, or leakage behaviour.[181]

A secure-room design should examine one-third-octave results beneath the rating; bands associated with loud male speech, audiovisual reinforcement, mass-air-mass resonance, door leakage, duct break-in, and coincidence

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deserve explicit review; rating-curve deficiencies can suggest mechanisms, but diagnosis requires construction and path evidence.

Design specifications should distinguish a required rating from mandatory band minima where such minima are justified and supported; inventing unofficial “secure STC” thresholds or controlled criteria is improper; public standards and competent-authority requirements must remain distinct.

5.21 Controlled perturbation and forensic proof

Causal diagnosis is strengthened by changing one suspected path while preserving others. Temporary sealing of a door perimeter, adding mass to a local panel, immobilising a grille, changing source orientation, or isolating equipment can reveal predicted changes. The intervention should be reversible, safe, and documented.[182]

A positive change supports the path hypothesis but may not quantify the permanent remedy; temporary putty can seal differently from a durable fire-rated joint; clamps can alter structural boundary conditions; multiple paths can mask one another. Repeated baseline and intervention measurements help distinguish drift.

Physical inspection should precede destructive work. Drawings, photographs, borescope observations, fastener maps, and service records can narrow the search. Any controlled opening in a secure or evidentiary environment requires authority, custody, restoration, and retesting.

5.22 From element performance to room design

Transmission loss becomes useful to acoustic security only when elements are assembled into a complete source-path-receiver model. The wall field,

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door, glazing, floor, ceiling, roof, ducts, penetrations, and structural junctions contribute in parallel or series. Source position and receiving access weight those paths. Background and masking affect audibility without changing passive transmission.[183]

Design should therefore begin with a path budget rather than a headline wall rating; each path receives a target, construction detail, submittal evidence, inspection hold point, and acceptance method; the weakest credible path should not consume the entire margin. Future penetrations, seal ageing, and configuration changes require reserve.

5.22.1 Path budgets and the allocation of margin

A path budget translates the room objective into provisional limits for walls, doors, glazing, ceilings, floors, services, and flanking. It is not an invitation to assign the same nominal rating to every element; the allocation should reflect area, source exposure, uncertainty, deterioration, testability, and the consequence of one element becoming dominant; a large wall field may tolerate a lower transmission coefficient per square metre than a small door because of area. Conversely, a door may require greater design reserve because seals drift and access is frequent.[184]

The budget is most transparent in the linear energy domain. Let τ_i represent the effective coefficient of path i, including area and exposure normalisation appropriate to the model. The aggregate coefficient is the sum of parallel contributions. If the target coefficient is τ_T, each path receives an allocation such that $\sum_i \tau_i \leq \tau_T$. A reserve term should cover unmodelled paths and

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uncertainty. Allocating every known path up to the target leaves no margin for workmanship or future change.

A path budget should be revised as evidence improves; early design may use conservative estimates; submittals replace generic values with tested assemblies; mock-ups and pretests refine junctions and seals. Final field measurements identify the installed distribution. The record should preserve these revisions so that later modifications can be evaluated against the same framework.

5.22.2 Parallel and serial combinations

Parallel paths transmit simultaneously and combine in energy; serial stages act sequentially, but their attenuations do not always add arithmetically because the intermediate field, coupling, and flanking can change. Two doors separated by a vestibule illustrate the distinction; if the vestibule is sufficiently absorptive and each door sees a diffuse field, a serial approximation may be useful; if frames are structurally coupled, doors open together, or the vestibule supports strong modes, simple addition is optimistic.[185]

Duct silencers in series also interact. Flow-generated noise between stages, inadequate separation, pressure drop, and breakout can limit the sum; a room-within-room system contains serial leaves but also parallel structural bridges and services; the model should therefore draw the network explicitly rather than assigning one “total STC”.

Network methods are particularly valuable for remediation; if a door path is reduced below a slab path, further door improvement yields little system

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benefit; the order of work should follow the present path ranking, not the original design intent. A second measurement after each major intervention confirms whether the next path has emerged.

5.22.3 Seal mechanics and contact continuity

Seal performance is governed by contact pressure, compression range, surface alignment, material stiffness, corner continuity, and ageing. A gasket can appear continuous while failing to touch along part of its length. Paper-strip tests, light tests, tactile inspection, and pressure-sensitive films can provide evidence, but each has limitations. Acoustic probing under controlled source excitation remains the decisive functional check.[186]

Compression set reduces recovery after prolonged closure. Temperature changes material modulus. Cleaning agents and lubricants can degrade polymers; automatic door bottoms depend on plunger adjustment and floor profile; a threshold joint can open with building movement; the inspection plan should record seal identity, date, compression, corner condition, latch force, clearances, and replacement criteria.

Permanent remediation must preserve fire, smoke, egress, accessibility, and security functions; a soft added seal that improves a test but prevents reliable latching is not acceptable; the system should be tested after operational adjustment, not while held closed by temporary pressure.

5.22.4 Material properties, production variability, and substitution

Prediction requires surface density, elastic properties, loss, dynamic stiffness, airflow resistivity, and geometric tolerances; nominal catalogue

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values often represent a product family rather than the delivered batch; moisture content changes gypsum and timber mass and stiffness; concrete density and cracking vary; viscoelastic layers depend on temperature and cure. Resilient mounts depend on load.[187]

Substitution review should compare the property controlling the mechanism, not only thickness or trade name; a replacement board of equal thickness can have different surface density and critical frequency; mineral fibre of equal nominal density can have different airflow resistivity. A seal of similar dimensions can have different compression force; the submittal should identify test evidence and exact configuration.

Where sensitivity is high, receive and verify critical materials; weigh representative boards, measure cavity depth, record stud gauge, verify clip model, and inspect seal profiles; the object is not laboratory characterisation of every component; it is preventing an unrecorded property change from invalidating the path model.

5.22.5 Tolerances as engineering variables

Construction tolerances create a distribution of installed states; a drawing may specify a 10 mm perimeter gap filled with sealant, but actual gaps can range from nearly closed to much wider; sealant depth, backing, adhesion, and cure vary; stud alignment affects cavity depth and board contact. Door frames can be out of square; treating every tolerance as its nominal value understates risk.[188]

A tolerance analysis should identify variables with nonlinear influence; open-gap area can dominate composite transmission; resilient-clip overload can

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change dynamic stiffness sharply; a narrow cavity can raise mass-air-mass resonance. Monte Carlo analysis or worst-credible scenarios can show whether ordinary workmanship variation consumes the design margin.

Inspection points should follow that sensitivity. Measure the variables that matter before they become concealed; if the model is insensitive to a small dimension, excessive inspection adds cost without protection; if a 2 mm seal discontinuity controls performance, the acceptance plan should examine the full perimeter rather than a few representative points.

5.22.6 Worked example: effect of an open perimeter slot

Consider a 20 m² partition with an otherwise ideal 55 dB transmission loss and a continuous open slot 2 mm wide along a 3 m edge. Slot area is $0.002 \times 3 = 0.006$ m². If the slot is approximated conservatively as an open path with $\tau = 1$, while the wall coefficient is $10^{-5.5} = 3.16 \times 10^{-6}$, the composite coefficient is

$$\tau_c = \frac{19.994\left(3.16 \times 10^{-6}\right) + 0.006\left(1\right)}{20} = 3.03 \times 10^{-4},$$

which corresponds to

$$TLc = 10 \log 10\left[1/\left(3.03 \times 10^{(}-4\right)\right)] = 35.2\, dB.$$

The tiny slot reduces the idealised result by nearly 20 dB. The model overstates some real narrow-slot transmission because it neglects inertance and viscous loss, but it correctly demonstrates the order of sensitivity. Seal continuity must be treated as a primary performance variable, not a finishing detail.[189]

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5.22.7 Evidence hierarchy for assembly selection

Assembly selection should begin with a report for the exact construction. If that is unavailable, evidence can progress through close tested variants, validated calculations, material-property data, mock-ups, and conservative engineering judgement. Each step away from the tested specimen increases uncertainty.[190]

A test report should be read beyond the rating; verify specimen dimensions, stud and board identity, screw pattern, cavity material, sealant, mounting, laboratory, method edition, test date, curve, and notes; a product brochure that cites only a rating cannot establish the configuration. A “generic” wall name is not a reproducible assembly.

The selected detail should be buildable and inspectable; an exceptional laboratory result dependent upon delicate channels, proprietary compounds, or inaccessible seals may be less reliable in the field than a simpler assembly with greater margin; procurement should evaluate evidence quality, workmanship sensitivity, repairability, and lifecycle access alongside nominal performance.

5.22.8 Distinguishing airborne leakage from structural bridging

A weak band can arise from an open air path, a vibrating leaf, or a structural bridge. The remedies differ. Airborne leakage often produces strong local pressure or intensity near a gap and can respond sharply to temporary sealing. Structural bridging can produce coherent velocity across a connection and may remain after surface gaps are sealed.[191]

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Several observations should be combined. Acoustic intensity identifies net outward power near a surface; laser or accelerometer measurements identify motion; smoke or pressure tests reveal continuity; source relocation distinguishes local direct excitation from room-average exposure. A controlled intervention provides the strongest discrimination.

Frequency response also assists. A broad high-frequency loss can indicate leakage, while narrow resonant peaks can indicate panels or cavities. These are tendencies, not rules. Long slots can be resonant, and bridges can transmit broadly; the physical inspection and perturbation should govern the conclusion.

5.22.9 Design reserve and deterioration

A newly commissioned assembly is not a permanent state. Door seals wear, sealants shrink, buildings move, and services are added. A design that barely meets its objective at initial acceptance has no lifecycle reserve. The path budget should include deterioration and change.[192]

Reserve can be created through better passive isolation, redundant vestibules, accessible replaceable seals, controlled penetrations, monitoring, and configuration management; the most suitable measure depends on the likely failure; adding mass does not reserve against a future conduit hole; a penetration permit and retest programme does.

Periodic checks should focus on variable elements. Door compression, masking level, flexible connectors, access panels, and new services deserve more frequent attention than monolithic wall mass. Baseline spectra and photographs make subtle change visible.

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The advanced sections that follow extend these foundations into statistical energy models, constrained-layer damping, complex multi-leaf behaviour, transfer matrices, periodic framing, massive elements, apertures, resilient supports, doors, glazing, tolerance, mock-ups, specification responsibility, and forensic remediation; their purpose is to refine the system model, not to replace verification.

5.23 Statistical energy models and their domain of usefulness

At sufficiently high modal density, building-acoustic prediction can be framed in terms of average energy rather than deterministic phase. Statistical energy analysis and related diffuse-field models partition a structure into subsystems, assign modal densities and internal loss factors, and describe power exchange through coupling loss factors; the approach is valuable for complex assemblies and flanking networks because it converts a large set of resonances into tractable average relations. Its assumptions must nevertheless be made explicit; a subsystem is not diffuse merely because the software labels it so; low modal overlap, strong local forcing, short dimensions, irregular damping, and dominant discrete junctions can invalidate the statistical approximation.[193]

For two coupled subsystems with modal energies E_1 and E_2, a simplified steady-state balance may be written

Equation 5.8

$$P_1 = \omega \eta_1 E_1 + \omega \eta_{12} E_1 - \omega \eta_{21} E_2,$$

with an analogous equation for subsystem 2. Here P_1 is injected power, η_1 is the internal loss factor, and η_{12} and η_{21} describe coupling. Reciprocity and

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modal-density relations constrain the coupling terms under the model. In a secure-room application, subsystems might include the source-room air, a wall leaf, a slab, the receiving-room air, and an adjoining corridor. The model can rank broad path families, but its parameters must represent the actual construction and frequency range.

A statistical result should not be presented as a deterministic guarantee at one point; it predicts an ensemble or spatial average, with variance related to modal overlap and uncertainty in properties; at low frequency, individual modes and junction conditions often dominate. A hybrid analysis is therefore appropriate: deterministic or measured treatment below the region of adequate modal density, statistical treatment above it, and explicit reconciliation across the transition; the choice of transition frequency should be supported by dimensions, damping, and observed response, not assigned as a convenient round number.

Model calibration should use independent evidence. If field measurements are used to tune loss factors and the same data are then cited as validation, the exercise is circular; a stronger procedure calibrates uncertain parameters from material tests, structural-response measurements, or one configuration, then predicts a second configuration or path intervention. Residual error and parameter non-uniqueness should be retained; a model can be useful for design sensitivity even when it cannot identify a unique physical parameter set.

5.24 Damping, constrained layers, and the distinction between loss and decoupling

Damping dissipates vibrational energy. Decoupling reduces force or velocity transfer between elements; the two mechanisms can complement each

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other but should not be described as synonyms. A viscoelastic layer between boards can increase structural loss factor and reduce resonance amplitudes; a resilient clip can reduce mechanical coupling between a lining and studs; if screws bypass the clip or the lining touches the slab, the decoupling can be defeated even though the board stack retains damping. Conversely, a well-decoupled but lightly damped leaf can exhibit pronounced resonant behaviour.[194]

Structural loss factor η is related to damping ratio ζ by $\eta \approx 2\zeta$ for lightly damped single-degree systems near resonance. Real panels are distributed and frequency-dependent. Viscoelastic properties vary with temperature, frequency, strain, age, and layer geometry. Product data measured under one shear condition cannot be transferred automatically to a different assembly. The design record should identify the treatment, coverage, thickness, curing, substrate, fastening, temperature range, and evidence supporting the claimed effect.

Constrained-layer damping works by shearing a lossy layer between stiffer faces; its efficiency depends upon strain energy being developed in the layer; a thick soft compound is not necessarily better than a thinner optimised layer; discontinuous application, rigid mechanical bridges, and incompatible surface conditions reduce performance. Field inspection is difficult once the wall is closed, so submittal control, mock-up observation, batch records, photographs, and witness points become important.

Damping treatments are most effective where resonant response contributes materially to the weakness; they do not close holes, increase

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door compression, lengthen a duct silencer, or eliminate slab flanking; a frequency-resolved diagnosis should precede remediation; if a wall underperforms broadly according to surface density, adding damping alone may produce little improvement. If a narrow coincidence or panel resonance is evident, damping can be valuable. The specification should state the intended mechanism and acceptance evidence rather than requiring a branded compound without a system-level criterion.

5.25 Double-leaf behaviour beyond the mass-air-mass resonance

The mass-air-mass resonance is the most familiar feature of a double-leaf partition, but it is not the whole response; below resonance, the leaves move substantially in phase and the assembly behaves as a coupled system. Near resonance, cavity stiffness and leaf masses exchange energy, producing a pronounced reduction in insulation; above resonance, improved performance is possible because the leaves can act more independently, yet studs, ties, screws, cavity modes, and coincidence limit the gain; the ideal two-mass model therefore supplies a design warning, not a complete prediction.[195]

Cavity absorption reduces standing-wave build-up and can damp interactions between leaves; it does not add significant surface mass, and fully filling a cavity with highly compressed fibre can create mechanical contact or change dynamic behaviour; the material should be selected and installed to avoid voids, slumping, moisture retention, and contact that bridges intended separations. Its airflow resistivity and thickness influence

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absorption; a generic instruction to “fill with insulation” is insufficient for a high-isolation assembly.

Framing changes the coupling mechanism. A single stud shared by both leaves creates direct structural transmission; staggered studs reduce direct contact but share plates and may still couple through blocking, services, or cavity air; double studs provide greater structural independence, subject to slab, head, jamb, and service connections. Resilient channels or clips can reduce coupling, but their orientation, spacing, load, screw length, and perimeter clearance are critical; the predicted benefit must be conditioned on workmanship.

Unequal leaf masses can separate coincidence and panel resonances, reducing the chance that both leaves exhibit weakness in the same band; the strategy is useful but not universally optimal; different boards may have different stiffness, fire classification, moisture behaviour, or fastening requirements. The assembly must be supported by test or validated prediction for the exact layer sequence; a schedule that simply assigns “two layers one side, three layers the other” without material identities and fastening details is not a reproducible design.

The junctions often govern. A double-stud wall built between a continuous slab and deck may still transmit through those structures; a ceiling that terminates at the wall can preserve isolation, while a continuous suspended ceiling or common plenum may bypass it. Door frames can tie leaves together. Perimeter sealant can harden, crack, or detach; the designer should draw the complete path from floor to structure above and through every intersection, not merely a typical field-of-wall section.

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5.26 Triple-leaf penalties and retrofit traps

Adding a new lining in front of an existing wall can improve sound isolation, but it can also create a triple-leaf system with two coupled cavities. Such systems contain multiple mass-air-mass resonances and can perform worse than a carefully designed double-leaf assembly of similar mass. The risk is greatest when a light independent lining is installed close to an existing hollow partition without understanding its internal leaves, cavity depths, and connections.[196]

A simplified three-mass model has two coupled resonance modes; their frequencies depend upon all three surface masses and both cavity stiffnesses; the modes can fall within speech-relevant bands and produce broad weakness if damping is low; the correct retrofit investigation should identify the existing construction through records, borescope examination, non-destructive methods, or controlled opening. Concealed board layers, resilient channels, insulation, and service chases cannot be inferred reliably from wall thickness alone.

Several retrofit principles reduce risk. Where practicable, remove an unnecessary intermediate leaf so that the final construction is a well-defined double-leaf system; if removal is impossible, increase the new cavity depth and new-leaf mass, avoid rigid ties, add appropriate cavity absorption, and model the coupled resonances. A heavy independent masonry or board lining can be effective, but floor loading, seismic restraint, fire stopping, moisture, and access must be coordinated; the design should include a testable mock-up when uncertainty remains high.

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Retrofit also changes flanking. A new wall may stop at a suspended ceiling while the original continues to structure, leaving a ceiling path; new furring can bridge to columns; added board can obstruct door swing or reduce seal compression; electrical boxes may be extended with rigid metal rings that short-circuit the lining. The remediation package should include plan, section, and detail drawings for every boundary rather than relying upon a generic lining note.

5.27 Composite transmission and the tyranny of small weak areas

A separating surface rarely has uniform performance. Doors, glazing, outlets, access panels, transfer grilles, and perimeter gaps occupy a small fraction of area but can dominate transmitted power because transmission coefficients vary exponentially with decibel rating. Composite transmission must therefore be calculated in linear power terms. The result is not a weighted arithmetic average of component decibels.[197]

For areas S_i with transmission coefficients τ_i, the composite coefficient is given by Equation 5.7. The sensitivity to a weak component can be quantified. A 20 m² boundary with 18 m² at 60 dB and 2 m² at 35 dB has a composite transmission loss of only about 44.8 dB. Improving the wall field from 60 to 65 dB changes the composite result by less than one decibel because the door remains dominant. Improving the door or adding a sound lock produces far greater benefit.

The calculation assumes all elements experience the same incident energy density and radiate into the same receiving relationship. Real rooms violate those assumptions. A door near the source may be more strongly excited; a

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grille may connect directly to a quiet remote space; a small gap can behave as an acoustic aperture with frequency-dependent end correction and flow effects; composite calculation is therefore a first-order screen. It identifies likely bottlenecks and prevents futile investment in already strong areas, but field verification remains necessary.

Perimeter leakage is particularly potent because its effective area can change with latch force, pressure differential, temperature, and wear; a nominal 1 mm gap around a door can constitute several thousand square millimetres of open area; the path may be invisible under ordinary light and may occur only when the leaf bows or the closer fails to pull against seals. Mechanical inspection, feeler gauges, light testing where appropriate, and acoustic scanning should be coordinated; the acceptance record should include the door’s operational force and hardware state, not only the acoustic result.

5.28 Reconciling laboratory, prediction, field, and speech-security results

Four evidence streams often coexist: laboratory test data, analytical or numerical prediction, field sound-isolation measurement, and speech-security assessment; they should agree in broad physical pattern, yet they do not measure the same object; laboratory data describe a specimen mounted in a prescribed opening under controlled flanking conditions. Prediction describes an idealised or parameterised model; field measurement includes workmanship, junctions, services, and actual rooms; speech-security assessment adds a source model, receiving background,

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listener access, and an intelligibility or probability criterion. Differences are expected. The task is to explain them, not force them into one number.[198]

A disciplined reconciliation begins with configuration identity; the tested specimen's board type, surface density, framing, fastener spacing, cavity depth, absorptive fill, dimensions, seals, and mounting must be compared with the design and installation; a product-family report is not evidence for every variant. If the field assembly is taller, contains different studs, has an operable door, or terminates at a different structure, the discrepancy must be modelled or acknowledged.

Prediction should be calibrated against independent data where possible; a model that reproduces a laboratory curve only after arbitrary frequency-dependent adjustment has limited predictive authority; residuals should be plotted by band; systematic low-frequency error may indicate boundary or modal assumptions, while a coincidence-region error may indicate incorrect stiffness or damping. Field residuals can reveal flanking or leakage. Speech-security residuals can reveal source or background modelling errors.

The evidence hierarchy should be proposition-specific; a current laboratory report for the exact assembly is strong evidence of specimen performance; it does not supersede a competent field test of the installed room; a field test under controlled conditions is strong evidence of apparent isolation at that time. It does not supersede an authority's accreditation decision or prove every operational speech state; a speech-privacy metric can support a listener-related proposition, but it does not certify the wall; the report

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should use separate headings or tables for these propositions to prevent accidental merger.

5.29 Transfer matrices and layered elements

Transfer-matrix methods represent acoustic or structural state variables on one side of a layer in terms of those on the other; for a fluid layer, the state may contain pressure and volume velocity. For plates and beams, it may include displacement, rotation, force, and moment; matrices for successive layers can be multiplied, permitting prediction of multilayer absorbers, cavities, membranes, and perforated facings; the method is powerful because it keeps phase and impedance, but its validity depends upon the assumed wave types and boundary conditions.[199]

For a plane fluid layer of thickness d, characteristic impedance Z_c, and wavenumber k, a common two-port form is

Equation 5.9

$$\begin{bmatrix} p_1 \\ u_1 \end{bmatrix} = \begin{bmatrix} \cos(k\,d) & j\,Z_c \sin(k\,d) \\ j \sin(k\,d)/Z_c & \cos(k\,d) \end{bmatrix} \begin{bmatrix} p_2 \\ u_2 \end{bmatrix}.$$

Losses can be included through complex k and Z_c. Porous materials require an appropriate equivalent-fluid or poroelastic model. A board leaf requires plate mechanics rather than a fluid transfer matrix. The analyst must state which formulation is used and whether oblique incidence, diffuse averaging, framing, and finite size are represented.

Transfer matrices are well suited to sensitivity studies; they can show how cavity depth shifts resonance, how resistive absorption damps it, or how a perforated layer changes impedance; they are less suited to a wall

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dominated by discrete studs, screws, outlets, and junction flanking unless those features are represented through additional paths. A smooth predicted curve can therefore be physically incomplete; comparison with measured data and a parallel path model is essential.

The numerical implementation should be checked for stability at high frequency or large thickness; direct matrix multiplication can become ill-conditioned when evanescent terms grow; scattering matrices or recursive impedance methods may be more stable; this is not merely computational housekeeping. Numerical overflow or cancellation can create false peaks and dips that a non-specialist may mistake for material behaviour.

5.30 Periodic framing, line bridges, and spatially distributed coupling

Studs, channels, ties, and fasteners create repeated structural connections between leaves; their effect is not equivalent to a uniform spring in every frequency range; at low frequency, the framing may behave as distributed stiffness. At higher frequency, periodicity can produce pass bands, stop bands, and coincidence with bending wavelengths; screw spacing, stud spacing, channel orientation, and the stiffness of connections influence the path; simplified models may smear these features into an average coupling, but the design should preserve the construction details that control them.[200]

A line bridge transmits force along a junction rather than at a point; its importance depends upon the mobility of both leaves and the bridge, the spacing of supports, and the relative wave impedances; a light steel stud can be flexible in one direction and stiff in another. Wood framing has different damping and variability; resilient channels can provide useful compliance

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but are susceptible to incorrect orientation, overloading, and screws that penetrate into studs. Isolation clips introduce discrete supports whose dynamic stiffness and load range matter.

Fastener count is not merely a workmanship variable; more fasteners can increase structural coupling, while too few can violate structural, fire, impact, or manufacturer requirements; a secure-room specification must coordinate acoustical objectives with code and durability; it should not instruct the contractor to omit required fasteners. Instead, it should select a tested or engineered system and ensure that acoustical short circuits are avoided within that system.

Periodic framing also affects cavity absorption. Batts may be interrupted, compressed, or left with gaps around studs and services; a nominal cavity fill percentage can conceal these local defects; mock-ups and concealed-work photographs should show insulation continuity, clips, channels, fasteners, perimeters, and service coordination. The acceptance test then verifies the completed relationship rather than presuming that materials on a submittal equate to installed performance.

5.31 Massive elements and low-frequency behaviour

Masonry and concrete are often assumed to be acoustically secure because of their mass; high surface density generally improves airborne transmission loss in the mass-controlled region, but massive elements can possess strong low-frequency modes, structural continuity, cracks, joints, and service penetrations; they can also carry structure-borne vibration over

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long distances. A 200 mm concrete wall may be an excellent direct airborne barrier while the continuous slab, beam, or column network bypasses it.[201]

The ideal mass law is least reliable near stiffness-controlled modes and where radiation efficiency changes; large concrete panels, precast units, and masonry wythes have finite dimensions and boundary restraints; cracking reduces local stiffness and can create air paths; hollow cores and cavities introduce resonances; grout state changes mass and internal connectivity; stone walls may contain voids, rubble, timber pockets, or historic alterations. Thickness observed at one opening cannot establish uniform construction.

For massive construction, low-frequency diagnosis should combine airborne excitation with structural response measurements; accelerometers on both sides, across junctions, and along slabs can reveal whether the receiving sound is produced by local panel radiation or remote structural propagation. Operational transfer functions can rank paths, but direct inspection and controlled intervention remain necessary; a flexible seal at a construction joint may reduce airborne leakage while leaving structural continuity unchanged.

Independent linings can improve massive walls by adding a decoupled leaf and cavity absorption; the new lining must not be rigidly bridged by furring, outlets, skirtings, ceilings, or anchors; the underlying wall should first be made airtight and repaired. Otherwise, the lining may conceal defects without controlling them; floor loading, moisture, heritage conservation, fire stopping, and access to services must be addressed.

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5.32 Apertures, neck inertance, and resonant leakage

An opening transmits sound through more than its geometric area. The moving air in a narrow neck has acoustic inertance, while a connected cavity has compliance; together they can form a Helmholtz resonator, producing frequency-selective transmission or absorption; door undercuts, keyholes, conduit sleeves, grille openings, and poorly sealed back boxes can therefore exhibit resonant behaviour rather than a flat open-area response.[202]

For a cavity volume V connected by a neck of area S and effective length L_e, the ideal Helmholtz resonance is

Equation 5.10

$$f_H = \frac{c}{2\pi}\sqrt{\frac{S}{V\,L_e}}.$$

End corrections increase effective neck length. Viscous and thermal losses add resistance. Irregular geometry, porous seals, leakage around the neck, and coupling to room modes broaden or shift the resonance; the equation is therefore a diagnostic estimate; it can explain a narrow weakness near a service box or double-door cavity, but field confirmation is required.

Small gaps also create nonlinear and flow-dependent effects at high particle velocity; a source level far above speech may drive turbulence or seal motion, causing the measured transmission to depart from linear scaling; a linearity check across source levels can expose this. If the purpose is speech-security assessment, the source should remain representative or the extrapolation should be justified.

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Aperture remediation should close the path with a material and geometry compatible with fire, smoke, movement, and maintenance; hard mortar in a movement joint can crack; soft foam without tested fire stopping can fail code requirements; a putty pad may be suitable for an electrical box but not a large sleeve. The detail should define backing, depth, adhesion surfaces, movement capability, inspection access, and rework after cable changes.

5.33 Dynamic stiffness of resilient supports

Resilient supports are characterised more completely by dynamic stiffness than by static softness alone. The force-displacement relation can vary with frequency, preload, temperature, amplitude, ageing, and boundary condition; a clip, pad, channel, or isolator that appears compliant by hand may stiffen under operational load or at acoustic frequencies; product selection should therefore use data relevant to installed load and frequency, supported by system tests where available.[203]

For a simple support with complex dynamic stiffness $k^{\prime}(\omega)=k'(\omega)+j\,k''(\omega)$, the loss factor is approximately

Equation 5.11

$$\eta(\omega)=\frac{k''(\omega)}{k'(\omega)}.$$

The real part stores energy and the imaginary part represents dissipation under the convention used; multiple supports act with the masses and bending stiffness of the leaves; their spacing changes local deformation and effective coupling; a very soft support may improve isolation but permit

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excessive deflection, impact, or serviceability problems. A very stiff support preserves alignment but transmits more vibration.

Installation controls are decisive. Clips require the correct fastener and substrate; channels must be oriented and lapped according to the tested system; board screws must terminate in the channel, not the stud behind; perimeters need clearance and resilient sealant. Heavy cabinets, displays, radiators, or handrails can bypass the supports. The design should provide independent support details for such loads rather than allowing site improvisation.

Dynamic stiffness also affects repair. Replacing a damaged clip with a visually similar product can alter system response; adding blocking for a display can create a new bridge; lifecycle configuration control should identify the isolation system and prohibit unreviewed attachments; a later field test that shows degraded mid-frequency isolation may be tracing a maintenance change, not material ageing.

5.34 Finite panels, specimen mounting, and laboratory repeatability

Laboratory transmission-loss data are influenced by specimen dimensions, mounting, edge restraint, receiving-room conditions, and flanking suppression. A wall tested in one opening may not reproduce identically in another laboratory. Interlaboratory dispersion is therefore part of the evidence context. It does not invalidate laboratory testing, but it cautions against treating one curve as an exact universal property.[204]

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Finite panels possess discrete modes and edge conditions; a gypsum board screwed to framing differs from a simply supported ideal plate; masonry may be toothed or sealed into a reveal; door frames can be grouted or mechanically fixed; sealants, perimeter gaps, and curing affect results. The report should describe the specimen rather than citing only a rating; photographs, drawings, material densities, and installation records strengthen transferability.

Scale matters. A small specimen can have different modal density and perimeter-to-area ratio from a full wall; impedance-tube measurements describe normal-incidence properties of small samples and are not substitutes for room-scale diffuse-field transmission loss; they can support material modelling, quality control, or comparison, provided their scope is stated.

Field expectations should account for laboratory flanking control; a laboratory is designed so that the specimen dominates. A building is not. Continuous slabs, façades, ducts, ceilings, and junctions introduce additional paths; a high laboratory value can therefore coexist with modest apparent field isolation; the correct response is not to dismiss the laboratory result but to recognise that it answers the first of the four propositions, while the field test addresses the second.

5.35 Model calibration, validation, and residual structure

A predictive model should be judged not only by the closeness of a single rating but by the structure of its residuals across frequency. Let measured transmission loss be $R_m(f)$ and predicted loss be $R_p(f)$. The residual $e(f)=R_m(f)-R_p(f)$ may reveal omitted physics. A broad offset suggests

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incorrect mass, calibration, or reference area. A narrow dip suggests resonance, leakage, or a boundary condition. A slope error suggests an incorrect governing regime. Collapsing the comparison into one root-mean-square number can hide these clues.[205]

Calibration adjusts uncertain parameters using one data set; validation tests the calibrated model against independent data or a controlled change; if both steps use the same curve, the model is only fitted; a secure-room programme can validate by predicting the effect of adding a board layer, increasing cavity depth, sealing an aperture, changing a door, or modifying a junction. The intervention should be documented and the before-and-after data acquired under comparable conditions.

Parameter identifiability should be examined. Damping, leakage area, and structural coupling can sometimes produce similar changes in a limited frequency range; a good fit does not prove the fitted value is physically unique; independent measurements, such as surface density, modal decay, airtightness, or vibration mobility, reduce ambiguity. The model report should state which parameters were measured, specified, inferred, or tuned.

Validation also includes numerical verification. Mesh refinement, time-step or frequency-step convergence, energy balance, limiting cases, and comparison with analytic solutions should be recorded; a finite-element model of a panel should reproduce known modal or mass-law behaviour in an appropriate limit; a transfer-matrix model should conserve energy for a lossless case. A statistical model should satisfy reciprocity relations; these checks catch implementation errors before field agreement is interpreted.

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5.36 Porous cavity materials and airflow resistivity

Fibrous and porous materials in a cavity dissipate acoustic energy through viscous and thermal interaction with their internal structure. Their behaviour depends upon airflow resistivity, porosity, tortuosity, thickness, density, fibre orientation, and mounting. Bulk density alone is an incomplete descriptor. Two products of similar density can have different flow resistance and therefore different absorption and coupling effects.[206]

In a wall cavity, the material is not used primarily to block sound by mass; it reduces cavity resonances and damps the air-spring interaction; its benefit varies with frequency and cavity geometry; a thin batt placed against one leaf may behave differently from a full-depth fill. Compression can increase flow resistance beyond an optimal range and create contact between leaves or framing. Voids and slumping reduce uniformity. Moisture can alter properties and durability.

Equivalent-fluid models, including Delany-Bazley-type or more detailed formulations, can predict characteristic impedance and complex wavenumber from material parameters; their empirical ranges and assumptions should be respected; a product with laminated facings or closed-cell structure may require a different model. Where proprietary data are used, the exact product and test method should be identified.

Installation inspection should verify continuity without inviting unnecessary handling of fibres or compromising fire and indoor-air requirements; photographs before closure can document fill, gaps, service coordination, and absence of rigid bridges; the record should distinguish nominal

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insulation thickness from clear cavity depth. A 150 mm stud cavity containing services may not provide 150 mm of uniform acoustic depth.

5.37 Doors as coupled leaf, seal, frame, and wall systems

An acoustic door is a system comprising leaf, internal construction, frame, perimeter seals, threshold, hinges, latch, closer, glazing where present, and wall interface. The leaf's laboratory rating cannot compensate for an uncompressed seal or an ungrouted frame. Door performance is strongly dependent upon adjustment and use, which makes lifecycle inspection as important as initial selection.[207]

The leaf itself can exhibit bending modes and coincidence; added mass generally helps, but stiffness, internal damping, core construction, and face-sheet coupling affect frequency response; vision panels introduce glazing and frame paths; hardware preparations remove material and can create local leakage. Electric transfer hinges, card-reader cabling, door contacts, and automatic operators must be integrated without bypassing the acoustic seals.

Seal compression should be sufficient and reasonably uniform; excessive compression increases operating force and wear, while insufficient compression leaves gaps; automatic door bottoms require correct drop timing, level thresholds, and clean contact surfaces; threshold discontinuities at carpet, floor joints, or cable covers can defeat them. A light test may reveal gross gaps, but acoustic scanning and mechanical measurement provide stronger evidence.

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A sound lock using two doors can provide substantial improvement if the vestibule is absorptive and the doors are not simultaneously open; its performance is not simply the sum of two leaf ratings; vestibule dimensions, absorption, door orientation, leakage, and user sequence matter. Access control and life safety must be coordinated; the operating protocol should not create a bottleneck that leads users to prop a door open.

5.38 Glazing, laminated interlayers, and frame-dominated performance

Glazing combines mass, bending stiffness, coincidence, cavity resonance, and edge support; monolithic panes can exhibit a pronounced coincidence dip. Laminated glass adds damping through the interlayer, subject to temperature and formulation; insulating glass units create a double-leaf system with a narrow gas cavity, and their resonance can fall in an unfavourable band; asymmetric pane thicknesses can separate coincidence features but do not remove frame and seal limitations.[208]

The visible glass area is only part of the system; mullions, stops, gaskets, setting blocks, perimeter sealants, and wall interfaces can govern; structural silicone and pressure plates have mechanical and acoustic properties; a frame that bridges independent wall leaves can create flanking. Operable windows introduce hardware and seals that are difficult to maintain at high isolation. Secure rooms should minimise unnecessary glazing unless operational need justifies it.

Secondary glazing can improve an existing opening when the new pane is heavy, well sealed, structurally independent, and separated by a generous cavity; a small cavity can introduce a mass-air-mass resonance; the reveal

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and perimeter require continuous treatment. Blinds, conduits, and decorative trims must not bridge the leaves; condensation, fire, egress, cleaning, and heritage requirements may constrain the solution.

Field tests should include multiple source positions and local scans because glazing is directional and frames are localised paths; a single room-average result may miss a weak corner; the report should record pane build-up, nominal thickness, measured dimensions, frame type, seal condition, and any interlayer identification available. A generic label such as “acoustic glass” is not a technical description.

5.39 Airtightness, pressure differentials, and seal durability

Airborne sound leakage and air leakage are related through openings, but building airtightness metrics are not direct substitutes for acoustic performance. A blower-door test integrates many paths under steady pressure and can locate gross leakage. Acoustic transmission depends upon frequency, path geometry, impedance, and oscillatory flow. Nonetheless, airtightness inspection is valuable because a high-isolation boundary cannot tolerate uncontrolled openings.[209]

Pressure differentials can change door seal contact and leakage; an HVAC imbalance may pull a door against its seals in one condition and away in another; testing only in the favourable direction can overstate robustness; the state matrix should record room pressure relative to adjacent spaces and fan modes. Where the differential varies, acoustic tests should include credible extremes or confirm that hardware maintains compression.

209 MB-0974. John L. Davy, “Predicting the Sound Insulation of Single Leaf Walls: Extension of Cremer’s Model”.

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Sealants age through movement, shrinkage, adhesion loss, hardening, contamination, and ultraviolet or chemical exposure; a perimeter that passes at commissioning may crack after seasonal movement or later service work; the design should use compatible substrates, backing, joint geometry, and movement capacity. Fire-rated joints require tested systems. Painting over flexible sealant can hide cracks or restrict movement.

Lifecycle inspection should include door seals, wall perimeters, penetrations, access panels, and any location disturbed by maintenance; acoustic retesting can be risk-based, triggered by change or periodic policy; the baseline should include photographs and local diagnostic spectra so that later degradation can be compared with known conditions. A maintenance log without technical locations is insufficient.

5.40 Fire, smoke, seismic movement, and acoustic continuity

Acoustic continuity must coexist with fire resistance, smoke control, structural movement, seismic restraint, accessibility, and life safety; these requirements are not obstacles to be traded informally; they are simultaneous design constraints. A detail that provides excellent acoustic sealing but lacks an approved fire-stopping system is unacceptable; a rigid fire-stop that prevents required movement can crack or damage the wall; coordination should occur during design, not after the penetrations are installed.[210]

Head-of-wall joints are a common conflict. The partition may need to accommodate slab or roof deflection while maintaining fire, smoke, and acoustic performance; the detail should define track configuration, board

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termination, mineral wool or backing, sealant depth, movement rating, and continuity at intersections. Trades should not pack the joint rigidly with board scraps or mortar. Inspection before closure is essential.

Seismic restraints for ceilings, equipment, ducts, and services can create flanking bridges; their locations and stiffness should be considered; flexible connectors must remain functional under movement and pressure; a cable tray or pipe support should not tie independent room shells without an engineered isolation detail. Fire dampers and smoke dampers inside ducts add discontinuities and regenerated noise. Their acoustic effect should be included in silencer and cross-talk design.

Door hardware must satisfy egress force, accessibility, security, and acoustic sealing; excessively heavy leaves or high seal compression can create operational noncompliance or lead users to defeat the closer; a coordinated schedule should state leaf mass, hinges, closer, latch, access control, threshold, seal set, fire label, and acoustic test evidence. Commissioning should observe actual operation, not only static closure.

5.41 Material verification and substitution control

Acoustic performance depends upon material properties that may not be evident from appearance. Gypsum board varies in surface density and stiffness. Steel studs vary in gauge and profile. Mineral wool varies in flow resistance; sealants vary in modulus and movement capability; glass varies in thickness and interlayer; masonry units vary in density and web geometry; substitutions should therefore be evaluated as changes to an

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assembly, not as equal products because they occupy the same specification section.[211]

Submittals should include exact product identity, technical data, test reports, specimen construction, and deviations from the specified system; a laboratory report for a proprietary assembly should be read line by line; if the proposed stud spacing, board layers, insulation, screws, or height differ, the design team should determine whether the evidence remains applicable. Marketing summaries and headline ratings are insufficient.

Receiving inspection can verify labels, thickness, density where practical, dimensions, batch, and damage; weighing representative boards or measuring unit density may be justified for critical work; certificates should be linked to delivered materials; photographs should show labels before concealment. Unlabelled substitute board installed behind finished surfaces cannot later be verified without opening.

The change process should record technical disposition; an approved substitution is not simply stamped “accepted”; the record should state the compared properties, source evidence, effect on fire and structural requirements, predicted acoustic consequence, and any added testing. This protects the design intent when procurement pressures arise.

5.42 Mock-ups and staged verification

A full-scale mock-up can reveal construction and coordination defects before they are multiplied. Its value is greatest when it includes representative junctions, door or glazing, services, fire stopping, and finishes rather than a

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pristine field-of-wall panel. The mock-up should be built by the intended trades using proposed materials and inspected at concealed stages.[212]

The test objective must be defined. A laboratory-style rating may be impractical on site, but comparative measurements, leakage scans, structural checks, and workmanship review can validate details; if a mock-up is used to qualify a contractor, acceptance criteria and permitted repairs should be established in advance. Repeated patching can produce a one-off specimen that is not representative of production work.

Lessons should be converted into revised drawings, specifications, checklists, and training; a successful mock-up left undocumented does not control later rooms; critical dimensions, screw patterns, sealant geometry, door adjustment, service supports, and inspection photographs should be incorporated into the quality plan. The mock-up may then be retained as a benchmark or carefully dismantled for forensic review.

Staged verification continues during production. Pre-close inspection confirms framing, absorption, isolation devices, and penetrations; intermediate acoustic checks can locate defects while access remains possible; final testing verifies the completed relationship; each stage answers a different question and reduces the risk of discovering a concealed bridge after decoration and occupancy.

5.43 Specification language and performance responsibility

A robust specification names the measurand, test method, frequency range, field condition, source and receiving rooms, background rule, rating method, uncertainty or decision rule, and acceptance authority. Vague

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instructions such as “provide STC 60 walls” do not state whether the requirement concerns a laboratory assembly, an installed field relationship, or a speech-security outcome. They also omit doors, junctions, and services.[213]

Prescriptive details and performance requirements should be coordinated; a tested assembly may be specified as a basis, but actual dimensions and interfaces must be drawn; if the contractor is responsible for performance, the contract should define design-submittal obligations and the consequences of failure. If the designer prescribes the complete system, the contractor should not be made responsible for hidden design inadequacy; allocation of responsibility should be explicit and legally reviewed.

The specification should require source evidence and prohibit unreviewed deviations; it should include mock-ups, inspection hold points, concealed-work records, door schedules, penetration registers, calibration requirements, test plans, and corrective-action procedures; retest obligations should distinguish contractor-caused defects from changes directed by the owner or design team.

Acceptance should not rely solely upon a single-number rating; band data, local leakage, operating states, and dependencies should be reviewed; a room can pass a broad field rating while containing a narrow speech-relevant weakness; conversely, a marginal band may be explained by background limitation. The acceptance memorandum should preserve the technical reasoning and competent authority’s decision.

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5.44 Forensic investigation of an underperforming partition

When a completed partition underperforms, random repairs can destroy evidence and obscure the mechanism. The investigation should begin with records: drawings, submittals, tested-assembly reports, photographs, inspection logs, change orders, and prior tests. The examiner then establishes the current state, including doors, services, finishes, pressure, and adjacent spaces. Non-invasive acoustic and vibration mapping precedes controlled opening.[214]

The frequency signature guides hypotheses. Broad poor isolation may indicate low mass, open paths, or gross flanking; a narrow low-frequency dip may indicate mass-air-mass resonance, panel mode, or cavity connection; a mid-frequency plateau may indicate structural bridging; high-frequency weakness often points to gaps, lightweight doors, grilles, or coincidence. These are hypotheses, not automatic diagnoses.

Controlled interventions provide discrimination. Reversible perimeter sealing tests leakage. Added temporary mass tests leaf response. Local damping tests resonance. Stopping services tests duct and mechanical paths. Accelerometers test structural correlation. Each intervention should have a predicted spectral effect and should be documented before and after; if the response changes elsewhere because the field redistributes, multiple receiver positions are needed.

Controlled openings should be minimised, authorised, photographed, measured, and restored; they may confirm missing insulation, incorrect screws, rigid bridges, unsealed boxes, or substituted materials; samples and

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removed components may require custody if dispute or litigation is foreseeable. The report should distinguish observed fact, engineering inference, and unresolved alternative.

5.45 Extended low-frequency evidence and source capability

Standard rating ranges do not always include the lowest frequencies relevant to large room modes, amplified speech, mechanical excitation, or massive structural flanking. Extended low-frequency measurement can be valuable, but it is difficult; laboratory and field rooms have sparse modes, source output falls, loudspeaker distortion rises, and spatial variance becomes large; results outside the formal rating range should be reported as supplemental band data rather than folded into a standard rating without authority.[215]

Source capability must be verified in each band; a subwoofer can generate high level but also harmonic distortion; a 31.5 Hz fundamental may be accompanied by stronger harmonics inside the ordinary rating range; source-room microphones and narrowband spectra should distinguish them. The room and building must be protected from excessive vibration and rattles. A source level selected merely to overcome background can drive the construction beyond representative linear behaviour.

Spatial sampling should reflect long wavelengths and room modes; several source positions and microphone positions may be needed; the resulting uncertainty can be larger than at mid frequency; a lower-bound isolation result may be the only defensible conclusion where receiving background or room variance dominates.

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Low-frequency supplemental data are especially useful for comparing alternative details, diagnosing resonance, and validating models; they should not be used to claim a public secure-room threshold that is unavailable; the report should identify the measurement method, deviations, and decision relevance.

5.46 Surface density, stiffness, and material-property verification

Prediction requires material properties, but nominal product descriptions seldom provide all that are needed; surface density can be measured by weighing a representative sample of known area; bending stiffness may be inferred from material modulus and thickness or measured through modal or static tests; damping can be estimated from decay. Porous-layer airflow resistivity can be measured or obtained from reliable data. Each property has variability.[216]

Gypsum products of the same nominal thickness can differ in mass and core composition; masonry units vary by aggregate and void geometry; concrete density and modulus vary with mix, moisture, age, and reinforcement; glass thickness tolerances affect mass and coincidence. Timber and boards can be orthotropic. A model using one generic density and modulus should be labelled accordingly.

Property verification should be proportionate to consequence; for a tested proprietary assembly, configuration identity may be more important than independent modulus testing; for an untested custom wall, measured surface mass and modal behaviour can materially improve prediction. Samples should be traceable to installed batches where possible.

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Uncertainty in property values should propagate into predicted resonance and transmission; a sensitivity study may show that exact modulus matters only near coincidence, while leakage area dominates overall; this helps allocate effort and prevents expensive testing of inputs that do not affect the decision.

5.47 Tolerances, workmanship distributions, and field performance

Construction drawings describe nominal geometry. Installed assemblies contain tolerances in stud alignment, cavity depth, board gaps, screw position, sealant depth, frame plumb, door clearance, and service location. These variations can have nonlinear acoustic effects. A 1 mm perimeter gap is not merely a one per cent dimensional deviation. It can become the dominant open path.[217]

Quality control should identify critical acoustic tolerances separately from ordinary finish tolerances; door seal contact, resilient-channel screw length, independent-leaf clearance, penetration annulus, and head-joint movement are examples. Inspection methods should be defined. Some conditions are visible before closure and impossible afterwards.

A probabilistic field model can represent workmanship distributions, but data are often sparse; mock-ups, first-work inspections, and production sampling provide evidence; the objective is not to predict every defect statistically; it is to design details that are robust, inspectable, and repairable.

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Field testing samples completed relationships. If many rooms are built, a sampling plan should consider repetition, contractors, locations, and criticality; one excellent room does not prove the entire programme; conversely, one failed room should trigger root-cause analysis before broad rejection; the construction register should link each test to materials and inspection records.

5.48 Comparative assembly selection and whole-system cost

Assembly selection should compare more than headline rating and material cost. Relevant factors include frequency response, expected field degradation, thickness, weight, structural load, fire rating, moisture, durability, inspection access, service coordination, door and glazing compatibility, construction skill, repairability, and lifecycle change. A thinner high-rated proprietary wall can be less robust than a thicker conventional double-stud wall if the site cannot maintain its details.[218]

Whole-system cost includes junctions, sound locks, silencers, independent services, testing, and remediation; improving the wall field beyond the door and flanking limit wastes money; composite and path models should identify the economically rational balance; a secure room often benefits more from a controlled vestibule, structural lid, and service transition zone than from another board layer on an already strong wall.

Programme risk should be considered. Materials with long lead times or proprietary installers can delay construction. Unfamiliar systems increase workmanship risk. Mock-ups and training cost money but reduce failure; the

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decision should be documented through a comparative matrix whose criteria and weights reflect the owner's mission.

5.49 Rating curves, adverse deviations, and design diagnosis

Single-number ratings are obtained by comparing measured band data with a reference contour under the applicable standard. The fitting rules limit adverse deviations and yield a convenient classification; the contour does not make every band equally important, nor does it explain the physical cause of a dip; two assemblies with the same rating can have markedly different spectra and therefore different behaviour under speech, music, machinery, or low-frequency excitation.[219]

A design review should retain the measured or predicted curve and mark the mass-air-mass region, coincidence region, door or aperture weaknesses, and background-limited bands. The rating can then serve as an index to the curve rather than a replacement for it. Where American STC and ISO R_w or field quantities are compared, the frequency ranges, reference contours, spectrum adaptation terms, and laboratory or field context should be stated. Numerical similarity does not establish equivalence.

Adverse deviations near a speech-important band may deserve remediation even if the single-number target is met; conversely, a low-frequency dip outside the rating range may be acceptable for one use and important for another; the authority or contract should define supplemental criteria before testing. The engineer should not retrofit a hidden criterion after reviewing the results.

219 MB-0974. John L. Davy, "Predicting the Sound Insulation of Single Leaf Walls: Extension of Cremer's Model".

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Curve shape also supports forensic diagnosis. A broad low-frequency trough in a double-leaf wall suggests coupled resonance or structural flanking; a flat high-frequency limit suggests leakage; repeated narrow dips can indicate cavity or panel modes; a change in slope may mark a transition in radiation efficiency. These interpretations should be tested through inspection and controlled perturbation.

5.50 Junction-first design for high-isolation rooms

High-isolation design is often drawn from the centre of the wall outward. A more reliable method begins at junctions and openings, where continuity is hardest to maintain. Floor, structure above, columns, façades, ceilings, doors, glazing, ducts, and service zones are resolved first. The field assembly is then selected to match the achievable junction network.[220]

A double-stud wall that cannot be kept independent at a door frame may not deliver its theoretical benefit; a concrete wall that stops below a continuous roof deck may be bypassed through the deck; a resilient lining attached rigidly at a column can short-circuit along its full height. Early details should show every leaf, cavity, seal, resilient element, fastener, and structural connection.

Junction-first design also improves procurement. Contractors can price complex interfaces instead of discovering them after award; mock-ups can include the actual head, base, corner, and service transition. Inspection hold points become clear. The strategy reduces reliance on broad notes such as “seal all gaps,” which provide little guidance about movement, fire stopping, or access.

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The design team should identify the weakest credible path in each band and avoid excessive imbalance; a wall field far stronger than its junctions adds cost and thickness without improving the room; a balanced system is not one in which every component has the same rating. It is one in which no inexpensive preventable path dominates the mission-relevant result.

5.51 Ageing, damage, and the changing transfer function

A completed assembly is not static; sealants harden, boards crack, doors sag, glazing gaskets shrink, resilient channels are overloaded, and new services are installed; moisture changes porous materials and timber; impact can loosen fasteners or create gaps; the acoustic transfer function can therefore drift even when the room appears visually serviceable.[221]

Baseline frequency curves provide a diagnostic fingerprint; later tests can compare not only the rating but band-by-band change; a broad high-frequency decline suggests leakage or seal deterioration; a shifted resonance may reflect stiffness, mass, or cavity change. New narrow peaks can indicate loose hardware or service contact. Comparison requires matched source and receiving states.

Inspection intervals should follow risk and change; a door used hundreds of times per day deserves more frequent checks than a sealed wall; any penetration, audiovisual installation, sprinkler work, ceiling access, or structural modification should trigger review. Maintenance staff should have drawings that identify protected boundaries and approved repair materials.

Repairs should restore a defined detail, not merely improve a spot test; temporary tape or foam may demonstrate a mechanism but is not

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necessarily durable, fire compliant, or inspectable; the permanent repair should be documented and the room retested under the baseline protocol.

5.52 Worked example: balancing wall, door, and transfer-air path

A proposed secure conference room has a total separating boundary area of 42 m²; the opaque wall occupies 36 m² and is predicted to provide 58 dB transmission loss in a representative mid-frequency band; a double-door sound lock appears in plan, but only the inner door lies in the immediate boundary calculation. Its area is 2.4 m² and measured transmission loss is 42 dB; a glazed panel occupies 2.8 m² at 49 dB. A transfer-air opening and silencer have an equivalent transmitting area of 0.8 m² with effective band transmission loss 35 dB.

Convert each loss to transmission coefficient:

$$\tau_w = 10^{-58/10} = 1.58 \times 10^{-6},$$

$$\tau_d = 10^{-42/10} = 6.31 \times 10^{-5},$$

$$\tau_g = 10^{-49/10} = 1.26 \times 10^{-5},$$

$$\tau_a = 10^{-35/10} = 3.16 \times 10^{-4}.$$

The area-weighted transmitted terms are 5.69×10^{-5}, 1.51×10^{-4}, 3.53×10^{-5}, and 2.53×10^{-4} m²-equivalent respectively. Their sum is 4.97×10^{-4}. Dividing by total area 42 m² gives composite coefficient 1.18×10^{-5}, corresponding to composite transmission loss

$$R_c = -10 \log_{10}\left(1.18 \times 10^{-5}\right) = 49.3\,dB.$$

Although the transfer-air opening occupies less than two per cent of the area, it contributes more transmitted power than the 36 m² wall. Improving

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the wall from 58 to 63 dB changes the composite result only slightly. Improving the air path by 10 dB reduces its term to 2.53×10^{-5} and raises the composite result to about 52.4 dB. Improving the door by 8 dB as well raises it further. The calculation identifies priorities, but it assumes uniform incident field and no additional flanking. The sound lock's outer door, vestibule absorption, duct geometry, and operational sequencing must be assessed separately.[222]

The worked example demonstrates why component schedules should be translated into a whole-boundary power model before procurement; it also shows why an apparently excellent wall can coexist with modest room performance; the system should be balanced by band, not by marketing rating.

5.53 Worked example: tolerance in a perimeter gap

Consider a door 1.0 m wide by 2.1 m high; a defective seal leaves an average open gap of 0.5 mm along the head and both jambs, a total length of 5.2 m. The geometric open area is

$$S_g = 5.2(0.0005) = 0.0026\,m^2.$$

The closed door area is 2.1 m². If the leaf and sealed frame provide 45 dB in a band, their transmission coefficient is 3.16×10^{-5}. Treat the open gap conservatively as $\tau_g = 1$ for a first screening. The composite coefficient is

$$\tau_c = \frac{2.0974\left(3.16 \times 10^{-5}\right) + 0.0026(1)}{2.1} = 1.27 \times 10^{-3},$$

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which corresponds to only 29.0 dB. The simplified aperture assumption neglects inertance, end correction, and diffraction, but it correctly shows the severity of a small continuous gap.[223]

If the average gap doubles to 1 mm, the open area doubles and the screening result falls by approximately 3 dB while the gap dominates; if the gap is intermittent rather than continuous, local acoustic scanning can identify it. The example supports tight mechanical tolerances, uniform seal compression, and inspection of latch and closer operation.

The calculation should not be used as an exact prediction for a labyrinth seal or porous gasket; it is a bounding model that explains why door adjustment can matter more than another heavy layer in the wall.

5.54 Experimental hierarchy for assembly development

A new or modified assembly should move through an evidence hierarchy; material tests identify density, stiffness, damping, airflow resistivity, and seal properties; component tests examine leaves, resilient supports, doors, glazing, or silencers; full assembly laboratory tests measure direct transmission under controlled flanking; mock-ups examine junctions and workmanship. Field tests measure the installed relationship. Speech-oriented tests address occupied conditions. Each stage reduces a different uncertainty.[224]

Skipping stages transfers risk. A full field test can reveal failure but may not identify why; material data alone cannot prove the assembly; a laboratory test without junction mock-up can overstate the building; a privacy test with

223 MB-0333. ASTM International, ASTM E90-23, ISO 10140-2:2021.
224 MB-0974. John L. Davy, “Predicting the Sound Insulation of Single Leaf Walls: Extension of Cremer’s Model”.

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high masking can conceal a weak boundary. The sequence should be planned around decision points and the cost of late repair.

Development tests should retain failed configurations. A negative result can reveal resonance, bridge, or seal sensitivity; altering several variables at once makes the lesson ambiguous; controlled one-factor changes are preferable where practical, followed by combined verification of the final system.

Repeatability and reproducibility should be considered. A result produced only by one specialist installer under laboratory supervision may not be robust for a large construction programme; the design should favour details that ordinary qualified trades can execute and inspectors can verify.

5.55 Whole-assembly review checklist

Before an assembly is accepted into the secure-room design, the reviewer should be able to answer the following:

1. What exact laboratory or analytical proposition is supported?
2. What are the frequency-resolved data and rating method?
3. Does the proposed construction match the tested or modelled configuration?
4. What are the mass-air-mass, coincidence, cavity, and structural-coupling risks?
5. Which junctions, openings, services, and flanking paths can dominate?
6. How are fire, smoke, movement, seismic, moisture, and accessibility requirements integrated?
7. Which details are concealed, and when will they be inspected?

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8. What substitutions require review?
9. What field measurand and decision rule will verify installation?
10. Which operational dependencies and lifecycle changes trigger retest?

A review that cannot answer these questions has not converted a product rating into a room design. The checklist should be linked to drawings, specifications, submittals, and the commissioning plan.[225]

5.56 Dynamic range, censored transmission-loss data, and test qualification

Very high transmission loss is often limited by the measurement system before it is limited by the specimen; the receiving-room level can approach microphone self-noise, electrical noise, ventilation noise, leakage through the test facility, or flanking around the specimen frame; at that point the reported value is not a precise estimate of the specimen loss. It is a lower bound conditioned by the source level, receiving background, room absorption, spatial sampling, and facility performance; treating such a bound as an exact curve exaggerates both the material evidence and the security conclusion.[226]

For a laboratory airborne-insulation test, the measurable band difference depends upon the source-room average level L_1, the receiving-room background L_b, and the correction permitted by the governing method. A simplified screening expression for the available receiving margin is

Equation 5.12

$$M_b = L_2 - L_b,$$

225 MB-1015. Marshall Long, Architectural Acoustics, 2nd ed.
226 MB-0336. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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where L_2 is the measured source-on receiving level. As M_b becomes small, background subtraction becomes sensitive to short-term variation and calibration error. If the method prohibits correction below a stated separation, the result is censored. The proper record is then a lower limit, such as $R(f) > R_{min}(f)$ under the stated test conditions, rather than a fictitious decimal value.

Increasing source level can extend dynamic range only while the source, rooms, instrumentation, and specimen remain linear and safe; loudspeaker compression, amplifier limiting, rattles, airflow through gaps, nonlinear seals, and vibration of the test opening can change the measured path. A source spectrum designed merely to lift weak receiving bands may overdrive other bands or excite flanking elements that are unrepresentative of normal use; the laboratory should document source linearity and repeat selected levels to show that the calculated insulation is independent of source amplitude within uncertainty.

Facility flanking establishes another ceiling. A nominally excellent specimen may be bypassed by the surround wall, test aperture, floor, ceiling, mounting frame, service penetration, or structural junction; a blank-wall or high-performance reference closure can characterise the facility limit, but the comparison must use compatible geometry and mounting. If the specimen result approaches that limit, attribution to the specimen becomes indeterminate; the report should identify affected bands and avoid ranking two products whose apparent differences lie within the facility ceiling.

Spatial sampling can also censor a result; in a small receiving room, modal minima can produce deceptively low levels at isolated positions; averaging procedures reduce this bias but do not create information below the

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instrumentation floor; a scanning microphone, multiple fixed positions, or repeated source states may improve representativeness. The uncertainty budget should include residual spatial variance, background non-stationarity, and any data-selection rule used to reject contaminated samples.

Single-number ratings require additional discipline. A reference-contour procedure can be numerically completed even when one or more high-loss bands are reported only as lower bounds. Whether the resulting rating is valid depends upon the method, the location of censored bands, and whether plausible true values could change the contour shift or adverse-deviation sum. The test report should disclose the bounds and, where necessary, provide a rating interval or state that the rating is limited by facility or background performance.[227]

Field measurements face the same issue with fewer controls; a quiet corridor at night may improve the receiving margin, but the resulting state may not represent ordinary access; turning off HVAC can reduce background while also changing duct transmission and pressure. Temporary sealing used to diagnose a path can improve the measurement floor but alters the assembly; each intervention should be identified, and baseline and diagnostic states should not be merged into one headline number.

For secure-room design, a lower-bound insulation result can still be useful; it may demonstrate that a path exceeds the required design reserve under a defined source and receiver state; it does not prove the exact residual level,

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the intelligibility of transmitted speech, or formal acceptance. If the decision depends upon distinguishing 70 dB from 75 dB performance, the test system must possess the necessary dynamic range and facility isolation; if the decision only requires demonstrating that the path is not governing, a rigorously stated lower bound may be sufficient.

A qualified report should therefore separate measured values, corrected values, lower bounds, facility-limited bands, and modelled extensions; graphs should use arrows or censoring symbols rather than joining bounded points as though they were exact; raw source-on and background data should be retained; this presentation is less visually smooth than a complete curve, but it is materially more defensible and prevents the strongest-looking numbers from being the least reliable.[228]

228 MB-0336. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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5.57 Chapter 5 glossary

Coincidence. The condition in which the trace wavelength of incident airborne sound matches a structural bending wavelength, increasing coupling and often reducing transmission loss.

Composite transmission coefficient. The area-weighted linear power ratio of several boundary elements or paths.

Dynamic stiffness. The complex ratio of harmonic force to displacement for a resilient element under stated frequency, preload, and amplitude.

Mass-air-mass resonance. The coupled resonance of two leaves separated by a compressible air cavity.

Radiation efficiency. The ratio between the sound power radiated by a vibrating surface and that of an ideal reference radiator with the same area and mean-square velocity.

Structural loss factor. A dimensionless measure of energy dissipated per radian relative to stored vibrational energy under the stated model.

Triple-leaf penalty. Reduced insulation caused by the coupled resonances of three leaves and two cavities compared with a properly designed double-leaf system.

Transmission loss is a frequency-dependent system response shaped by mass, stiffness, damping, coincidence, cavity dynamics, framing, apertures, and boundaries. Ideal laws provide insight and useful bounds, but they do not replace evidence for the exact assembly. Double-leaf and massive constructions can fail through resonances, bridges, junctions, and small

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weak elements. Composite power calculation exposes bottlenecks that headline ratings conceal.

Design and forensic work should reconcile laboratory data, prediction, field measurement, and speech-security evidence without merging their propositions. Models require configuration identity, independent validation, and residual analysis. Materials and resilient systems require exact specification and substitution control. Fire, smoke, movement, and life safety must be integrated into acoustic details.

The complete boundary, not the field of wall, determines room performance. The next chapter extends that principle into structural dynamics, where slabs, frames, services, and resilient supports transmit energy beyond the direct airborne path.

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Chapter 6. Structural Dynamics, Vibration, Mobility, and Structure-Borne Propagation

6.1 Why structural dynamics belongs within acoustic-security engineering

Airborne isolation can be excellent while structure-borne transmission remains consequential. Floors, columns, beams, façades, door frames, ducts, pipes, cable trays, and equipment supports form a connected mechanical network. Force introduced at one point propagates as waves, excites junctions and modes, and radiates sound elsewhere. A secure-room assessment that measures only airborne pressure can therefore overlook a path carried by the building fabric.[229]

Structure-borne sound differs from airborne leakage in source, propagation, and diagnosis; the source may be a fan imbalance force, a pump pulsation, footfall, loudspeaker reaction, door impact, or airborne pressure exciting a panel; the path is governed by mechanical impedance, wave type, junction geometry, damping, and boundary conditions. The receiver may be a vibrating wall, duct, window, or item of furniture that radiates into an accessible space.

The engineering proposition must name the structural quantity; acceleration level at one point is not force, velocity, mobility, power flow, or radiated sound; a large acceleration on a light local panel may transmit little power, while modest motion of a large efficient radiator can dominate. Measurement and modelling should retain the chain from force to structural response to radiation.

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6.2 Force, velocity, displacement, and acceleration

For harmonic motion at angular frequency ω, displacement x, velocity v, and acceleration a are related by

Equation 6.1

$$v = j\omega x, a = -\omega^2 x,$$

using complex amplitudes and the $e^{j\omega t}$ convention. Magnitudes therefore scale as $|v) = \omega|x)$ and $|a) = \omega^2|x)$. Converting between quantities without frequency information is impossible.[230]

Accelerometers are convenient at moderate and high frequencies, but their low-frequency acceleration can be small even when displacement is appreciable; laser vibrometers measure velocity or displacement without contact, subject to line of sight, surface reflectivity, speckle, and angular sensitivity. Force transducers require a defined load path; each sensor changes the mechanical system to some degree.

Vibration levels may be expressed relative to reference quantities, but linear spectra should remain available; a decibel acceleration plot can hide phase and sign; for modal and transfer-function work, complex response is usually required; time histories are necessary for impacts, run-up, and intermittent machinery.

6.3 Mechanical impedance, mobility, and receptance

Mechanical impedance is force divided by velocity:

Equation 6.2

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$$Z_m(\omega)=\frac{F(\omega)}{v(\omega)}.$$

Mobility is its reciprocal,

Equation 6.3

$$Y(\omega)=\frac{v(\omega)}{F(\omega)},$$

and receptance is displacement divided by force. These are complex frequency-response functions. Magnitude describes response amplitude; phase identifies the relationship among force, velocity, stored energy, and damping.[231]

For a single-degree mass-spring-damper system,

Equation 6.4

$$Y(\omega)=\frac{j\omega}{k-m\omega^2+j c_d \omega},$$

where m is mass, k is stiffness, and c_d is viscous damping coefficient. Below resonance, stiffness dominates. Near resonance, damping controls peak response. Above resonance, mass dominates. Real building elements contain many modes, but the regime distinction remains useful.

Worked example 6.1. Point mobility at resonance

Let $m=500$ kg, natural frequency $f_n=25$ Hz, and damping ratio $\zeta=0.03$. The angular frequency is $\omega_n=157.1$ rad/s. Stiffness is

$$k=m\omega_n^2=500(157.1)^2=1.234\times10^7\ N/m.$$

Damping coefficient is

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$$c_d = 2\zeta m \omega_n = 2(0.03)(500)(157.1) = 4.71 \times 10^3 \, N\,s/m.$$

At resonance, the mobility magnitude of the ideal model is approximately $1/c_d = 2.12 \times 10^{-4}$ m/(N s). A 100 N harmonic force would produce about 0.0212 m/s velocity. The example is deliberately simple. A slab has distributed modes, spatially dependent mobility, and radiation loading.

6.4 Mechanical power flow

Instantaneous mechanical power is force multiplied by velocity. For complex rms quantities, time-averaged active power is

Equation 6.5

$$P = \Re\{F\, v^{*}\}.$$

The imaginary component represents reactive exchange. A large force or velocity alone does not prove large transmitted power because phase matters. Power-flow measurements can rank junctions and supports when forces and velocities can be defined at the interface.[232]

In building structures, distributed line and surface forces complicate the calculation; a stud transmits along a line, a resilient pad over an area, and a pipe support through several fasteners; the interface should be partitioned into physically meaningful components. Summing powers requires consistent sign conventions and reference directions.

Active structural intensity extends the concept to plates and beams, combining stresses or moments with velocities; it can visualise power flow but is sensitive to spatial derivatives, sensor spacing, and model assumptions; forensic use should preserve uncertainty and avoid

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interpreting a colourful vector map as direct proof without controlled perturbation.

6.5 Wave types in solids and building elements

Solids support longitudinal and shear waves. Beams and plates also support bending waves whose dispersion is central to structure-borne sound. Torsional and surface waves can matter in particular geometries. Each wave type has different speed, impedance, attenuation, and junction behaviour.[233]

Longitudinal waves involve particle motion parallel to propagation and have high speed in dense solids. Shear waves involve transverse motion. Thin-plate bending waves are dispersive, with phase speed increasing with frequency; this dispersion produces coincidence with airborne sound and changes how energy crosses junctions; thick plates and high frequencies require shear deformation and rotary inertia corrections beyond classical thin-plate theory.

Building elements are waveguides. A beam can carry bending energy along its length; a slab carries waves in two dimensions; a pipe carries shell and fluid-borne modes; a metal stud can connect leaves. At junctions, incident energy partitions among reflected and transmitted wave types. Geometry and orientation matter as much as material name.

6.6 Modes, damping, and spatial dependence

Finite structures support modes. Their frequencies and shapes depend upon dimensions, stiffness, mass, restraint, and coupling. A measurement at a nodal line can understate response, while an antinode can overstate a

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spatial average. Modal testing therefore requires multiple response points or scanning methods.[234]

Damping determines bandwidth and decay. Structural damping can arise in material hysteresis, joints, friction, sealants, finishes, air loading, and attached systems. It is often amplitude-dependent. A lightly excited test may not reproduce slip or contact nonlinearity under operational load; temperature and moisture can change viscoelastic and masonry behaviour.

Modal overlap increases with frequency as modal density grows; at low frequency, deterministic mode shapes and boundary conditions dominate; at higher frequency, statistical descriptions may become useful; the transition is not identical for every subsystem. A thin lining can have high modal density while a supporting frame remains sparse.

Worked example 6.2. Damping from decay

If vibrational energy decays by 60 dB in 8.0 s, the energy decay rate is 7.5 dB/s. For an approximately exponential decay at 50 Hz, a loss-factor estimate is

$$\eta \approx \frac{13.8}{\omega T_{60}} = \frac{13.8}{2\pi(50)(8.0)} = 0.00549.$$

The relation depends on the stated energy-decay convention and a diffuse or modal ensemble assumption. A single isolated mode should instead be analysed with an appropriate modal method.

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6.7 Junction transmission and flanking networks

At a junction, incident structural power is reflected, transmitted into connected elements, converted among wave types, and dissipated. Transmission depends upon characteristic impedances, angle, junction geometry, thickness ratio, and restraint. A rigid cross-junction between masonry walls behaves differently from a lightweight T-junction between boards and studs.[235]

Building-acoustic flanking standards and prediction methods organise paths through element pairs and junction attenuation. The path from a source-room floor to a receiving-room wall is distinct from the path through the separating wall; apparent sound insulation results from the energetic combination of direct and flanking contributions; ISO 10848-1 describes laboratory and field measurement principles for flanking transmission, while ISO 12354-1 provides a calculation framework for estimating building performance from element and junction data.[236]

These methods require careful mapping to actual construction; a junction index derived for homogeneous heavy elements should not be transferred to a steel-framed wall without evidence; continuous façades, curtain-wall mullions, raised floors, and ceilings can create paths outside simplified room-to-room models. Drawings should show every structural and service connection that crosses the protected boundary.

6.8 Rigid bridges, line connections, and short circuits

A small rigid bridge can carry disproportionate structural power. Long screws through resilient channels, mortar droppings across cavities, door-

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frame anchors tying independent leaves, ceiling hangers, pipe clamps, and cable trays can bypass intended isolation. The effect depends upon dynamic stiffness and number of bridges, not merely visible area.[237]

For N identical uncoupled point bridges under similar motion, transmitted power may scale roughly with N, but coherent interactions and structural waves can change the relation. A continuous line bridge is not equivalent to many independent points. Periodic bridges can produce pass bands. The design should minimise both stiffness and unnecessary connection count, while satisfying structural, seismic, fire, and operational requirements.

Detection can combine drawings, inspection, impact testing, local mobility, operating-deflection shapes, and controlled release of suspected contacts; a bridge hidden behind finishes may be inferred from a repeatable high-coherence path, but destructive verification may be needed before final attribution. Removal must not compromise required restraint.

6.9 Equipment forcing and blocked force

Mechanical equipment transmits through airborne radiation, structure-borne force, and connected fluids. Free-field sound power does not define structure-borne input. A useful source descriptor is blocked force, the force the source would exert against an infinitely rigid support under specified operation. Installed vibration then depends upon source and receiver mobilities.[238]

For a source with free velocity v_f and source mobility Y_s coupled to receiver mobility Y_r, a simplified installed velocity is

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Equation 6.6

$$v = \frac{v_f Y_r}{Y_s + Y_r}.$$

Equivalent formulations use blocked force. The model shows why the same fan or pump behaves differently on a concrete slab, steel frame, or isolated inertia base; catalogue vibration levels measured on another support are not transferable without mobility information.

Forces can be tonal at rotational speed, blade-pass frequency, gear mesh, or electrical frequency, with harmonics and broadband components; variable-speed drives change both frequency and amplitude. Start-up and shut-down produce transients. The operating-state schedule should include realistic load, control mode, connected duct or pipe state, and maintenance condition.

6.10 Vibration isolation and transmissibility

A resilient support seeks to reduce force transmission above its natural frequency. For a damped single-degree system under harmonic force, force transmissibility is

Equation 6.7

$$T_F = \frac{\sqrt{1 + (2\zeta r)^2}}{\sqrt{(1 - r^2)^2 + (2\zeta r)^2}},$$

where $r = f / f_n$ is frequency ratio. Isolation begins only when $r > \sqrt{2}$ for the ideal relation. Near $r = 1$, response is amplified.[239]

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Worked example 6.3. Isolator selection

A machine's lowest governing forcing frequency is 30 Hz. An isolator system has $f_n = 5$ Hz and $\zeta = 0.08$, so $r = 6$. Equation 6.7 gives

$$T_F = \frac{\sqrt{1 + (0.96)^2}}{\sqrt{(1 - 36)^2 + (0.96)^2}} = 0.0396.$$

Ideal force reduction is $20 \log_{10}(1/0.0396) = 28.0$ dB. The result assumes rigid foundations, linear springs, equal load distribution, no rocking, no service bypasses, and steady harmonic force. A rigid pipe or duct can negate the calculated benefit.

Damping presents a trade-off. It controls resonance during start-up and transients but can increase high-frequency force transmission through the damping element; elastomer properties vary with temperature, age, preload, and frequency; steel springs require lateral restraint and may need high-frequency pads; air springs require pressure control and fail-state analysis.

6.11 Service connections and secondary bypasses

Ducts, pipes, conduits, drains, flexible hoses, electrical grounds, and control cables can bridge isolated equipment. Their dynamic stiffness depends upon geometry, material, pressure, fluid loading, supports, and installation strain. A flexible connector that is too short, taut, misaligned, or restrained by insulation may behave rigidly.[240]

Pipework can carry both structural and fluid-borne energy; pulsation travels in the fluid and excites walls at bends and valves; supports transmit shell motion into the building; duct walls radiate from internal pressure and carry

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vibration from fans. Electrical conduit can couple enclosures across a boundary. Each service requires a path-specific detail and inspection record.

The isolation design should be reviewed as a complete six-degree-of-freedom system; centre of gravity, spring locations, rocking modes, seismic restraints, snubbers, and housekeeping pads matter; a restraint that contacts during ordinary operation creates a short circuit; clearances should be inspected under full operating load and after settlement.

6.12 Measurement, calibration, and forensic interpretation

Structural measurements require a declared coordinate system, sensor orientation, mounting, mass, cable restraint, and calibration. ISO 16063-21 provides vibration-transducer calibration by comparison, while ISO 20816-1 gives general guidance for evaluating machine vibration measurements. These documents serve different purposes and should not be conflated.[241]

Accelerometer mounting changes usable frequency range. Stud mounting generally provides better high-frequency fidelity than magnets or wax, but may not be permissible; adhesive and magnetic mounts introduce compliance; handheld probes are unsuitable for quantitative phase work; laser vibrometry avoids mass loading but measures the velocity component along the beam and can lose signal on rough or moving surfaces.

A causal investigation should record simultaneous source and response channels where possible; run-up orders, coherence, operating-deflection shapes, mobility, and controlled isolation changes help separate equipment forcing from ambient vibration; repeated measurements under unchanged

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conditions establish repeatability, not causation. Competing sources and common building excitation must be considered.

The conclusion should identify the mechanism at the level supported; “coherent structural response at blade-pass frequency decreased 12 dB after the duct connector was released” is stronger than “the fan caused the leak” because it states the observation and intervention. Attribution to design defect, installation error, damage, or responsibility requires additional evidence.

6.12.1 Distributed plate response

A plate cannot be represented adequately by one mass and spring when wavelength is comparable with dimensions. The classical thin-plate equation for transverse displacement $w(x, y, t)$ is

Equation 6.8

$$D \nabla^4 w + m' \frac{\partial^2 w}{\partial t^2} = q(x, y, t),$$

where D is bending stiffness, m' is surface density, and q is transverse load per unit area. Damping and boundary terms are added according to the model. The fourth-order spatial operator produces dispersive bending waves and makes edge conditions central.[242]

For an unbounded plate with harmonic wavenumber k_b, the ideal dispersion relation is $D k_b^4 = m' \omega^2$. Thus $k_b = (m' \omega^2 / D)^{1/4}$ and bending-wave phase speed is ω / k_b. Group speed differs from phase speed. These relations explain why

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arrival time and spatial pattern change with frequency and why a short impact spreads into a dispersive wave packet.

Secure-room details often interrupt the plate approximation; studs, ribs, joints, openings, and attached masses scatter waves; the equation remains useful for scale and mesh selection, but the model should represent actual discontinuities when they govern; a smooth finite-element colour plot is not evidence unless boundary conditions and material properties are validated.

6.12.2 Reciprocity and mobility matrices

Linear reciprocal structures obey relationships between force at one coordinate and velocity at another. If Y_{ij} is velocity at coordinate i per unit force at j, reciprocity gives $Y_{ij}=Y_{ji}$ under compatible coordinates and boundary conditions. This permits practical tests in which source and receiver positions are exchanged.[243]

Multiple interfaces require a mobility matrix, not a single scalar; a machine may transmit vertical force, horizontal force, and moments through several feet; a wall junction carries translational and rotational components; neglecting cross-mobilities can miss rocking or torsional response. Coordinate definitions and sign conventions should be fixed in drawings and data files.

Reciprocity checks are valuable quality controls. Large disagreement can indicate sensor orientation error, time variance, nonlinearity, loose contact, or inadequate signal-to-noise ratio; agreement does not prove that the model includes every path, but it supports the measurement chain.

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6.12.3 Impacts, transients, and nonlinear contacts

Doors closing, footsteps, dropped objects, relays, and machinery start-up produce transient forces. Their broadband response can reveal resonances efficiently, but amplitude may drive contacts into nonlinear states. A gap can close, a restraint can engage, or friction can slip. Transfer functions measured at low force may then fail to predict operational behaviour.[244]

Impact-hammer testing requires force-window and response-window choices, adequate record length, double-hit rejection, and coherence review; hammer tip stiffness controls input spectrum; a soft tip cannot excite high frequencies adequately; a hard tip can overload local sensors; the point and direction of impact should be repeatable.

Nonlinearity can be investigated by varying force amplitude and comparing normalised responses; frequency shifts, harmonic generation, and changing coherence indicate amplitude dependence; the report should not average across different structural states; a restraint that only contacts during high load may be the governing security path under real operation.

6.12.4 Transfer-path analysis

Transfer-path analysis decomposes receiver response into contributions from source-interface forces and path transfer functions. In matrix form,

Equation 6.9

$$v_r = H_{rf} F ,$$

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where F contains interface forces and H_{rf} contains transfer responses from each interface to the receiver. The method can rank machine feet, pipe supports, ducts, and frame connections.[245]

Direct force measurement can be difficult in an installed building; inverse methods estimate forces from measured responses and a transfer matrix, but the inversion may be ill-conditioned; regularisation and sensor placement affect the answer; a contribution plot should therefore include condition number, residual, and sensitivity to noise.

Operational transfer-path analysis can combine measured blocked force, receiver mobility, and validation interventions; disconnecting or softening one path, where safe, provides a strong check; the result should guide remediation by identifying the path whose reduction will change the receiver, not merely the point with the largest local vibration.

6.12.5 Sensor uncertainty and mounting bias

Sensor sensitivity uncertainty is only one part of structural measurement uncertainty. Transverse sensitivity, base strain, cable motion, magnetic-field response, thermal drift, mounting resonance, mass loading, and orientation all contribute. ISO 16063-21 addresses comparison calibration, but field mounting and structural variability remain additional terms.[246]

Mass loading is material when sensor mass is not negligible relative to local modal mass; a small accelerometer on a light gypsum panel can lower a resonance and alter damping; laser methods avoid contact but require angular correction and can suffer dropouts. A triaxial sensor reduces remounting but adds mass and cross-axis considerations.

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The uncertainty budget should be frequency-dependent. A mounting method acceptable at 100 Hz may be unsuitable at 5 kHz. Cable restraint should be photographed. Pretest and post-test checks detect gross drift but do not calibrate the complete installed response.

6.12.6 Structural acceptance and lifecycle change

Structural acceptance should be based on mechanism-specific evidence. A vibration criterion for machinery protection is not automatically a speech-security criterion. ISO 20816-1 provides general machinery-vibration guidance, but secure-room path acceptance must connect source forcing, structural transfer, radiation, and the protected conversation objective.[247]

Baseline data are valuable after occupancy. Record representative transfer functions, vibration spectra, support clearances, service connector states, and operating conditions; later equipment replacement, pipework alteration, slab coring, door-frame work, or ceiling installation can change the network; configuration control should identify changes that require retesting.

A structural finding should distinguish susceptibility from observed compromise; a highly mobile junction may be vulnerable under a stronger source but not presently carrying information-bearing energy; conversely, a modest broadband vibration can contain coherent speech modulation; the conclusion must follow the measured source and path, not the appearance of the spectrum.

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6.12.7 Structural attenuation and distance

Vibration does not generally follow the airborne inverse-square law. Amplitude decreases through geometric spreading, material and joint loss, scattering, conversion, and radiation. The rate depends upon wave type and geometry. A bending wave in a plate, a longitudinal wave in a beam, and a shell wave in a pipe exhibit different distance relations.[248]

An empirical attenuation curve should be measured along a defined path with consistent coordinates and operating state; a straight-line fit in decibels per metre can be useful over a limited range, but it should not be extrapolated across junctions or modal transitions. Peaks can persist at resonances while neighbouring bands decay rapidly.

6.12.8 Radiation efficiency and secondary sound

Structural response becomes an acoustic-security concern when a vibrating element radiates into an accessible space or modulates another path. Radiated power from a panel can be expressed conceptually as

Equation 6.10

$$W = \rho_0 c S \sigma \langle v_n^2 \rangle ,$$

where S is area, σ is radiation efficiency, and $\langle v_n^2 \rangle$ is spatial mean-square normal velocity. Radiation efficiency depends upon frequency, dimensions, mode shape, and surrounding boundaries.[249]

A large panel with moderate velocity can radiate more power than a small panel with high local acceleration; measurement should therefore combine

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spatial response with area and radiation behaviour; near coincidence, efficiency can rise markedly; a suspended ceiling, duct wall, or glazing panel can become a secondary loudspeaker.

Worked example 6.4. Panel radiation estimate

A 4.0 m² panel has rms normal velocity 2.0×10^{-6} m/s in a band, with estimated radiation efficiency $\sigma = 0.30$. Taking $\rho_0 c = 412$ Pa s/m,

$$W = (412)(4.0)(0.30)\left(2.0 \times 10^{-6}\right)^2 = 1.98 \times 10^{-9}\,W.$$

The sound-power level is $10\log_{10}\left(1.98 \times 10^{-9}/10^{-12}\right) = 33.0$ dB. Uncertainty in spatial velocity and radiation efficiency may dominate. The estimate does not include other radiators.

6.12.9 Concrete slabs and long-range propagation

Massive concrete provides high airborne transmission loss, yet its low damping and continuity can support structure-borne propagation across rooms and floors. Post-tensioning, reinforcement, beams, columns, toppings, raised floors, and façade connections create a network. Saw cuts and joints alter but do not necessarily interrupt every wave type.[250]

A slab path should be investigated with source and receiver points along plausible routes, including across joints and columns; modal density, support conditions, and finish layers change response; floating floors can reduce impact transmission but may bridge at perimeters, services, or door thresholds. A heavy slab is not proof of structural isolation.

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6.12.10 Structural path interventions

Remediation options include source balancing, resilient mounts, inertia bases, flexible connectors, path breaks, damping, local stiffening, isolation joints, and receiver-side treatment. Each changes a different term. Stiffening can reduce local velocity but transmit more force to supports. Damping reduces resonant response but not necessarily low-frequency rigid-body motion. Soft isolation can amplify near resonance.[251]

The selected intervention should be predicted to change the observed signature; before-and-after measurements should preserve load, speed, temperature, and system configuration; if several changes are made simultaneously, causal attribution becomes difficult; staged interventions are slower but produce stronger evidence and prevent unnecessary work.

6.12.11 Operating-deflection shapes and modal interpretations

An operating-deflection shape shows relative motion at one frequency during actual operation. It is not automatically a normal mode. Several modes and forced responses can contribute, and amplitude depends upon the source. Experimental modal analysis seeks poles, mode shapes, damping, and participation from controlled excitation.[252]

The distinction is important in forensic work; a wall pattern at blade-pass frequency can identify a radiating region without proving that the pattern is one structural mode; modal testing may show that the forcing lies near a resonance, while an operating shape shows how the installed system responds. Both can guide remediation.

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Scanning laser vibrometry provides dense spatial data but requires stable operation and line of sight; multi-accelerometer arrays provide simultaneous phase but add mass and cabling; sparse measurements should not be interpolated into detailed shapes without stating the assumption.

6.12.12 Impact transmission through floors and thresholds

Footfall and impacts can enter protected rooms through slabs, raised floors, stairs, and thresholds. Impact insulation metrics address building comfort but do not alone define speech security. The same floor construction can also transmit loudspeaker reaction or machinery vibration.[253]

Floating floors reduce force transmission when the resilient layer is continuous and perimeter bridges are absent; door thresholds, partitions built through the floating layer, penetrations, and heavy equipment can short-circuit the system; the floor's natural frequency should remain below the governing excitation range, with sufficient damping and load capacity.

Testing should distinguish airborne source, standardised impact, and operational impacts; a tapping machine is repeatable but may not represent a door slam or dropped object; the conclusion should identify the source class and whether transmitted sound contains information or merely disturbance.

6.12.13 Coupled structural-acoustic transfer

A vibrating structure and the adjacent air form a coupled system. Air loading can shift resonances and add radiation damping, particularly for light

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panels. Enclosed air cavities add stiffness and modes. A wall response measured in free air may therefore differ after installation between rooms.[254]

The transfer from structural velocity to receiving pressure depends on radiation efficiency, room modes, receiver position, and absorption. A high-coherence relation can be modelled as $p_r = H_{pv} v_s$, where H_{pv} is a complex structural-acoustic transfer function for stated coordinates. The function is not a universal material property. It changes when furnishings, doors, or receiving-room absorption change.

Coupled modelling is most useful where one structural path has been identified and its radiation surface is known; for complex buildings, measured transfer functions and controlled interventions may be more reliable than an unconstrained numerical model; the model should predict a measurable change, such as the receiving pressure reduction expected from a defined velocity reduction.

6.12.14 Structural data preservation

Structural evidence requires more than plotted spectra. Preserve raw time histories, calibration, coordinates, sensor mounting photographs, orientation, force input, operating state, averaging, and complex data. Modal fits should retain poles, residues, stabilisation diagrams, and analyst selections.[255]

Geometry and configuration are inseparable from the data; a moved cable, added sensor mass, opened access panel, or changed machine load can alter response; file names should not carry the only metadata; a machine-

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readable register should link each channel to the physical coordinate and instrument.

When data support a forensic or litigation-facing conclusion, original files should be hashed and derivatives tracked; processing scripts or parameter exports allow reproduction; screenshots can illustrate findings but should never be the sole retained evidence.

The advanced sections that follow extend this foundation into distributed parameters, wavenumber methods, complex power, junction experiments, statistical energy exchange, blocked-force characterisation, nonlinear contacts, finite-element validation, sensor uncertainty, operational deflection shapes, transfer-path analysis, and structural acceptance criteria.

6.13 Distributed systems and the limits of lumped models

A single-degree-of-freedom oscillator is indispensable for explaining resonance, damping, and isolation. Buildings are distributed systems. Their mass and stiffness occupy space, waves propagate between locations, and many modes can contribute within one measurement band. The lumped model remains useful when one mode dominates or when a resilient mount and supported mass behave approximately as a rigid body. It becomes misleading when wavelengths are comparable with element dimensions, when several supports interact, or when local deformation controls transfer.[256]

The transition can be assessed by comparing structural wavelength with geometry; flexural waves in plates are dispersive, so wavelength decreases with frequency differently from airborne sound; a slab that moves nearly

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rigidly at very low frequency can support many local bending shapes at higher frequency. A point force then excites a spatial response that depends on location relative to nodes, boundaries, beams, and discontinuities; point mobility measured at one position cannot automatically represent the whole slab.

Distributed models include beams, plates, shells, finite-element representations, boundary-element radiation models, and wave-based junction methods; the simplest adequate model should be used; a full finite-element mesh is unnecessary if a beam approximation captures the governing mode, but a beam model cannot represent two-dimensional slab spreading or torsional coupling. Model selection should be justified by the question, frequency range, and observable data.

The measurement plan should mirror the model; if a local mode is suspected, a spatial accelerometer grid or scanning vibrometer can reveal its shape; if long-range propagation is suspected, a line of sensors across junctions can estimate decay and transmission. If a rigid-body mount mode is suspected, simultaneous measurements on the supported equipment and base are more informative than one room microphone; the strongest conclusion follows when model and measurement use compatible coordinates and reference planes.

6.14 Longitudinal, shear, torsional, and flexural waves

Solids support several wave types. Longitudinal waves involve particle motion largely parallel to propagation; shear waves involve motion transverse to propagation. Beams and plates support flexural waves governed by bending stiffness, mass, and boundary conditions; structural

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members can also support torsion; at junctions, one wave type can convert into another; a wall-slab intersection may therefore transmit energy through mechanisms not visible in an airborne sound map.[257]

Wave speed and impedance differ among types; longitudinal and shear speeds in homogeneous isotropic solids depend upon elastic moduli, density, and Poisson's ratio; flexural waves are dispersive, with phase and group velocities varying with frequency; this affects coincidence with airborne sound and the distance over which a transient spreads. A short impact can excite a broad family of modes and wave types. A steady rotating machine can excite a small set of harmonics that propagate efficiently if they align with structural modes.

Junction behaviour depends upon angle, member thickness, material, and continuity; a heavy concrete slab intersecting a lightweight stud wall is not a simple impedance discontinuity because the wall, tracks, fasteners, ceiling, and air cavity provide several parallel routes. A pipe sleeve through the slab can add a local bridge; a façade anchor can connect remote bays; path analysis should identify these physical connections rather than assigning all unexplained energy to an abstract "flanking" term.

Wave-type discrimination can use directional sensor orientation, operational deflection shapes, phase, and controlled force excitation; tri-axial accelerometers reveal components but can perturb light elements; laser vibrometry avoids mass loading but requires line of sight and surface preparation. Strain gauges measure local deformation but require careful

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installation; the chosen sensor should follow the expected wave field and the evidence burden.

6.15 Modal density, overlap, and the change from discrete to statistical behaviour

A structure at low frequency often responds through separated modes; each mode has a natural frequency, shape, modal mass, and damping. As frequency rises, modal density usually increases and resonances overlap; the modal overlap factor compares average modal bandwidth with modal spacing; when overlap is low, deterministic resonances and source position dominate; when overlap is high, spatial and ensemble averages become more stable and statistical models become more plausible.[258]

For modes with average spacing Δf and average half-power bandwidth δf, an indicative overlap factor is

Equation 6.11

$$M = \frac{\delta f}{\Delta f}.$$

Values well below one indicate separated modes; values near or above one indicate substantial overlap; the threshold is not absolute, and irregular structures may contain localised modes among diffuse behaviour; estimation from measured frequency-response functions can be preferable to reliance on asymptotic formulas alone.

Modal overlap affects uncertainty. A response measured at one point near a low-frequency node can be unrepresentative; small changes in source or sensor location produce large variation; at high overlap, averages are more

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stable, but local junctions and coherent forcing can still dominate. The report should not use “diffuse” as a blanket description across the entire frequency range.

For secure rooms, the transition matters because speech, machinery, and impacts excite different regions; a low-frequency fan harmonic may couple to one slab mode and create a strong remote radiation patch; mid-frequency speech may encounter many overlapping modes and distributed flanking. High-frequency vibration may be strongly attenuated at junctions but radiate from lightweight panels; a frequency-resolved structural model is therefore necessary.

6.16 Mobility matrices, blocked force, and operational transfer paths

Point mobility relates velocity at a response coordinate to applied force at an excitation coordinate; a mobility matrix extends the relation to multiple inputs and responses. Its diagonal terms are driving-point mobilities, while off-diagonal terms are transfer mobilities; the matrix retains phase and can represent coupling among translations and rotations if the coordinate set is complete; in practical building work, measurements often capture only selected translational coordinates, so omitted moments and rotations must be recognised.[259]

For a linear system,

Equation 6.12

$$v(\omega)=Y(\omega)F(\omega).$$

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If the source and receiver subsystems are characterised separately, interface forces can be predicted from their mobilities; blocked force describes the force a source would exert if motion at the interface were constrained; it can characterise machinery independently of a particular receiver structure more effectively than free velocity alone. The concept is valuable for comparing equipment or predicting transfer to several building locations.

Operational transfer path analysis seeks to decompose measured receiver response into path contributions during normal operation; it may use measured interface forces, transmissibilities, inverse force estimation, or principal-component methods. Correlated paths create difficulty. Forces at several mounts can be coherent because they arise from one machine, making contribution estimates non-unique; a mathematically separated path is not necessarily a physically independent source.

Validation again requires intervention. Isolating one mount, changing speed, adding temporary mass, or interrupting a service connection should alter the predicted contribution; the method should preserve complex data, reference coordinates, sensor orientation, and operating state; a bar chart of “percent contribution” without these records can overstate certainty.

6.17 Junction transmission and standardised flanking characterisation

Flanking transmission occurs when energy reaches the receiving space by paths other than the nominal separating element. Structural junctions are central. ISO 10848-1 provides a laboratory framework for measuring flanking transmission among building elements, while ISO 12354-1 provides calculation concepts for estimating airborne sound insulation including

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direct and flanking paths. These standards belong to different propositions from a site-specific security decision. They provide measurement and calculation structure, not classified-room accreditation criteria.[260]

A junction can be described through vibration reduction indices or coupling quantities derived from level differences, junction dimensions, and element properties; the exact standard definition should be used when claiming a standardised quantity; informal vibration level differences can still support diagnosis, but they should not be labelled as a standard index without satisfying geometry and method requirements.

Path order matters. Energy can pass from source-room air into a wall, through a wall-slab junction, along the slab, through a slab-wall junction, and into receiving-room air; other paths begin with direct structure-borne excitation from a loudspeaker support or service. Prediction should enumerate source element, junction, receiving element, and radiation surface; this prevents one generic flanking allowance from concealing several physically different routes.

Junction remediation depends upon where energy enters and leaves; adding absorption in the receiving room may lower pressure without reducing structural transfer; adding a resilient lining to the receiving wall may reduce radiation if that wall is the final radiator. Cutting or isolating a structural junction is usually impractical and may be unsafe; early design should therefore use discontinuities, independent shells, and service isolation where the risk justifies them. Retrofitting a continuous concrete frame is far harder.

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6.18 Material damping, connection loss, and uncertainty in existing structures

Structural damping arises from material hysteresis, friction, joints, finishes, radiation, and attached systems. It is often represented by modal damping ratio or loss factor, but the measured value depends upon frequency, amplitude, boundary conditions, and operating state; concrete cracking, masonry joints, bolted connections, floating floors, partitions, and furnishings can all add or remove damping; a handbook value is a starting assumption, not a site fact.[261]

Decay tests, half-power bandwidth, curve fitting, and time-domain system identification can estimate damping. Each method has limitations. Closely spaced modes corrupt simple half-power estimates; noise and short records affect decay fitting. Nonlinear friction produces amplitude-dependent decay. The report should identify the method and whether the fitted mode is adequately separated.

Connection loss can be more uncertain than material damping; a nominally rigid anchor may slip microscopically; a dry joint can open and close. A resilient pad may creep. A pipe clamp can change with temperature; these conditions can create intermittent transmission and harmonics. Inspection under static conditions may not reveal them. Operational measurements during relevant loads are necessary.

Existing structures often lack complete records. Concrete strength, reinforcement, slab thickness, masonry fill, and concealed connections may vary; non-destructive examination, selective opening, and sensitivity analysis should be combined; the model should use ranges rather than one invented

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exact value; if several plausible constructions produce materially different conclusions, the uncertainty must be resolved through evidence or retained as a limitation.

6.19 Isolation systems as six-degree-of-freedom assemblies

A supported room, floor, machine, or duct can translate and rotate in three axes; vertical isolator calculations alone may miss rocking, pitching, yawing, horizontal sway, and torsional modes; the centre of mass, centre of stiffness, isolator locations, and load distribution determine coupled modes; unequal loading can leave one support too stiff and another unstable. A room-within-room shell with many perimeter supports requires a coordinated rigid-body and structural analysis.[262]

For a rigid body with mass matrix M and stiffness matrix K, undamped natural frequencies satisfy

Equation 6.13

$$det\left(K-\omega_n^2 M\right)=0.$$

The matrices include translational and rotational terms about a defined reference point; damping and flexible-body modes require a more complete formulation; the calculation should use actual support stiffness at design load, not nominal catalogue values alone.

Isolation begins only above the relevant natural frequency by a sufficient ratio; very low natural frequency improves high-frequency isolation but increases static deflection and susceptibility to movement; snubbers, seismic restraints, service connections, doors, and access bridges can bypass the system. Flexible hoses and cable loops need enough compliance

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in all directions; a restraint that contacts during normal operation converts the design into a hard bridge.

Commissioning should measure natural frequencies and transmissibility under operating load; an impact or controlled shaker can identify modes; relative motion sensors can confirm clearances; the result should be compared with calculation and inspected after settling. If the supported mass changes through furniture, equipment, or storage, load distribution and natural frequencies may change. Lifecycle limits should be defined.

6.20 Accelerometer calibration, mounting, and mass loading

Accelerometers convert motion into electrical output, but the measured response includes the sensor, mounting, cable, conditioner, and digitiser. ISO 16063-21 describes vibration calibration by comparison to a reference transducer; a calibration certificate establishes sensitivity under stated conditions; it does not prove that a field mounting reproduces the calibrated response on a thin panel, nor that transverse sensitivity, cable strain, temperature, and magnetic mounting are negligible.[263]

Mounting stiffness controls high-frequency response. A stud or adhesive mount generally provides stronger coupling than a handheld probe or soft wax; magnetic mounts require ferromagnetic surfaces and can introduce rocking or poor contact on rough paint. Adhesive pads add compliance. The report should identify mounting method, surface preparation, orientation, torque where applicable, and any mounting resonance relevant to the band.

Sensor mass can alter light elements. A five-gram accelerometer attached to a thin suspended ceiling tile or light metal panel may shift local resonances

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and reduce response; miniature sensors or non-contact laser vibrometry may be needed; the perturbation can be estimated by comparing sensor mass with effective modal mass or by repeated tests with different sensors. An apparently improved response after adding a heavy sensor is not evidence of better construction.

Cable management is part of mounting. A loose cable can slap the surface, transmit force, or create triboelectric noise; it should be strain-relieved without constraining the local motion; integrated electronics piezoelectric sensors require appropriate power and settling; charge-output sensors require low-noise cables and charge amplifiers. Saturation and low-frequency discharge behaviour must be checked, especially for impacts and long-duration motion.

6.21 Laser vibrometry and optical measurement limitations

Laser Doppler vibrometry measures surface velocity along the optical axis without contact. It avoids mass loading and supports scanning of operational deflection shapes; its result depends upon optical return, speckle, incidence angle, surface motion, and line-of-sight stability; reflective tape can improve return but adds a small local mass and changes the surface; highly reflective glass or polished stone can produce unstable returns or multiple reflections.[264]

A single-beam instrument measures one component. Out-of-plane motion is captured only along the beam; three-dimensional motion requires several beams or assumptions; a panel whose dominant motion is oblique may be

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underestimated; coordinate transformation must use measured geometry. A camera image of the scan grid should be tied to the structural drawing.

Speckle can cause signal dropouts and phase jumps as the surface moves; averaging or slight beam relocation may help, but selective removal of bad points should be documented; environmental vibration of the instrument or tripod becomes part of the reference. A reference beam or stable foundation may be necessary; long standoff measurements are affected by air turbulence and line-of-sight interruption.

Scanning maps are compelling but should preserve frequency, operating state, phase reference, spatial resolution, and colour scale; normalising each frequency to its own maximum conceals absolute significance; a weak high-frequency mode can look as dramatic as a strong low-frequency response. The report should include representative absolute velocity or acceleration values and compare them with microphone or force data.

6.22 Cross-spectral vibration analysis and operational coherence

The same cross-spectral principles used in airborne acoustics support structural diagnosis. Coherence between an equipment force proxy and slab acceleration can identify harmonics associated with the source; coherence between slab acceleration and receiving-room pressure can support a radiation path; a chain of high coherence across source, structure, and air is stronger than one correlation alone, though common forcing and shared references must be considered.[265]

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Frequency-response functions require an input. In impact testing, force is measured with an instrumented hammer and response with accelerometers. The estimator choice matters when input or output noise dominates. H_1 minimises effects of output noise under assumptions; H_2 addresses input noise differently. A report that says only “FRF measured” omits a material processing choice.

Operational data lack a measured input force; transmissibility between two responses can be useful but is source-dependent and cannot be treated as a universal structural transfer function; if several sources operate, changes in source mix alter the ratio. Operational deflection shapes show correlated motion at observed frequencies, not necessarily normal modes. Terminology should remain precise.

A controlled run-up or coast-down can separate speed-related orders from structural resonances; order tracking resamples data relative to rotational phase; a fixed structural resonance appears at nearly constant frequency while rotating orders sweep through it; the amplification near crossing identifies interaction. In a secure facility, permission and operational safety may limit such tests, so natural operating changes or controlled substitute excitation may be used.

6.23 Transients, impacts, and non-stationary structural propagation

Door closure, footfall, dropped objects, valve action, relay impacts, and mechanical starts create transients. Their broad spectra can excite many structural modes. A time-averaged spectrum can smear the event, while peak acceleration alone ignores duration and frequency content. Time-

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frequency analysis, impulse response, and energy decay provide more useful descriptions.[266]

An impulse response $h(t)$ describes a linear time-invariant relationship between input and output. Its Fourier transform is the transfer function. Buildings are only approximately time invariant. Doors move, joints slip, services cycle, and damping changes with amplitude. Repeated impacts at controlled force and location can test repeatability. Large variation may be evidence of nonlinear contact or operational state change rather than measurement noise.

Wave arrival times can help trace paths; a direct structural route may arrive before reverberant airborne energy, subject to sensor and filter delays; cross-correlation and group delay should be interpreted with known sound and structural wave speeds. Reflections and dispersive flexural waves broaden arrivals; an apparent early peak can also arise from electrical cross-talk or common trigger signals. Verification with altered sensor routing or independent recorders may be warranted.

Transient events can matter operationally even if they do not carry speech; they can raise background temporarily, trigger automatic systems, reveal occupancy, or excite objects that then radiate; more importantly, the same mechanical path that carries impacts may carry low-frequency speech-induced vibration or equipment modulation. The investigation should identify the mechanism without assuming equivalence of source strength.

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6.24 Structural radiation into receiving rooms

A vibrating wall, slab, ceiling, duct, or pipe radiates airborne sound according to its velocity distribution, radiation efficiency, area, boundary condition, and receiving environment; average velocity alone is incomplete because different mode shapes can have different radiation efficiency. At frequencies where structural wavelength couples efficiently to air, radiation can increase. Below coincidence, a large panel may radiate inefficiently except through edges and finite-size effects.[267]

A first-order sound-power estimate uses Equation 6.10. Radiation efficiency σ is generally frequency-dependent. For a finite panel it depends upon dimensions and mode. A structural map can be combined with a radiation model, but the model should be validated with receiving-room pressure or intensity. A hot vibration patch that radiates poorly may contribute less than a broader moderate patch.

The receiving room modifies pressure through modes and absorption; a structural source close to a corner can excite different room modes from a diffuse airborne path; microphone arrays or source reconstruction may locate the radiation region, while accelerometers confirm correlation. The diagnosis should distinguish the transmitting structure from the final radiator; energy might travel along a slab and radiate from a lightweight receiving partition rather than from the slab itself.

Remediation can target source force, transmission path, or radiator. Balancing a fan reduces input. Resilient mounting reduces force transfer. A discontinuity or isolation joint reduces propagation. A decoupled lining

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reduces radiation. Adding damping reduces resonant velocity. The most effective intervention depends upon which stage dominates; treating the final radiator alone may leave energy to emerge elsewhere.

6.25 Fluid-structure interaction in ducts and pipes

Ducts and pipes support internal fluid waves, wall vibration, and structural motion through supports. Pressure pulsation can excite the wall, which radiates or transmits force into the building. Conversely, structural vibration can excite the fluid and carry sound through the service. Flexible connectors, silencers, lagging, supports, and penetrations must be analysed as a coupled system.[268]

A thin rectangular duct can exhibit panel modes and breakout noise; internal sound pressure acts over large surfaces, and stiffeners change response; lining absorbs internal energy but may not control low-frequency wall vibration; external lagging adds mass and damping, provided it is continuous and compatible with fire and hygiene requirements. A rigid sleeve through a high-isolation wall can bypass both leaves.

Pipes carry longitudinal fluid-borne pressure and bending or longitudinal structural waves; pumps, valves, turbulent flow, and water hammer can excite them; resilient hangers help only if anchors, branches, and penetrations do not create hard paths; flexible hoses must be selected for pressure, movement, fire, and maintenance as well as vibration.

Diagnosis should use simultaneous pressure or acoustic measurements and structural sensors; stopping flow, changing speed, or operating valves can discriminate sources; a clamp-on accelerometer may alter a small pipe less

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than a large transducer; contact microphones can locate activity but require calibration if quantitative conclusions are made.

6.26 Room-within-room structures and bridge control

A room-within-room system seeks to create an inner shell structurally and acoustically separated from the host building; it may include an isolated floor, independent walls, and a suspended ceiling; its performance depends upon every support and connection; one rigid pipe, threshold, duct, cable tray, brace, or door frame can bypass the isolation. The system should therefore be designed as a complete load path and service interface.[269]

The isolated floor must support dead load, occupancy, partitions, equipment, and dynamic loads while maintaining clearances; spring or elastomer supports require load equalisation; a floating screed on resilient material behaves differently from a heavy slab on discrete springs. Edge isolation must remain continuous. Finishes, skirtings, ramps, and door thresholds often create hidden bridges.

Independent walls should bear on the inner floor if the intended shell is fully isolated, subject to structural design; if they connect to the host slab or roof, the path changes; the inner ceiling may hang from the inner walls or an independent frame. Seismic and lateral stability require engineered restraints that do not engage under normal motion; fire stopping and egress details must preserve both safety and isolation.

Services should cross through grouped, accessible transition zones where flexible elements and seals can be inspected; each penetration requires sufficient length and compliance; electrical earthing and bonding must

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remain safe without creating unintended mechanical bridges; access doors and sound locks require a strategy for connecting the inner and outer floors. Commissioning should include structural transfer measurements, not only airborne room-to-room tests.

6.27 Numerical structural models and validation hierarchy

Finite-element models can represent complex geometry, material variation, junctions, and mode shapes. Their apparent detail can exceed the certainty of the inputs. Mesh density, element type, boundary conditions, damping, contact, and support stiffness determine the response. A model should be built to answer a defined question, not to create a visually convincing animation.[270]

Mesh convergence should be checked against structural wavelength; bending waves may require several elements per wavelength, with more near discontinuities; solid elements, shells, beams, springs, and acoustic elements each have appropriate domains; connections can dominate, so representing a clip as a rigid tie when its dynamic stiffness is central defeats the purpose. Contact and friction introduce nonlinearity and uncertain parameters.

Validation proceeds through increasing complexity. First, compare with analytic natural frequencies or static stiffness for a simplified case; second, compare component mobility or modal data; third, compare assembled response at points not used for calibration. Fourth, predict a controlled modification. Residuals should be examined spatially and spectrally.

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Model uncertainty includes material properties, geometry, boundary conditions, damping, and model form; monte Carlo or interval studies can show whether the conclusion is robust; if several plausible boundary conditions reverse the predicted dominant path, more measurement is needed. The model should guide evidence collection rather than mask uncertainty.

6.28 Lifecycle drift in structural isolation

Structural isolation systems change with time. Elastomers creep and age. Springs settle or corrode. Pads become contaminated. Fasteners loosen. Flexible connectors are replaced with stiffer parts. Equipment mass changes. Floors are overloaded. Seismic restraints shift into contact. A room that passed commissioning can therefore lose isolation without visible damage.[271]

Baseline records should include support type, location, design load, measured deflection, clearance, natural frequency, and transfer response; photographs should show service loops and restraints; maintenance instructions should define permitted loads and replacement products; any equipment change should trigger review of load distribution and forcing frequencies.

Periodic inspection can combine visual checks with spot vibration measurements; a reference excitation and fixed sensor locations improve comparison; changes in resonance frequency may indicate stiffness or mass change; increased high-frequency transfer may indicate a bridge. Increased damping is not always beneficial if it accompanies contact or degradation.

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Change control is especially important where the inner shell supports cabinets, displays, security equipment, or cable infrastructure; a contractor may anchor through the shell into the host structure for convenience; the resulting bridge can be small visually and large dynamically. Permit procedures should identify protected isolation zones and require post-work inspection.

6.29 Acoustic excitation of structures by speech and loudspeakers

Speech and loudspeakers exert fluctuating pressure on room boundaries. The force on a panel is the integral of pressure over area, including spatial phase. At low frequency, room modes can create coherent pressure over large regions and excite panel modes efficiently. At higher frequency, pressure varies spatially and net modal force depends upon overlap between the acoustic field and structural mode shape.[272]

A room-average sound level does not fully describe structural excitation; source position and orientation determine modal participation; a loudspeaker close to a wall creates a different pressure distribution from a talker in the centre; an amplified conference system can produce sustained low-frequency energy above natural speech. Structural vibration measurements during representative source states can reveal whether speech-induced structure-borne paths are plausible.

The force magnitude from ordinary speech is usually small compared with machinery, but high-isolation conditions make small paths relevant; lightweight glazing, suspended ceilings, and large thin panels may respond measurably; contact transducers can detect motion, yet detection does not

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prove useful information recovery. The response must be related to radiated sound or a validated sensing mechanism.

Design can reduce acoustic-structural coupling through panel stiffness and damping, cavity design, independent leaves, source placement, and interior absorption; interior absorption reduces reverberant pressure for a given source power, but occupants may alter vocal effort; the complete operational model is necessary.

6.30 Cracks, frictional contacts, and nonlinear junctions

Cracks and imperfect contacts can transmit, dissipate, or generate vibration nonlinearly; a closed crack may carry compression but open under tension; frictional interfaces can slip, producing harmonics and amplitude-dependent damping; loose ceiling components or door hardware can rattle; linear transfer functions measured at low excitation may not predict response at higher levels.[273]

Nonlinearity can be tested by varying excitation amplitude; in a linear system, response scales proportionally and transfer functions remain stable; harmonic generation, resonance shift, hysteresis, or changing coherence indicates nonlinearity; the intervention should remain within safe structural and operational limits.

Forensic inspection should correlate spectral features with physical conditions; a second harmonic of fan speed may arise from source force or nonlinear contact; tightening a fastener, applying controlled preload, or temporarily separating a contact can test the hypothesis. Any alteration should be documented and reversible where dispute is possible.

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Cracks in masonry or concrete also create airborne leakage; structural and acoustic roles should be distinguished; sealing a surface crack may reduce air transmission without changing structural continuity; injecting grout may change stiffness and vibration. Remediation should state which mechanism is intended and verify both where relevant.

6.31 Ground-borne and exterior structural inputs

Railways, road traffic, construction, plant, and neighbouring buildings can introduce ground-borne vibration. Energy travels through soil and foundations, propagates through the frame, and radiates inside rooms. The resulting low-frequency sound can raise background, mask speech, or contaminate tests. It may also be mistaken for internal equipment or flanking.[274]

Site measurements should establish source timing, ground conditions, foundation type, and sensor locations; vibration velocity or acceleration spectra can be correlated with external events; transfer varies with soil layering, distance, foundation stiffness, and building modes; a single daytime survey may miss infrequent trains or night construction.

Ground-borne background can be operationally beneficial as masking but should not be credited unless stable and controlled. External sources change. A rail service may stop, traffic may fall, or construction may finish; the quietest credible condition remains relevant to speech security.

Isolation at the building or room level may use trenches, base isolation, floating floors, or resilient inner shells, but feasibility depends upon frequency and structure; low-frequency ground vibration is difficult to

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isolate because required compliance and displacement are large. Source control or site planning is preferable where available.

6.32 Criteria, human perception, and security relevance

Vibration criteria used for human comfort, sensitive equipment, or building damage address different outcomes from acoustic security. A vibration below perception can still radiate measurable sound in a quiet room. A vibration acceptable for office comfort may interfere with microphones or create low-frequency background. Conversely, a perceptible transient may have no relevance to speech leakage.[275]

The report should identify the criterion's purpose and units; velocity, acceleration, displacement, and decibel references should not be mixed; frequency weighting for human response is not a substitute for unweighted structural analysis; equipment criteria may be expressed in one-third-octave velocity bands, while damage criteria use peak particle velocity or strain. Security analysis needs the transfer from source to receiver and the resulting information-bearing or masking effect.

Where no public security-specific criterion exists, the engineer should avoid inventing one; instead, measure the structural path, relate it to receiving sound or sensor response, quantify uncertainty, and present the evidence to the competent authority. The institutional decision remains separate.

6.33 Path-ranking experiments and falsifiable hypotheses

A useful path hypothesis predicts observable changes. If a continuous slab is dominant, interrupting airborne paths should leave correlated slab vibration and receiving pressure; if a duct is dominant, stopping the fan or applying a

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temporary silencer should change the relevant bands; if a door frame is the bridge, local structural response and perimeter treatment should affect the result. Experiments should be designed before intervention to reduce confirmation bias.[276]

A path-ranking matrix can list candidate source, coupling point, transmission element, final radiator, predicted bands, discriminating test, and safety constraints. The matrix keeps alternatives visible. Results should update confidence qualitatively or quantitatively where justified, rather than declaring a path proved after one suggestive map.

Negative results require care. A temporary treatment may fail because it was ineffective, not because the path was absent; a fan shutdown may alter room background and pressure; added mass may move a resonance into another band; the test should include controls and verify that the intervention changed the intended physical parameter.

The final ranking should state supporting and contrary observations. Multiple paths can be comparable. Remediation may need a package rather than one repair; post-remediation testing should use the same state matrix and include local diagnostics to ensure energy has not simply shifted to another route.

6.34 Rotational coordinates, moments, and support geometry

Building vibration measurements often focus on translational acceleration because it is readily measured. Rotations and moments can be important at beams, frames, equipment bases, and wall junctions. A pair of spatially separated accelerometers can estimate rotation over a short baseline if the

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field is smooth and sensors are synchronised. Six-axis force transducers or moment estimation may be required for complex source characterisation.[277]

Ignoring rotation can mischaracterise a support. Two mounts may experience equal vertical forces but opposite moments; a wide equipment base can excite slab bending through a force couple even when net force is small; door frames and glazing mullions can transmit moments across leaves. Structural models should include the coordinates necessary for the mechanism.

Measurement uncertainty grows as rotational estimates use small differences between sensors; baseline geometry, phase match, and mounting become critical; the method should be validated with a known rigid-body motion or calibrated fixture; where such evidence is unavailable, rotation should remain an inferred rather than measured quantity.

Support geometry also changes load distribution. If the centre of stiffness does not coincide with the centre of mass, a vertical force can excite rotation; an isolator schedule should therefore include plan coordinates and design loads; commissioning should verify deflection or load at each support rather than checking only total supported mass. A room shell or equipment skid that is level may still be unevenly loaded if shims or floor tolerances alter support engagement.

6.35 Active isolation and control boundaries

Active vibration control uses sensors, controllers, and actuators to generate forces that reduce motion in selected coordinates or frequency bands. It can be effective for low-frequency narrowband or predictable disturbances. It

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adds power, software, stability, maintenance, and cybersecurity dependencies. It is not a universal substitute for passive structural separation.[278]

Control performance is spatially limited. Reducing response at one sensor can increase it elsewhere through spillover; unmodelled modes and time delay can destabilise the loop; a secure-room application would require fail-safe behaviour, controlled software, monitored health, and assessment of whether sensors or communication paths introduce other security concerns.

Passive isolation should carry the basic protection where practicable; active systems may supplement a difficult low-frequency condition; acceptance should test normal, degraded, bypass, power-loss, and fault states; the report should identify which state supports the security conclusion.

A controller's displayed attenuation is not independent evidence; the same sensors may provide both control and performance indication, creating common-mode error; independent reference sensors and source-state records are needed; firmware updates, gain changes, sensor replacement, and network configuration should be subject to change control and retest.

6.36 Worked example: transfer from machine to receiving wall

Consider a small air-handling unit producing a harmonic vertical force of 80 N rms at 31.5 Hz; it is mounted on an isolator system with force transmissibility 0.12 at that frequency; the transmitted force to the slab is therefore

$$F_t = 80 \times 0.12 = 9.6\,N\,rms.$$

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Suppose the measured transfer mobility from the machine base location to a receiving wall patch is $|Y_{tr}) = 1.8 \times 10^{-6} m/(N s)$. The patch rms velocity is

$$v_r = F_t |Y_{tr}) = 9.6 (1.8 \times 10^{-6}) = 1.73 \times 10^{-5} m/s .$$

If the effective radiating area is 6.0 m², radiation efficiency is conservatively estimated as 0.08, air density is 1.20 kg/m³, and sound speed is 343 m/s, Equation 6.10 gives

$$W = 1.20 (343) (6.0) (0.08) (1.73 \times 10^{-5})^2 = 5.9 \times 10^{-8} W .$$

Relative to $W_0 = 10^{-12}$ W, the idealised sound-power level is about 47.7 dB. This is not a receiving-room sound-pressure level. Room absorption, radiation directivity, other radiators, background, and uncertainty remain. The example shows the chain of force, isolation, structural mobility, surface velocity, and radiation. It also shows where measurements can replace assumptions.

Uncertainty is substantial. A factor-of-two error in mobility changes velocity by 6 dB and radiated power by 12 dB; radiation efficiency may be poorly known; isolator transmissibility may vary with load; the result is therefore a screening estimate until validated by simultaneous force, vibration, and acoustic measurements.

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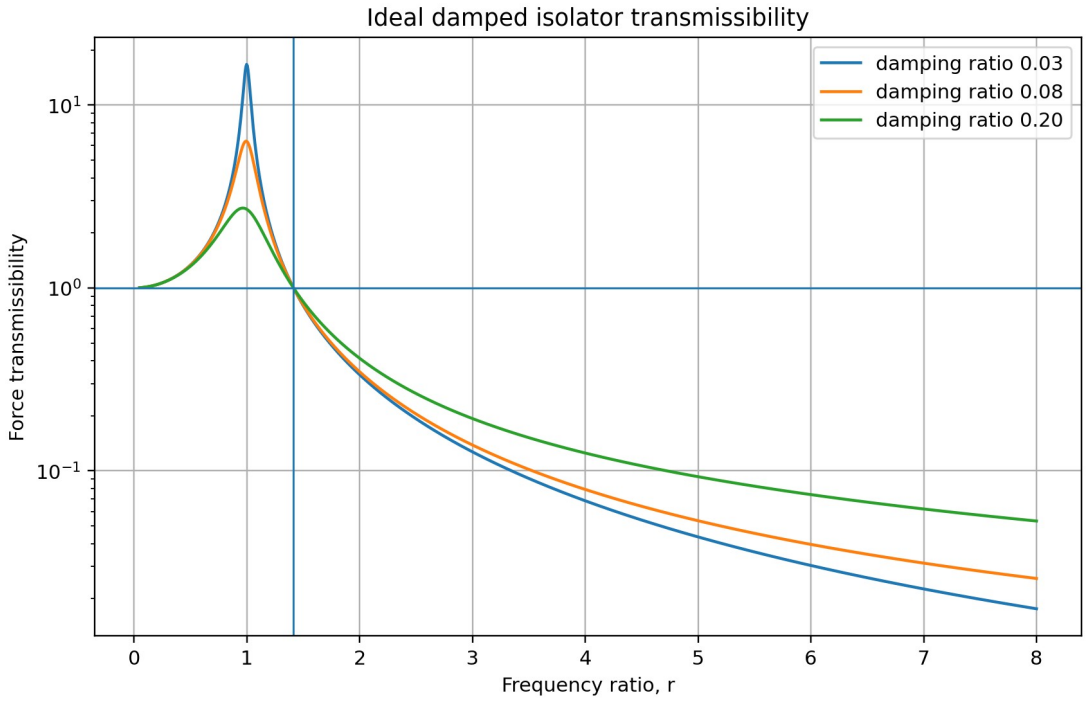

Figure 6-1. Force transmissibility of an ideal damped isolator for three damping ratios. Author's original calculation.

The figure illustrates the trade-off created by damping; greater damping reduces the resonance peak but can increase high-frequency force transfer relative to a lightly damped ideal spring; real isolators also contain stiffness and damping that vary with frequency, amplitude, preload, and temperature. The curves are therefore educational reference cases, not product predictions.

6.37 Worked example: mobility resonance and sensor placement

Assume a local structural coordinate is approximated by a mass of 500 kg, natural frequency 25 Hz, and damping ratio 0.03. The stiffness is

$$k = m\left(2\pi f_n\right)^2 = 500\left[2\pi\left(25\right)\right]^2 = 1.23\times10^7\, N/m.$$

The viscous damping coefficient is

$$c_d = 2\zeta\sqrt{k\,m} = 2\left(0.03\right)\sqrt{\left(1.23\times10^7\right)\left(500\right)} = 4.71\times10^3\, N\,s/m.$$

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Driving-point mobility follows from Equation 6.1 and the dynamic stiffness:

$$Y(\omega)=\frac{j\omega}{k-m\omega^2+j c_d \omega}.$$

At resonance, the magnitude is approximately $1/c_d=2.13\times10^{-4}\,m/(N\,s)$ for the ideal model. Away from resonance it falls sharply. A sensor positioned at a modal node would measure far less than the ideal coordinate, while a sensor near an antinode would approach it. The result demonstrates why point selection and modal shape must accompany a mobility value.

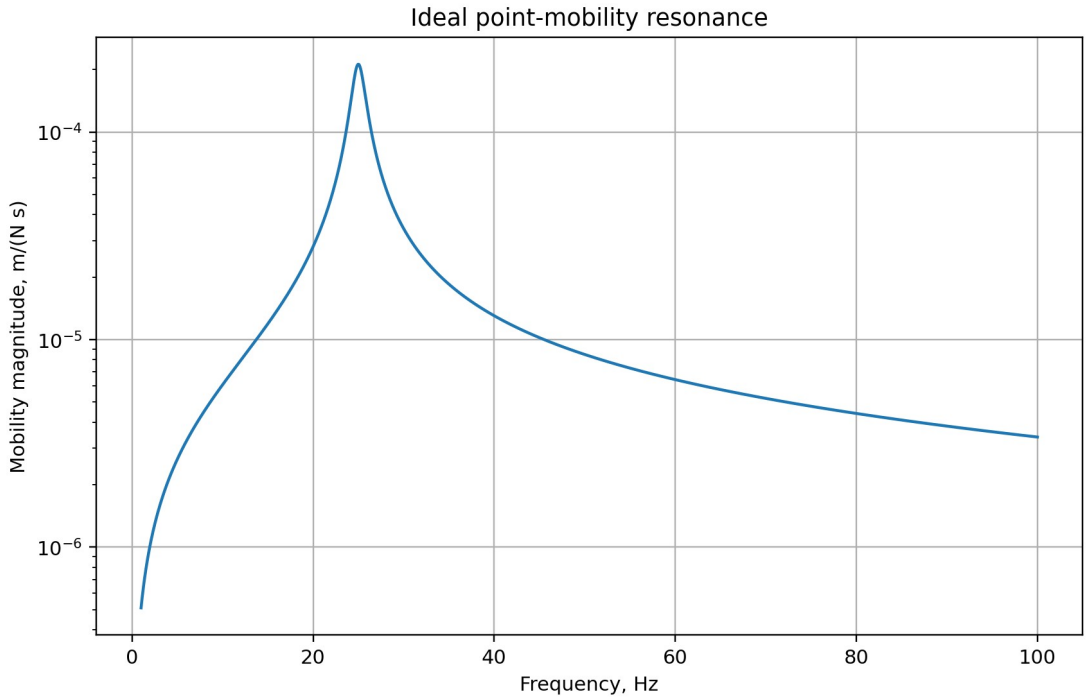

Figure 6-2. Ideal point-mobility magnitude for the worked single-degree model. Author's original calculation.

The curve should not be fitted blindly to a building response; several modes, non-proportional damping, local compliance, and measurement mounting can alter it; it can nevertheless guide a shaker or hammer test by identifying the need for fine frequency resolution near resonance and adequate record length at low frequency.

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6.38 Structural path maps and coordinate discipline

A structural path map should name physical components and coordinate systems. “Slab path” is too broad if the actual route passes from a duct hanger into a beam, through a column head, across a transfer slab, and into a receiving partition track; the map should identify source interface, intermediate junctions, final radiator, and measurement coordinates; plan and section drawings should use the same identifiers as sensor channels and data files.[279]

Coordinate discipline prevents sign and orientation errors; accelerometer axes should be tied to a building coordinate system, not merely to coloured sensor leads; probe polarity, force-hammer direction, and laser line of sight should be recorded; complex transfer functions can change phase by 180 degrees when an axis is reversed. If several survey teams use different conventions, path comparison becomes unreliable.

Channel naming should be stable and machine-readable; a name such as “A17-Z-SLAB-L3-GRIDC4” can encode sensor, axis, element, level, and location. The scheme should be documented. Photographs with scale and marked coordinates should accompany each installation; temporary sensors should be removed without leaving damage or unrecorded attachments.

The path map also supports security handling; a broadly distributed report may show aggregated conclusions, while a controlled technical annex retains exact weak-path locations and sensor maps; the release authority should decide the level of detail appropriate to each audience.

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6.39 Structure-borne speech and information recovery boundaries

The detection of vibration correlated with speech does not by itself establish recoverable information. A surface may respond strongly at low-frequency voicing while lacking the higher-frequency modulation and articulation cues required for intelligibility. A contact sensor may have sufficient sensitivity in controlled laboratory conditions but not at a remote accessible location. Mechanical noise and structural modes can further distort the signal.[280]

Assessment should separate susceptibility, detectable correlation, partial phonetic information, intelligibility, and operational exploitability. Each is a different proposition. Controlled test signals can characterise transfer without recording protected conversation; if listening or reconstruction tests are necessary, they require authority, standardised material, listener controls, and secure handling.

A structural transfer function can be combined with a representative speech source spectrum and sensor noise model to estimate signal-to-noise ratio by band; the calculation should include contact conditions, accessible measurement location, and realistic acquisition duration; it should not assume an ideal sensor attached directly to a protected surface if an adversary could not obtain that access.

Remediation may reduce vibration through added damping, increased stiffness, decoupling, or relocation of sources; interior treatment that reduces room sound level can also reduce structural excitation; operational controls, such as keeping amplified loudspeakers away from glazing or

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exterior walls, may supplement construction. Formal security acceptance remains an authority decision.

6.40 Mechanical service supports and hidden parallel paths

Services frequently create parallel structural paths through supports and penetrations; a duct may have a flexible connector at the fan but be hard-supported to the building immediately afterwards; a pipe may use resilient hangers in one room and rigid clamps at a boundary; a cable tray can bridge independent shells. Fire-stopping material can harden around a sleeve and create contact; the path should be traced continuously, not inferred from one visible flexible element.[281]

Support stiffness and spacing affect force distribution; a long duct on many hangers can couple several structural bays; flexible connectors need enough unrestrained length and appropriate pressure capability; short connectors can become stiff in tension. Misalignment can preload them. Braided hoses may be flexible laterally but stiff axially. The design should specify orientation and installation tolerances.

Inspection requires access. Supports hidden above ceilings should be photographed and logged before closure; a service-penetration register should identify both acoustic sealing and mechanical support; later maintenance should not replace a resilient support with an ordinary threaded-rod connection; spare capacity and planned routes reduce improvised additions.

Acoustic and structural tests can be combined; internal duct excitation with wall accelerometers reveals breakout and support transmission; a shaker or

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impact on a pipe can map structural coupling; source-off and source-on conditions distinguish service noise from transmission of room sound. The evidence should identify whether the service is a source, a conduit, a structural bridge, or several at once.

6.41 Floating floors, impact paths, and edge conditions

Floating floors use a resilient layer or discrete supports beneath a wearing slab or deck. Their isolation depends upon mass per area, dynamic stiffness, damping, support continuity, and edge separation; a continuous hard screed at the perimeter, a door threshold, a column collar, or a service penetration can bridge the system; impact sound and airborne sound interact with the same construction but are not governed by identical metrics.[282]

For a floating mass per unit area m' on resilient layer dynamic stiffness per unit area s', an ideal vertical resonance is

Equation 6.14

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{s'}{m'}}.$$

The calculation assumes uniform support and rigid mass; real floors have bending modes, load variation, seams, and finite boundaries; heavy furniture or partitions can locally compress the layer and create contact; a floating slab that supports inner walls must be designed for concentrated loads.

Edge strips must remain continuous and be trimmed without filling the gap with grout, adhesive, skirting fixings, or floor finish. Doorways require

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carefully detailed transitions. A ramp can bridge inner and outer floors; access panels and raised-floor pedestals can create local paths; photographs and feeler checks before skirting installation are valuable.

Commissioning can include tapping or impact tests, airborne tests, and structural transfer measurements; the purpose of each should be stated; a low impact level below the floor does not prove room-to-room speech isolation; conversely, a floating floor may improve structural flanking even if impact criteria were not the governing security requirement.

6.42 Structural discontinuities and deliberate impedance changes

A structural discontinuity can reduce wave transmission by changing impedance, geometry, or connection. Examples include isolation joints, breaks in slabs, double frames, resilient connections, and changes in thickness. The effect is frequency- and wave-type-dependent. A discontinuity that reflects flexural waves may transmit longitudinal force through reinforcement or services.[283]

Deliberate breaks require structural, fire, moisture, and movement design; cutting a slab or wall for acoustic reasons is not a field remedy to be attempted without structural authority; in new construction, separation joints can be planned around secure zones. Reinforcement, façades, roofs, and foundations must be considered; a nominal architectural joint filled with rigid material is not an acoustic discontinuity.

Where a break is impractical, local impedance changes and damping can reduce transfer; a heavy inertia block on isolators can contain machinery

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force; a decoupled lining can reduce final radiation; a resilient track can reduce partition input. These measures should be ranked through the complete path model.

Field tests across a junction can estimate vibration reduction, but source and receiving element mobility influence levels; the method and geometry should be documented; a difference measured at two arbitrary points is useful diagnostic evidence but should not be labelled as a standard junction index unless the standard procedure is followed.

6.43 Structural health observations and limits of acoustic inference

Vibration surveys can reveal cracks, looseness, unusual modes, or changing stiffness, but an acoustic-security examination is not automatically a structural safety assessment. Observations that suggest damage should be referred to a qualified structural engineer. The report should avoid declaring a member safe or unsafe beyond the examiner’s competence and scope.[284]

Conversely, a structure that is safe can still transmit vibration efficiently; structural adequacy and acoustic isolation are different propositions; adding mass, cutting connections, or changing supports for acoustic reasons can affect safety; all remediation should be coordinated with the responsible disciplines.

Trend data can support lifecycle monitoring. A shift in modal frequency or damping may indicate a change, but temperature, load, boundary conditions, and sensor placement can produce similar shifts; baseline comparability and uncertainty are essential; the conclusion should identify

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change, plausible mechanisms, and recommended investigation rather than overstate diagnosis.

6.44 Structural evidence package

A complete structural-acoustic evidence package includes authority, scope, drawings, coordinate system, sensor register, calibration, mounting photographs, channel map, excitation records, operational state, raw time histories, processing settings, complex spectra, uncertainty, path hypotheses, interventions, and post-intervention results. Derived figures should link to data files by stable identifier and checksum.[285]

The package should preserve both positive and negative evidence; a path rejected after a controlled test remains part of the reasoning; selective retention of only confirming plots weakens reproducibility; environmental and service logs should accompany the data because they explain state changes.

Where records disclose sensitive facility details, access and distribution should be controlled; a public scholarly treatment can describe method without publishing site-specific weak paths; the technical file retained by the authority may contain the detailed map necessary for maintenance and retest.

6.45 Force-source characterisation and source replacement

A mechanical source can be characterised by forces and moments at its interfaces, by free velocity, by blocked force, or by an operational source descriptor; the appropriate quantity depends upon whether the receiving structure is included in the measurement; a casing acceleration measured

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on one installation is not a source invariant. It changes with receiver mobility. Blocked force seeks a more transferable source description, but its estimation requires adequate interface coordinates and source-receiver modelling.[286]

Source replacement can reduce uncertainty during diagnosis; the operating machine is stopped and a controlled shaker or impact source excites the same interface; the measured transfer path can then be combined with operational source data; this separates path from source, provided the substitute excites the relevant coordinates and the structure remains linear. A single vertical shaker cannot represent torsional or horizontal forces if they matter.

Operational force reconstruction from response data is an inverse problem; it can be ill-conditioned when mounts are close, responses are correlated, or the mobility matrix is uncertain; regularisation and reduced coordinate sets should be documented; results should be validated by predicting response at independent sensors.

Equipment procurement can include source force or vibration-emission data, but the test conditions and mount interfaces must match the design; catalogue vibration velocity on a rigid foundation cannot predict force into a resiliently mounted slab without further modelling. The specification should define the source descriptor and acceptance test.

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6.46 Masonry and concrete as structural transmission networks

Massive walls and slabs provide high inertia but also continuous load paths. Reinforcement, bond beams, grout, floor diaphragms, columns, and façades connect regions that appear architecturally separate. Flexural and longitudinal waves can travel around a high-performing wall and radiate from a remote surface. The path may be strongest at low and mid frequency where damping is modest and large elements are efficient receivers.[287]

Concrete properties vary with cracking, reinforcement, boundary restraint, and construction joints; a crack can reduce local stiffness, alter modes, and provide airborne leakage; a construction joint may reduce some wave transfer but retain reinforcement continuity. Post-tensioning changes stress and stiffness. Hollow-core slabs introduce directionality and voids. Models should represent the actual structural system.

Masonry can be discontinuous at control joints or continuous through bond beams and ties; hollow cells and partial grout create local resonances and variable stiffness; independent linings can reduce radiation from the room surface, but the masonry may continue to transmit energy to adjacent spaces. Vibration measurements along the wall and at junctions help rank this.

Remediation of massive structures usually targets source isolation, final radiation, or service bridges rather than cutting the primary structure; a floating inner shell can be effective if it is truly independent; damping treatments may reduce local resonances. Structural modifications require engineering authority.

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6.47 Uncertainty in transfer-path contribution estimates

A reported contribution from one structural path depends upon source force, transfer function, phase relation, and receiver metric. Each carries uncertainty. Correlated paths make the uncertainty nontrivial because contributions do not add independently. A decomposition can assign large positive and negative coherent contributions whose sum matches the receiver, but the individual values may be unstable.[288]

Contribution uncertainty should be evaluated through repeated measurements, alternative sensor sets, parameter perturbation, and intervention; if the path ranking changes under small reasonable variations, the evidence supports a family of plausible paths rather than one dominant route. The report should state this.

For incoherent energy models, uncertainties in coupling loss factors, modal densities, and damping propagate to predicted band powers; lognormal distributions may be more appropriate than normal distributions for positive multiplicative quantities; for deterministic models, complex amplitude and phase uncertainty should be retained.

Decision-making can tolerate uncertainty if remediation addresses several plausible paths or if testing can resolve them; the engineer should not manufacture certainty merely to recommend one repair; a staged remediation with diagnostic retest can be more economical and evidentially stronger.

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6.48 Structural measurement test programme

A defensible test programme links each engineering question to a deliberately selected excitation, sensor set, controlled operating state, processing method, and decision output. The following five measurement families illustrate the necessary correspondence.

Local resonance identification. Apply an instrumented impact or electrodynamic shaker while recording the applied force and one or more structural-response channels. Establish transducer mounting, linearity, impact quality, frequency resolution, and repeatability before interpreting mobility, modal frequency, or damping.

Operating-machine path tracing. Record normal operation, run-up, coast-down, or controlled load changes with a tachometer, accelerometers, and receiving microphones. Preserve rotational speed, load, valve and damper states, control commands, and service configuration so that orders, coherence, and transfer-path estimates remain tied to a reproducible operating condition.

Isolator evaluation. Measure equipment and support motion during controlled operation or shaker excitation, adding interface force when practicable. Record supported load, static deflection, clearances, restraints, flexible connections, and foundation condition before calculating transmissibility or natural frequency.

Radiating-surface ranking. Excite the system acoustically or structurally and measure surface velocity together with receiving-room pressure or sound intensity. The source spectrum, room state, sensor grid, boundary

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condition, and background sound must remain controlled before a path contribution or radiation map is assigned evidentiary weight.

Remediation confirmation. Repeat the original test with the same channels, coordinates, source state, processing, and environmental controls. Report the before-and-after change by frequency, together with repeatability and uncertainty, rather than relying upon an overall subjective impression.

These categories are planning disciplines, not substitutes for a complete method. Every test still requires an explicit frequency range, sample rate, calibration record, coordinate system, duration, safety review, and decision rule. The programme should be approved before access and intervention.[289]

6.49 Structural intensity and vibrational power flow

Structural intensity describes the flow of vibrational energy through a solid. In beams and plates it involves products of internal forces or moments with translational or rotational velocities. The exact formulation depends upon structural theory and coordinate convention. Unlike a simple acceleration map, structural intensity retains direction and can indicate how energy crosses a section or junction.[290]

Measurement is demanding. Force and moment quantities are not usually observed directly across a building surface; they may be inferred from arrays of accelerometers, strain, or a validated model. Spatial derivatives amplify noise. Boundaries and near fields create reactive power that

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circulates without net transfer; a visually smooth arrow plot can therefore exceed the evidentiary strength of the inputs.

The method is most useful when supported by controlled excitation and model validation; it can compare alternative junctions, identify energy entering a receiving panel, or assess a damping treatment; for routine field diagnosis, transfer mobility, coherence, and intervention may provide stronger evidence with fewer assumptions. Structural intensity should be selected because it answers a necessary question, not because it produces sophisticated graphics.

A power-flow result should state active and reactive components, averaging, coordinate system, mesh, derivative method, boundary assumptions, and uncertainty; integration across a section can estimate transmitted power, which can be compared with acoustic radiation; energy balance provides a useful check.

6.50 Statistical decay, reverberant structural fields, and coupling loss

At higher modal overlap, a structural subsystem can be described by average vibrational energy and decay. When excitation stops, energy decays through internal loss, radiation, and coupling to other subsystems. Measured decay rates can estimate total loss factor, subject to the field being sufficiently diffuse and the decay being approximately exponential.[291]

For modal energy $E(t)$ with loss factor η at angular frequency ω, an ideal decay is

Equation 6.15

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$$E(t) = E_0 e^{-\omega \eta t}.$$

Because measured acceleration or velocity squared is proportional to energy under the model, a logarithmic decay can be fitted; double-slope or spatially variable decay indicates coupled subsystems, localised modes, or non-uniform damping; one fitted loss factor may then be inadequate.

Coupling loss factors can be estimated from power injection and subsystem energies or from specialised decay methods; their transferability depends upon junction geometry and frequency; a value inferred from one bay should not be assigned to a different junction without evidence.

Statistical structural fields can support flanking prediction, but low-frequency speech and machinery may remain deterministic; a hybrid model should retain discrete modes and measured transfer where modal overlap is low, then use energy methods above a justified transition.

6.51 Source-receiver coupling and installation effect

A machine's vibration emission changes when it is installed on a receiver structure because source and receiver mobilities interact. A stiff laboratory foundation and a flexible building slab produce different interface forces and casing motion. This installation effect explains why catalogue vibration data can mispredict site response.[292]

For a simple one-coordinate source with free velocity v_f and source mobility Y_s coupled to receiver mobility Y_r, the interface force can be represented conceptually as

Equation 6.16

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$$F = \frac{v_f}{Y_s + Y_r}.$$

The expression assumes linear complex mobilities referred to the same coordinate; it shows that force is not solely a source property unless blocked force or an equivalent descriptor is used; a flexible receiver can permit motion and reduce force, while a stiff receiver can increase force. Resonances complicate the relation.

Mounts lie between source and receiver and add their own mobility; several mounts create a matrix problem with moments and cross-coupling; the design should therefore match source, mount, and receiver rather than selecting isolators by load alone. Field measurements of both source and base motion can validate the installed system.

Installation effect also applies to loudspeakers mounted in walls, ceilings, or furniture; structural attachment can transmit force in addition to airborne sound; a ceiling speaker supported from the isolated shell differs from one hung from the host structure. The source path should be drawn explicitly.

6.52 Case study: fan room above a secure conference space

A composite case considers a variable-speed fan room above a conference space. Airborne breakout from the duct is moderate, but a 40 Hz tone appears in the room below; the tone follows fan speed and is coherent with vertical acceleration on the slab; the fan has spring isolators, yet inspection finds a rigid electrical conduit, a short flexible duct connector under tension, and one seismic restraint touching its stop.[293]

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Operational run-up shows a structural resonance near 39 Hz; the touching restraint provides a strong force path; releasing the contact under authorised safe conditions reduces slab acceleration by 8 dB; correcting the duct connector reduces another 3 dB. The conduit remains correlated and is replaced with a compliant, code-compliant transition. Final reduction is 14 dB at the tone, with smaller changes in adjacent bands.

The diagnosis does not rely upon the isolator catalogue; it uses speed order, coherence, mobility, inspection, and staged intervention; the remediation also includes clearance markers and a maintenance inspection schedule; the room’s speech-security assessment is repeated because the changed mechanical background alters masking as well as intrusive noise.

This case illustrates a general principle. A nominally isolated source can be dominated by parallel paths. Correcting the obvious spring selection would have missed them. The complete source-interface-service-receiver system must be examined.

6.53 Case study: slab flanking around a high-rated masonry wall

A high-mass masonry wall divides a protected room from an office. Local airborne scans show no major gaps, and the door is satisfactory. Field isolation is nevertheless below expectation in low and mid bands. Simultaneous accelerometers reveal similar slab response on both sides, with receiving pressure coherent to the slab near the office partition.[294]

The masonry wall is founded on the continuous slab, and the floor finish bridges beneath it; the office side contains a lightweight lining attached to

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the slab and wall; structural excitation in the protected room couples into the slab, passes beneath the wall, and radiates through the office lining. Temporary damping on the lining and a resilient base intervention in a mock-up reduce receiving response, supporting the path model.

A full structural break is impractical. The remediation uses a decoupled receiving lining, treatment of the floor bridge where feasible, relocation of amplified sources, and interior absorption to reduce low-frequency excitation; the final field result improves, but the report retains the continuous slab as a residual limitation and defines source and access conditions.

The case shows why massive wall rating does not guarantee room performance. The direct element answered the laboratory proposition. The slab controlled the installed relationship.

6.54 Structural test safety and facility protection

Shakers, impacts, run-ups, shutdowns, and temporary disconnections can affect equipment, finishes, alarms, and operations. A structural-acoustic test plan should include safety review, maximum force, attachment method, exclusion zones, equipment owner approval, and restoration. Fire, security, and life-safety systems should not be disabled without authority.[295]

Instrumented hammers can damage brittle finishes or stone. Adhesive sensors can pull paint. Magnetic mounts can mark surfaces. Laser equipment creates eye-safety obligations. Cables create trip hazards and can cross controlled boundaries; the method should minimise intrusion and use protective fixtures.

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Operational changes can alter environmental control for sensitive equipment or records. Fan shutdowns may change pressure or temperature. Valve operations can cause water hammer. The test should include competent facility staff and abort criteria.

Evidence preservation also matters. A dispute-related inspection should not alter suspected defects before documentation. Reversible interventions should precede permanent repair. Samples and removed components may require identification and custody.

6.55 Structural-acoustic diagnostic decisions

Common observations should be treated as hypotheses requiring discriminating tests, not as automatic classifications.

A narrow tone follows rotational speed. A source order interacting with a structural resonance is plausible. Confirm the relationship with tachometer data, controlled run-up or coast-down, coherence, and mobility. Common electrical interference, shared clock artefacts, or processing leakage can imitate coherence and must be excluded.

Broad receiving vibration is concentrated near a wall. Distributed flanking transmission or radiation from a local surface may be responsible. Use a spatial velocity survey, source relocation, and pressure or intensity measurements. On lightweight panels, sensor mass and cable restraint can perturb the response being measured.

A high response occurs only at one junction. A rigid bridge, intermittent contact, or local junction mode is plausible. Apply controlled preload changes or a reversible separation while monitoring adjacent paths.

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Intervention can redistribute energy, so a reduction at one point does not by itself prove total-path control.

Apparent isolation changes when a door, fan, or control state changes. Seal pressure, service-path transmission, source strength, or background sound may have changed. Use a documented state matrix and matched repeated tests. Do not assign a background-noise change to structural isolation without separate evidence.

Strong structural vibration accompanies weak receiving-room sound. The measured surface may possess low radiation efficiency, or it may not be the dominant radiator. Examine pressure-velocity correlation, radiation efficiency, and competing receiving surfaces. A vibration hot spot is not necessarily the dominant acoustic path.

This diagnostic sequence is a hypothesis discipline. Each site still requires explicit geometry, source state, frequency range, access condition, and decision authority.[296]

6.56 Worked example: isolation with static-deflection uncertainty

An equipment skid has total supported mass 1,200 kg and is carried by four nominally identical spring isolators. The measured static deflections are 21, 24, 27, and 30 mm. Using Equation 6.8, the corresponding vertical natural frequencies are approximately 3.44, 3.22, 3.03, and 2.88 Hz. The spread reveals unequal load or stiffness. Treating the system as four perfectly equal supports would conceal coupled rocking and load imbalance.[297]

296 MB-0921. ISO 10848-1:2017, ISO 12354-1:2017.
297 MB-0930. ISO 16063-21:2003.

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At a forcing frequency of 20 Hz, the frequency ratios range from 5.8 to 6.9; for damping ratio 0.05, the ideal force transmissibilities are all low, but they are not identical; more importantly, the unequal supports shift the rigid-body rotational modes and can cause one restraint or flexible connector to carry disproportionate load.

A commissioning response should measure load or deflection at each support, check skid level and centre of mass, inspect restraints and services, then measure equipment and base motion in vertical and horizontal axes; if one isolator is underloaded, shimming or spring selection may be required. The calculation provides a screening result, while the multi-axis measurement verifies the installed assembly.

The uncertainty in deflection should be included. If each measurement has standard uncertainty 1 mm, natural-frequency uncertainty follows from $f_n \propto \delta_s^{-1/2}$. The relative standard uncertainty in frequency is approximately half the relative uncertainty in deflection. This is small compared with the observed support spread, supporting the conclusion that imbalance is physical rather than metrological.

6.57 Worked example: vibration reduction across a junction

A controlled shaker excites a concrete wall in one room; spatially averaged velocity level on the source wall near a wall-slab junction is 82 dB relative to the stated velocity reference; the receiving slab average is 61 dB. A raw vibration level difference of 21 dB is observed; after a resilient receiving lining is installed, the slab level remains 61 dB but the room-side lining level falls from 66 to 53 dB.

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The first result indicates energy crosses the structural junction. It is not automatically a standard vibration reduction index because geometry, element properties, and normalisation may not satisfy ISO 10848. The second result shows the lining reduces final radiation response without changing slab propagation. This distinction guides remediation: the structural path remains, but the receiving radiator is controlled.[298]

If receiving-room sound falls 11 dB in the same bands and coherence between lining velocity and room pressure remains high, the evidence supports the lining as the former dominant radiator; any residual door or duct path should still be checked. The case demonstrates why structural and acoustic channels should be measured together.

6.58 Uncertainty budget for a structural transfer function

A transfer mobility estimate includes force-transducer calibration, accelerometer calibration, mounting, channel phase, source repeatability, background vibration, windowing, spectral averaging, and spatial variability. Some inputs affect amplitude, others phase, and some are correlated. A simple percentage added to the final magnitude is inadequate near anti-resonances or when complex path summation is performed.[299]

An uncertainty table should identify quantity, unit, distribution, standard uncertainty, sensitivity, correlation, and contribution; mounting and spatial variability may be evaluated experimentally rather than from certificates; repeat hammer impacts quantify source and estimator variance; re-mounting a sensor estimates installation sensitivity. A common calibrator or clock can create correlation among channels.

298 MB-0939. ISO 20816-1:2016.
299 MB-0986. JCGM 100:2008.

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Where the transfer function is used only to rank paths separated by 15 dB, a moderate uncertainty may not change the conclusion; where two paths differ by 2 dB, the ranking may be indeterminate; the report should align numerical effort with decision sensitivity.

6.59 Structural maintenance acceptance criteria

Maintenance criteria should focus on observable conditions that preserve the baseline: isolator deflection and clearance, restraint gap, flexible-connector condition, support type, service-loop geometry, attachment restrictions, door and threshold bridges, and absence of debris in isolation gaps. Numerical vibration checks can supplement these observations.[300]

A maintenance pass should not be defined solely by “no visible damage”; a restraint in light contact can look normal; a replacement hose can be visually neat but axially stiff; a new cable ladder can bridge shells. Checklists should identify prohibited contacts and reference baseline photographs.

After significant work, a reduced verification test can use fixed source and sensor points from commissioning; if the response remains within a predefined tolerance, full retest may not be necessary; if it changes materially, the broader diagnostic protocol is triggered. The competent authority should define the threshold and documentation.

6.60 Sensor noise, integration, and low-frequency drift

Acceleration, velocity, and displacement are related by frequency-domain integration or differentiation; converting acceleration to velocity divides by angular frequency, while displacement requires division by angular frequency squared; this amplifies low-frequency noise and offset; a small

300 MB-0765. Frank Fahy and Paolo Gardonio, Sound and Structural Vibration: Radiation, Transmission and Response, 2nd ed.

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accelerometer bias can become an apparently large displacement trend; high-pass filtering may be necessary, but it also removes real low-frequency motion. The filter and cutoff must be recorded.[301]

A velocity transducer can offer better direct sensitivity in a limited low-frequency band, while geophones and seismometers have their own natural frequencies and calibration models; laser vibrometry measures velocity directly along the beam; the instrument should be selected for the measurand rather than acquiring acceleration by habit and integrating beyond a defensible range.

Noise floors should be expressed by band and referred to the final quantity; a flat acceleration noise density becomes rising velocity and displacement noise towards low frequency after integration; long records improve spectral resolution but expose drift and non-stationarity. A source-off record and a rigid-reference check help identify the measurement floor.

Filtering can create phase delay and ringing; zero-phase offline filtering uses future data and is not causal, though it can be acceptable for analysis if disclosed; impact timing and cross-channel phase require special care; raw data should remain available so alternative processing can be tested.

6.61 Complex power, reactive motion, and misleading amplitude maxima

Structural active power depends upon the in-phase component of force and velocity. Near resonance, velocity can be large and relatively in phase with force, producing substantial power flow. Away from resonance, large reactive motion can store and return energy with smaller net transfer. An

301 MB-0921. ISO 10848-1:2017, ISO 12354-1:2017.

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acceleration maximum therefore does not always identify the path carrying the greatest active power.[302]

For complex rms force F and velocity v, complex power may be written

Equation 6.17

$$S = F\, v^{*} = P + jQ,$$

where P is active power and Q is reactive power under the adopted convention. Phase calibration is essential. A small phase error can create a large relative error in P when force and velocity are nearly in quadrature.

Reactive fields are common near sources and junctions; they can produce strong local vibration maps; the engineer should combine amplitude, phase, coherence, and intervention; structural intensity or power-flow analysis can assist where justified. A local maximum that disappears when sensor position changes slightly may reflect a standing-wave or modal feature rather than a dominant transfer route.

6.62 Vibration dose, intermittency, and speech-security testing

Some structural sources are intermittent: lift motion, pumps, compressors, door impacts, and periodic plant cycles. Comfort and occupational standards may use time-integrated vibration measures, but acoustic-security relevance depends upon whether the source masks, contaminates, or reveals information during specific intervals. A daily vibration dose is not a direct privacy metric.[303]

302 MB-0930. ISO 16063-21:2003.
303 MB-0939. ISO 20816-1:2016.

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The state record should mark source events and correlate them with receiving sound; an intermittent machine can create high background during operation and a quiet window when off; privacy assessment should include the quiet credible state unless machine operation is guaranteed and monitored. Conversely, the machine may introduce a speech-modulated structural path only while running if controls or ducts change state.

Long-term monitoring can use event detection and state classification; thresholds should be above instrument noise and validated against logs; automated classifications should retain confidence and permit manual review; data collection must respect facility authority and minimise sensitive acoustic recording.

6.63 Structural acceptance and retest triggers

Structural-acoustic acceptance should identify the tested configuration, source states, sensor coordinates, frequency range, uncertainties, and residual limitations. It should not declare that a building is “vibration-free.” The relevant finding is that measured transfer or receiving response met defined criteria under stated conditions and that no unresolved dominant path remained within the scope.[304]

Retest triggers include equipment replacement, isolator change, added services, new penetrations, structural repair, altered floor loading, contact at restraints, door or threshold work, and unexplained change in room background; a reduced diagnostic test may suffice for minor work, while major changes require full recommissioning.

304 MB-0986. JCGM 100:2008.

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The baseline should include frequency-response fingerprints and photographs; maintenance staff need concise criteria for supports, gaps, connectors, and attachments; technical records should be protected according to authority because they reveal path locations and system dependencies.

6.64 Heavy construction measurement: reference frames, sensor coupling, and low-frequency noise

Concrete, grouted masonry, stone, and composite slabs can carry structure-borne energy with very small local acceleration; their high mass and stiffness often move the diagnostically important response towards low frequencies, where accelerometer sensitivity, integration drift, building sway, traffic, lifts, wind, and thermal movement complicate interpretation. A visually quiet trace is not necessarily an absent path; the measurement chain must be selected for the expected velocity, displacement, and frequency range rather than copied from a lightweight-panel survey.[305]

Sensor mounting is part of the boundary condition; a magnetic base may be impossible on masonry and can introduce a compliant adaptor on steel reinforcement covers; wax, adhesive pads, threaded studs, and temporary clamps have different stiffness, mass, repeatability, and removal risks. A hand-held probe is rarely adequate for low-level phase or mobility work; the report should identify the mount, preparation, cure time, orientation, cable restraint, and surface condition. Where conservation constraints prohibit drilling or adhesive contact, laser vibrometry or a purpose-designed reversible fixture may be preferable.

305 MB-0863. International Organization for Standardization, ISO 16063-21:2003, JCGM 100:2008.

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The reference frame must also be explicit; acceleration normal to a wall differs from acceleration in a global building axis; a slab may move as a rigid body while a local panel mode is superimposed; rotational motion can create apparent translational differences between sensors at separated points. Multi-axis measurements, coordinate photographs, and a defined sign convention are required before a transfer function is assembled. For large structures, a common optical or geodetic reference may help distinguish local deformation from overall settlement or sway.

Low-frequency integration requires particular care. Converting acceleration to velocity or displacement amplifies offset, bias drift, and tilt sensitivity; high-pass filtering can suppress these errors but can also remove the phenomenon of interest; the filter corner, order, phase response, and initial conditions should be stated. A parallel velocity transducer, geophone, or displacement sensor can provide an independent check; agreement over an overlapping band is stronger evidence than a long double integration from one accelerometer.

Ambient excitation can be both useful and confounding; traffic, plant, wind, footsteps, lifts, and distant machinery may provide broadband or tonal input without intrusive testing. Operational modal analysis can exploit such input when its statistical assumptions are reasonable; yet an unknown source distribution prevents a simple transfer interpretation; a controlled impact or shaker test may be required to identify mobility, while the ambient record establishes operational relevance; the two data sets answer different questions and should not be collapsed.[306]

306 MB-0863. International Organization for Standardization, ISO 16063-21:2003, JCGM 100:2008.

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Heavy structural paths are frequently spatially extended; measuring one point beside a suspected junction may miss a mode shape or nodal line; a grid should include the source region, junction, receiving element, and plausible parallel routes; the spacing should follow wavelength and structural complexity, not architectural convenience. If only a sparse survey is possible, the conclusion should be bounded to the observed coordinates and should not describe the entire wall or slab.

Concrete and masonry also exhibit local discontinuities; cracks, control joints, bond beams, hollow cores, grout variations, reinforcement, embedded conduits, and finishes change local stiffness and damping; a transfer path can be strong through a bond beam while weak through the adjacent field of block. Non-destructive information, drawings, construction photographs, and controlled openings can explain a spatial anomaly; the acoustic investigator should not infer concealed construction solely from a vibration map when several internal configurations could produce the same response.

A practical test sequence begins with sensor self-noise and mounting checks on a quiet reference mass, followed by operational background, controlled excitation, and repeated remounting at selected coordinates; coherence, phase, mobility, and spatial pattern are reviewed together. A result that disappears after remounting is an instrumentation finding; a result that follows operating speed but not controlled force may indicate source-state dependence; a result reproduced by independent sensors and predicted by the structural model supports a physical path.

The report should distinguish the limits of detection from the absence of transmission. It should identify frequency bands obscured by sensor noise

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or ambient motion, the effect of filtering, and any coordinate where mounting was unreliable; if the intended security conclusion depends upon a low-frequency path below the demonstrated measurement floor, additional instrumentation or a different method is required. A low-noise plot is not evidence merely because it is visually calm.[307]

307 MB-0863. International Organization for Standardization, ISO 16063-21:2003, JCGM 100:2008.

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6.65 Chapter 6 glossary

Blocked force. The interface force a source would exert if motion at the interface were constrained, used as a receiver-independent source descriptor under stated assumptions.

Driving-point mobility. The complex ratio of velocity to force measured at the same coordinate.

Flexural wave. A bending wave whose speed depends upon frequency and the bending stiffness and mass of the element.

Modal overlap factor. A measure comparing modal bandwidth with modal spacing, indicating the degree to which resonances overlap.

Operational deflection shape. The spatial pattern of motion at an operating frequency, which need not be a normal mode.

Transfer mobility. The complex velocity response at one coordinate per unit force at another coordinate.

Vibration reduction index. A standardised junction quantity used in building-acoustic flanking analysis under the applicable method.

Structure-borne transmission is governed by forces, mobilities, wave propagation, junctions, damping, radiation, and operational state. Distributed behaviour, multiple wave types, rotations, and correlated paths limit simple lumped interpretations. Measurement must preserve amplitude, phase, coordinates, mounting, calibration, and source state.

The most reliable diagnosis combines a physical path model with controlled experiments. Mobility and blocked-force concepts characterise source and receiver. ISO flanking frameworks support standardised relationships where

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their scope is met. Accelerometers and laser vibrometry reveal motion, while pressure and intensity measurements connect motion to receiving exposure. Models require independent validation and explicit uncertainty.

Isolation systems must be treated as complete six-degree assemblies with services, restraints, clearances, and lifecycle controls. A single bridge can defeat an otherwise sophisticated shell. Chapter 7 turns from the structure to the human source and receiving environment, where speech variability and room response determine whether transmitted energy carries recoverable information.

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Chapter 7. Room Acoustics, Human Speech, Vocal Effort, and Information-Bearing Energy

7.1 Speech as a variable engineering source

Human speech is not a stationary broadband noise source. It is a time-varying, directional, spectrally structured signal whose level and content depend upon talker, language, vocal effort, posture, emotion, room response, listener distance, and communication task. Acoustic-security design therefore requires a source model that is explicit enough to be reproduced and conservative enough for the intended use.[308]

Long-term speech spectra describe average energy over connected speech; they do not reproduce every consonantal burst, vowel peak, pause, or orientation; maximum vocal effort is not a universal sound-power value; some occupants speak quietly, while others can sustain substantially greater levels. Amplified conference systems can exceed ordinary unaided speech and can direct energy towards doors, glazing, or ducts. The source state should be selected by the owner or competent authority and recorded in the basis of design.

A speech source description should include reference distance or power, frequency bands, time weighting, crest factor, directivity, source height, orientation, and operating duration; where a calibrated loudspeaker surrogate is used, its equalisation, directivity, distortion, and limiting behaviour must be stated. Human trials may supplement the surrogate, but they introduce variability and privacy considerations.

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7.2 Vocal effort and spectral redistribution

As vocal effort increases, overall level rises and the spectrum changes. Higher bands can increase differently from lower bands, articulation can change, and phonation may become less sustainable. A fixed broadband increase applied to one reference spectrum is therefore an approximation. It can be useful for design sensitivity if the limitation is disclosed.[309]

Speech levels should not be confused across descriptors; a level at one metre in front of a talker, a diffuse room-average level, and a sound-power level are different quantities; converting between them requires a field model and directivity. A near-field measurement can be affected by mouth geometry and microphone position; published spectra should be checked for gender or population, language, effort category, and reference convention.

For protected conversations, occasional names, numbers, commands, and short emphatic statements may govern risk even when average conversation is moderate; the source model should therefore consider percentile level and short-term peaks, not only a ten-minute average; if a design claims containment for “normal speech”, that term must be operationally defined.

Worked example 7.1. Effect of vocal-effort uncertainty

Suppose a receiving position is predicted to have a speech-to-background ratio of minus 8 dB using a nominal source; if credible talker variability is plus or minus 5 dB and background variability is plus or minus 3 dB, the favourable combination gives minus 16 dB, while the adverse combination

309 MB-0780. Heinrich Kuttruff, Room Acoustics.

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gives 0 dB. The nominal result alone is not robust; a probabilistic or bounded assessment should carry both source and background distributions.

7.3 The Lombard response and behavioural feedback

People tend to raise vocal effort when background noise increases or communication becomes difficult. This Lombard response creates feedback between masking, room acoustics, and source level. Raising room background by 6 dB does not necessarily improve privacy by 6 dB if occupants respond by speaking 2 or 3 dB louder.[310]

The response varies with individual, task, spectrum, duration, and whether the talker can hear their own voice and the listener; poor reverberation or inadequate electroacoustic coverage can prompt louder speech even at modest background; a well-designed room should support effortless internal communication before masking is used as a privacy control.

Operational testing can compare representative talker levels under several background states using neutral reading material; the study should avoid recording sensitive content and should not imply that a small sample defines all occupants; a design margin can accommodate behavioural uncertainty. Where operating procedures limit loudspeaker levels or vocal conditions, those controls require governance and verification.

7.4 Speech directivity and source orientation

The mouth, head, and torso create frequency-dependent directivity. Forward radiation generally becomes more pronounced at higher frequencies. Turning the head can therefore change the energy incident on a nearby

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door or window and the speech spectrum reaching a remote listener. A talker facing a weak element may produce a more adverse condition than the room-average source field.[311]

Source positions should be chosen from the actual seating and technology plan; a chair beside glazing, a lectern facing the entrance, a wall-mounted display with integrated loudspeakers, and a speakerphone on a conference table create different exposures. The test schedule should include credible orientations rather than one convenient central position.

Directivity also affects calibration of a surrogate source; an omnidirectional dodecahedron is appropriate for many room-acoustic measurements but does not reproduce talker directivity; a directional loudspeaker can represent certain operational states, but its polar response and level must be documented. The source is a model of a use case, not a universal substitute for speech.

7.5 Temporal structure and information-bearing events

Speech carries information through spectral shape, amplitude modulation, timing, and transitions. Vowels provide sustained energy, while consonants often contain brief bursts or frication. Reverberation and noise can smear modulation, but isolated words can remain recognisable even when a long-term average suggests poor audibility.[312]

The analysis interval matters. A slow equivalent level can conceal short peaks; fast or time-resolved band levels reveal transient exposure; intelligibility metrics use different integration and modulation principles; a

311 MB-0236. ASTM International, ASTM E2638-24.
312 MB-0800. International Electrotechnical Commission, IEC 60268-16:2020.

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privacy conclusion should specify whether it concerns continuous discourse, isolated words, repeated material, or occasional high-value utterances.

Recording and repeated listening can improve recovery relative to a casual real-time listener; signal processing may reveal patterns below immediate audibility, though its capability depends on signal-to-noise ratio, stationarity, and prior information; public-source engineering should not make categorical claims about every adversarial method. It should state the tested listener and processing conditions and retain an appropriate margin.

7.6 Room modes and low-frequency spatial variation

A rectangular room has modal frequencies approximated by

Equation 7.1

$$f_{n_x n_y n_z} = \frac{c}{2}\sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2 + \left(\frac{n_z}{L_z}\right)^2},$$

where L_x, L_y, and L_z are room dimensions and the indices are non-negative integers not all zero. Real rooms depart from rigid rectangular boundaries, but the relation demonstrates why low-frequency fields are spatially non-uniform.[313]

Source and receiver positions couple differently to each mode; a position at a nodal surface can miss a resonance, while a corner often exhibits strong pressure for several modes; spatial averaging is necessary for standardised room quantities, whereas local accessible positions must be retained for privacy analysis.

313 MB-0779. Heinrich Kuttruff, ISO 3382-2:2008, ASTM E2235-04.

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Modal damping depends upon boundary absorption, leakage, furnishings, and coupling to adjoining spaces; a door opening changes the modal field and background simultaneously; occupancy adds low- and mid-frequency absorption; acceptance testing should use the intended furnished and service state, or the difference should be bounded.

Worked example 7.2. Lowest axial modes

For a room 6.0 m by 4.5 m by 3.0 m with $c = 343$ m/s, the first axial frequencies are

$$f_{100} = 343/(2 \times 6.0) = 28.6\,Hz,$$

$$f_{010} = 343/(2 \times 4.5) = 38.1\,Hz,$$

$$f_{001} = 343/(2 \times 3.0) = 57.2\,Hz.$$

These modes lie below much of the speech-information range but can affect amplified systems, mechanical noise, and low-frequency measurement stability. Higher combinations populate the speech bands increasingly densely.

7.7 Modal transition and statistical room behaviour

As frequency rises, modal density and overlap increase. Above a transition region, statistical room-acoustic relations become more useful. A widely used estimate of the Schroeder frequency is

Equation 7.2

$$f_s \approx 2000\sqrt{\frac{T_{60}}{V}},$$

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where T_{60} is reverberation time in seconds and V is room volume in cubic metres. The coefficient depends upon convention and the estimate should not be treated as a sharp boundary.[314]

Below the transition, deterministic positions and individual modes dominate; above it, spatially averaged energy models become more plausible, although source directivity, local absorption, and non-diffuse geometry remain relevant; small secure rooms can retain substantial spatial variation well into speech-relevant bands.

The estimate supports method selection. A low-frequency test may need many source and receiver configurations or deterministic modelling. A mid- or high-frequency room-average can use statistical concepts. No single microphone position represents both regimes.

7.8 Reverberation time and equivalent absorption

Reverberation time describes decay after a source stops under a specified method and band. In a diffuse-field approximation, Sabine's relation is

Equation 7.3

$$T_{60} = 0.161 \frac{V}{A},$$

where A is equivalent absorption area in square metres sabin for SI units. The relation assumes diffuse energy and modest average absorption. Eyring-type expressions can be more appropriate at higher absorption.[315]

Reverberation affects internal communication, source behaviour, room-average levels, and receiving-room corrections in sound-insulation tests;

314 MB-0800. International Electrotechnical Commission, IEC 60268-16:2020.
315 MB-0779. Heinrich Kuttruff, ISO 3382-2:2008, ASTM E2235-04.

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lower reverberation can reduce average source-room boundary excitation for the same source power, while improving speech clarity and potentially reducing vocal effort; it does not change the intrinsic transmission loss of the wall specimen.

Absorption must be frequency-resolved. A thin porous panel may control high frequencies while leaving low bands reverberant; furniture and occupants alter the occupied condition; a room designed solely for a target mid-frequency reverberation time can still have problematic low-frequency modal decay or flutter echoes.

Worked example 7.3. Required absorption area

A 150 m³ room is intended to have $T_{60}=0.50$ s. Sabine's equation gives

$$A=0.161\,V/T_{60}=0.161\,(150)/0.50=48.3\,m^2\,sabin.$$

If existing finishes provide 22 m² sabin in the band, an additional 26.3 m² sabin is required under the approximation; product area will differ from equivalent absorption area and depends on mounting and frequency.

7.9 Direct, early-reflected, and late energy

A listener receives direct sound, early reflections, and later reverberant energy. Early reflections can support intelligibility when they arrive promptly and with favourable direction. Late energy smears temporal modulation. The balance depends upon source-receiver geometry, absorption, diffusion, and room volume.[316]

Inside the protected room, useful early energy can reduce the need for high vocal effort; outside, a local direct leakage path can dominate even when the

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receiving room is reverberant; a duct grille, door undercut, or wall crack can create a directional component that spatial averages dilute. Privacy assessment should therefore include both standardised averages and accessible local positions.

Impulse-response measurements separate arrival time and can identify paths by delay and direction; interpretation requires sufficient dynamic range and source bandwidth; windowing an impulse response can isolate early components but changes frequency resolution; the processing and reference time must be retained.

7.10 Speech intelligibility metrics and their limits

Speech Transmission Index, Speech Intelligibility Index, articulation measures, and word tests address related but distinct propositions. STI evaluates modulation transfer across frequency bands under a specified method. SII estimates the proportion of speech information available through band audibility and importance. Subjective tests measure performance for a population, vocabulary, language, and procedure.[317]

A metric should be selected for its scope; STI is widely used for communication quality, but a low value at one point does not establish that no isolated information can be recovered; SII depends upon source spectra, background, hearing assumptions, and masking; word-test results depend on familiarity and learning. ASTM E2638 provides an objective method specifically oriented towards speech privacy of enclosed rooms, with defined assumptions and terminology.[318]

317 MB-0800. International Electrotechnical Commission, IEC 60268-16:2020.
318 MB-0800. International Electrotechnical Commission, IEC 60268-16:2020.

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Results should be reported by position and state before reduction to a room conclusion; the installed communication system, automatic gain control, codecs, beamforming, and noise suppression can affect test signals differently from natural speech; direct and electroacoustic paths may require separate tests.

7.11 Background noise, masking, and spectral margin

Privacy depends upon the relation between transmitted speech and receiving background, not passive isolation alone. Background can arise from HVAC, exterior noise, occupied activity, and deliberate masking. Its spectrum, spatial uniformity, temporal stability, and tonal content determine effectiveness.[319]

A masking system should not be specified by overall A-weighted level alone; speech bands require appropriate spectral coverage; excessive high-frequency masking can be objectionable without controlling low-frequency audibility; tonal or modulated components can attract attention. Spatial hot and cold spots create unequal privacy and comfort.

Background may be quieter at night, during unoccupied periods, or when ventilation is reduced; a room secure during daytime operation can become vulnerable in a quiet maintenance state; the acceptance matrix should include governing low-background conditions and state whether masking is a required control. Loss of masking power should trigger an operational response if privacy depends upon it.

319 MB-0236. ASTM International, ASTM E2638-24.

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Worked example 7.4. Bandwise masking margin

At one listener position, transmitted speech band levels are 27, 25, 20, and 16 dB for four consecutive bands; background levels are 31, 27, 18, and 17 dB; speech-to-background margins are minus 4, minus 2, plus 2, and minus 1 dB. The third band remains exposed despite the background having a higher broadband sum; improving only the first band would not address the governing information path.

7.12 Source protocol, listener access, and evidentiary restraint

A defensible speech-security test defines source material, source position, orientation, level, spectrum, temporal characteristics, equipment state, receiving positions, background, listener assumptions, and processing. The protocol should include adverse credible conditions rather than only convenient central averages.[320]

Listener access is a spatial and institutional variable; a public corridor, neighbouring office, ceiling void, service shaft, exterior ledge, or controlled technical space presents different opportunities and constraints; the room boundary alone does not define the receiving region. The threat and authority determine which positions require assessment.

Human listening tests require ethical and privacy safeguards; neutral standard material should be used; participants, language, hearing status, training, and scoring should be documented; recordings must not contain actual sensitive conversations. Instrumental metrics can reduce exposure to human variability but cannot erase their own assumptions.

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A conclusion should be bounded. “Under the documented source, background, access positions, and measurement method, connected speech was below the stated objective” is defensible; “the room is impossible to overhear” is not; formal approval remains the decision of the competent authority, supported but not replaced by acoustic evidence.

7.12.1 Calibrated speech surrogates

A speech surrogate should reproduce the quantity relevant to the test; a source used for field sound insulation may need stable broadband energy and room excitation; a source used for intelligibility should preserve modulation and speech-like spectrum. A source used for local boundary exposure should have appropriate directivity. No single loudspeaker configuration satisfies every purpose.[321]

Calibration begins with electrical and acoustic limits; the source should remain linear over the operating range, with distortion and limiter state recorded; equalisation can create the desired spectrum at a reference position, but room interaction changes it elsewhere. A sound-power calibration or free-field reference can improve transferability; the exact waveform, file hash, playback gain, channel, loudspeaker orientation, and mounting should be retained.

Speech-shaped noise supports spectral audibility studies but lacks linguistic modulation. Modulated test signals support STI. Recorded speech supports realism but introduces content, talker, and privacy issues; a protocol can use several source classes, provided the conclusion identifies which one supports each proposition.

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7.12.2 Electroacoustic systems as variable sources

Conference bars, ceiling loudspeakers, telepresence systems, and assistive listening devices can produce the highest sustained room source. Their automatic gain control, echo cancellation, beamforming, noise reduction, equalisation, and remote updates make source state software-dependent.[322]

A system should be tested in normal, maximum authorised, fault, and maintenance states where relevant; muting a microphone does not necessarily mute every loudspeaker path; remote participants, alert tones, playback, and diagnostic modes can excite the room. The equipment inventory should include firmware, settings, network control, and maximum permitted level.

Distributed loudspeakers can reduce local level by improving coverage, but they may place sources close to boundaries or ceiling plenums; a table device can point directly towards a door; the acoustic design and audiovisual design should therefore be coordinated before equipment locations are fixed.

7.12.3 Time-varying backgrounds and operating-state matrices

A single background spectrum does not describe a building. HVAC stages, occupancy, traffic, rain, lifts, generators, and masking create time-dependent states. The lowest credible background can govern privacy because transmitted speech remains while masking falls.[323]

An operating-state matrix should include occupied normal, unoccupied, night, emergency power, reduced ventilation, maintenance, masking fault, and nearby-room use where applicable; each state receives source

322 MB-0800. International Electrotechnical Commission, IEC 60268-16:2020.
323 MB-0236. ASTM International, ASTM E2638-24.

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assumptions, accessible receiver positions, and acceptance consequences; not every state requires a full test, but exclusions should be justified.

Percentile spectra and time histories distinguish stable background from intermittent events. An L_{90}-type statistic can describe a lower background, while L_{eq} describes energy average. Tonal and modulated components require separate treatment. Averaging a loud intermittent event into a quiet period can give a misleading privacy benefit.

7.12.4 Multi-position decision logic

A room privacy conclusion must address the distribution of accessible listener positions. Averaging all points can hide one local leak. Requiring every arbitrary point to satisfy the same criterion can be impractical if some positions are inaccessible or not part of the threat model. The position schedule should therefore be derived from access, path geometry, and authority.[324]

Results can be organised into required positions, diagnostic positions, and surveillance positions. Required positions govern acceptance. Diagnostic positions help locate mechanisms. Surveillance positions support later monitoring. Each should be labelled so that a severe diagnostic reading inside a locked service cavity is not confused with a public corridor result, and a corridor hotspot is not diluted by room averages.

A conservative decision rule may require all required positions and source states to conform, subject to measurement uncertainty; another authority may permit risk-weighted treatment; the rule should be agreed before

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testing; retesting only failed points after an intervention should include control points to detect global change.

7.12.5 Human listening, recording, and repeat exposure

Instrumental metrics do not reproduce every listener. Human tests can provide direct evidence but require a controlled corpus, scoring method, listener selection, training, presentation level, and statistical plan. Familiar words, names, and repeated phrases are easier to recognise than arbitrary material.[325]

Real-time audibility differs from recorded analysis. Repeated listening, visual spectrograms, and prior knowledge can improve recovery; a public engineering report should state whether recording was permitted and what processing was used; it should not claim immunity against unspecified future processing.

Privacy and ethics are central. Actual protected conversation should never be used as test material; neutral balanced word lists or standard passages should be employed; recordings should be controlled, minimised, and destroyed or retained according to authority and evidence needs.

7.12.6 Operational controls and residual risk

Architecture alone cannot govern every source state. Operational controls may limit loudspeaker output, prohibit certain devices, require masking operation, control adjoining-room access, or suspend sensitive discussion during maintenance. Such controls are valid only if they are documented, practicable, monitored, and incorporated into accreditation or organisational procedures.[326]

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326 MB-0779. Heinrich Kuttruff, ISO 3382-2:2008, ASTM E2235-04.

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Reliance on behaviour should be visible in the risk statement; a room that meets its objective only when occupants whisper is not equivalent to one that contains maximum authorised speech; a room that depends on active masking requires alarm, maintenance, and fail-state provisions. A door-dependent design requires closure and seal inspection.

Residual risk should identify the source states, positions, and paths not demonstrated; it should distinguish lack of evidence from evidence of failure; the final engineering conclusion supports a competent authority's decision but does not replace it.

7.12.7 Spectral importance and uneven margins

Speech bands do not contribute equally to intelligibility. Low frequencies carry energy and voicing, while mid and high bands often carry consonantal distinctions. A design that provides an excellent overall level difference but a weak band near a high importance region can permit more information than the broadband number suggests.[327]

Band importance depends on metric, speech material, and listener; the analysis should preserve the full transmitted spectrum and receiving background; weighting by a standard intelligibility model is preferable to invented factors, but the standard's population and signal assumptions must remain visible.

Worked example 7.5. Weighted audibility score

Consider four bands with importance weights 0.10, 0.30, 0.35, and 0.25. Suppose audibility factors are 0, 0.2, 0.8, and 0.4. A simplified score is

$$0.10(0)+0.30(0.2)+0.35(0.8)+0.25(0.4)=0.44\,.$$

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The example shows how one exposed high-importance band controls the result. It is not a substitute for the complete ANSI/ASA S3.5 SII calculation.

7.12.8 Interior treatment and source control

Interior absorption is often discussed only as comfort. It also affects source behaviour and boundary exposure. A highly reverberant room raises average level for a given source power, reduces clarity, and can encourage greater vocal effort. Strategic absorption can lower late energy while preserving useful early reflections.[328]

Treatment location matters. Absorption near a weak wall can reduce incident reverberant energy, but it does not change the wall's transmission loss; a suspended absorber can create a ceiling-plenum path if the partition does not continue to structure. Fabric systems can conceal penetrations. Fire and maintenance requirements must be integrated.

Diffusion and scattering can reduce flutter and spatial extremes, but they can also redirect energy; a visual interior design should not be assumed acoustically neutral; acceptance should use the furnished state or quantify the difference from the final fit-out.

7.12.9 Masking-system calibration and governance

A masking system requires spectral equalisation, spatial commissioning, level limits, and stability monitoring. Loudspeakers should be arranged to avoid local hotspots and audible localisation. The system's control network, power supply, schedules, and fault reporting are part of the privacy architecture.[329]

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Calibration should use multiple positions and one-third-octave bands. Overall level alone is inadequate. Changes to ceiling tiles, furniture, partitions, and HVAC can alter the field; periodic verification should compare against the accepted baseline; a system that silently fails can leave occupants relying on a control that no longer exists.

Masking must not be represented as passive isolation; its benefit vanishes if power is lost or level is reduced; it may also affect comfort, communication, and the Lombard response; the residual-risk statement should identify those dependencies.

7.12.10 Privacy maps and decision surfaces

A spatial privacy map combines source states, path response, background, and listener access. The map should use measured or validated values, show uncertainty, and distinguish interpolated from observed regions. Colour scales must not exaggerate small differences or conceal censored data.[330]

Several maps may be needed for different talker positions, orientations, and building states. A worst-case envelope can identify governing points, while individual maps preserve mechanism. Averaging maps across incompatible states is misleading.

The acceptance surface is not purely acoustic; a technically accessible service void may be protected by access control; a public corridor is not; the map should therefore be read with physical-security and operational information; formal approval remains with the authority responsible for the complete risk.

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7.12.11 Audibility, recognition, and intelligibility

Audibility means that a listener detects a sound. Recognition means identifying its class or a feature. Intelligibility concerns understanding linguistic content. These are different thresholds. A listener may hear that someone is speaking without recovering words, or recognise a familiar name from a fragment when connected discourse remains unintelligible.[331]

Privacy objectives should name the outcome. A clinical consultation may require that ordinary speech content not be intelligible in a corridor; a classified-discussion authority may apply a different criterion and operational controls; an engineering report should not substitute one term for another merely because the measurement returned a low level.

Psychoacoustic detection depends on temporal and spectral masking, listener attention, hearing, and expectation; instrumental signal-to-noise ratio is evidence, not a complete perceptual conclusion; human testing or a validated metric may be needed where the distinction controls acceptance.

7.12.12 Language, semantic redundancy, and prior knowledge

Speech recovery is influenced by language, vocabulary, context, and repetition. Technical jargon, names, numbers, and expected phrases can be recognised with less acoustic information than unfamiliar material. Conversely, an unfamiliar language can reduce recognition for one listener without reducing the physical transmission.[332]

A standard test corpus should be documented and balanced; it should not contain actual project names or sensitive terms; results should not be generalised across languages or listener populations without evidence;

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where the use case includes multilingual discussion, the source and validation plan should reflect that diversity.

Semantic uncertainty reinforces the need for physical margin; a room should not rely on an assumption that a listener lacks context; the engineering task is to reduce the transmitted information-bearing signal under defined conditions; operational security addresses the remaining human and institutional factors.

7.12.13 Joint source-background distributions

Source level and background are not necessarily independent. Occupied periods can raise both speech and activity noise. Quiet night conditions can reduce background while limiting occupancy. HVAC demand can rise with room use. A privacy model that combines independent worst cases may be conservative, but the assumption should be stated.[333]

Joint scenario analysis is often clearer than one probability distribution; define credible states such as quiet unoccupied adjacent space with a loud meeting, normal occupied building, reduced ventilation, and masking fault. Calculate or measure each state. The governing state then has a physical description, not merely a statistical tail.

Where sufficient data exist, Monte Carlo analysis can sample source, background, path response, and position uncertainty. Correlations should be retained. The output can report probability of exceeding a metric under the assumed distributions, but it remains conditional and does not replace authority.

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7.12.14 Documentation of speech-security tests

The test record should identify source waveform and hash, loudspeaker or talker, reference level, spectrum, directivity, positions, orientations, background state, masking, room configuration, listener positions, instruments, metrics, processing, uncertainty, and limitations.[334]

Results should include frequency-resolved transmitted levels and backgrounds beneath any summary metric. Censored bands and unstable states should be visible. Audio examples, if retained, require access control and should use non-sensitive source material.

The conclusion should distinguish passive isolation, masking contribution, operational dependence, and formal approval; a future reader must be able to determine whether a changed loudspeaker level, removed masking system, or new listener access invalidates the original result.

The advanced sections that follow develop statistical source distributions, directivity maps, Lombard feedback, modulation transfer, STI and SII methodology, time-varying background, masking governance, electroacoustic systems, human-listener protocols, and multi-position privacy decisions.

7.13 Source-filter theory and the acoustic production of speech

Human speech is produced by an excitation source shaped by the resonances and radiation of the vocal tract. Voiced sounds begin with quasi-periodic glottal excitation, while many unvoiced consonants begin with turbulent airflow at constrictions; the vocal tract acts as a time-varying filter

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whose resonances, commonly described as formants, carry vowel and speaker information; radiation at the lips adds a frequency-dependent effect, and the head and torso shape directionality. This source-filter description is a model, but it explains why speech cannot be represented adequately by one broadband level.[335]

The fundamental frequency of voicing is not the same as the dominant frequency of intelligibility; a low fundamental can be strongly transmitted through a massive boundary while higher formants and consonantal energy are attenuated; the receiver may detect voicing, rhythm, or occupancy without understanding words. Conversely, modest energy in mid and upper bands can preserve articulation even when low-frequency level is reduced; a security assessment should distinguish audibility, detection of speech-like modulation, intelligibility, and comprehension.

Vocal-tract resonances move rapidly during connected speech; long-term average speech spectra smooth this variation and are useful for repeatable engineering calculations; they do not preserve phoneme sequence or short-time peaks; a speech-shaped noise source can reproduce average spectral energy but not natural modulation. A standardised speech transmission test signal can represent modulation more directly. The chosen source should match the metric and proposition.

A talker’s radiation varies with azimuth and elevation; high-frequency energy is generally stronger forward, while low frequencies are more nearly omnidirectional; the chest and room surfaces contribute reflections; seated posture, a table, laptop, mask, lectern, or telephone handset can change the

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field. These variations should be treated as source uncertainty or measured operational states rather than ignored.

7.14 Talker distributions and statistical source models

A secure room is used by populations, not by an idealised average talker. Vocal effort, sex, age, language, speaking style, emotional state, distance to listener, hearing needs, and room conditions all influence level and spectrum. A design source model should therefore use a distribution or several defined source states. One state may represent ordinary seated conversation, another formal presentation, another raised voice, and another installed amplification at controlled maximum setting.[336]

A probabilistic source model can express band level $L_{s,k}$ as a random variable with mean, variance, and covariance across bands. Covariance matters because a louder talker often raises several bands together. Treating each band as independent can produce unrealistic spectra. Empirical speech data or controlled measurements should support the distributions. Where public data do not cover the intended population, conservative bounded states may be preferable to invented precision.

Percentiles should be linked to design intent; a 95th-percentile source state may be appropriate where occasional loud speech must be contained, but the choice is an owner or authority decision; maximum vocal effort is not a stable universal number. It depends upon instruction, duration, and individual capacity; testing should use a repeatable electroacoustic surrogate if human variability would dominate, while supplemental human trials can assess behavioural realism under approved protocols.

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The source distribution interacts with receiving background; a probabilistic privacy model may integrate the probability that transmitted speech exceeds background or an intelligibility threshold; the result is conditional on both distributions and on listener access; it should not be interpreted as a timeless property of the wall. A quieter night-time background or louder future conference system changes the probability.

7.15 Directivity, seating geometry, and local boundary excitation

Conference-room geometry determines which elements receive the strongest speech exposure; a talker seated close to glazing and facing it can produce a local high-frequency incident field greater than the room average; a person at the centre may excite room modes differently; a lectern loudspeaker aimed towards doors can create a governing path that ordinary seated conversation does not. Seating plans and audiovisual layouts are therefore part of the acoustic-security design record.[337]

An operational source-position schedule should include representative seats, standing positions, lecterns, displays, and speakerphone locations; the number of positions follows room size and symmetry; positions adjacent to weak elements deserve priority; a source should be oriented in credible directions, including towards entrances and remote participants. The result can be presented as a sensitivity map rather than one averaged value.

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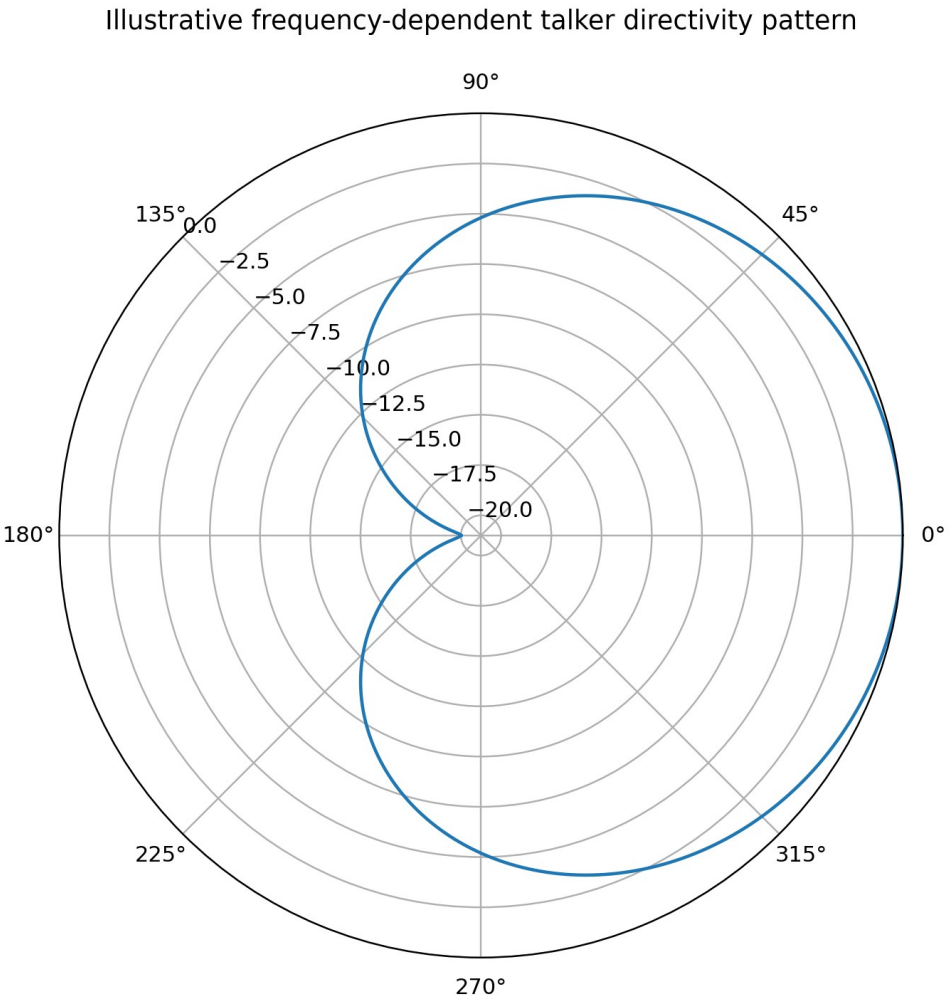

Figure 7-2. Illustrative talker directivity showing increased forward radiation. Author's original conceptual plot.

The figure is intentionally illustrative. Actual polar response depends upon talker, frequency, phoneme, posture, and measurement convention; its purpose is to show why orientation is a state variable; a real assessment should use measured source data or a defined surrogate.

Furniture changes both direct and reflected fields; a hard table can reinforce horizontal propagation; upholstered chairs and occupants add absorption. High-backed seating can scatter sound. A ceiling cloud may improve interior clarity but redirect energy; the design model should represent the furnished

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state expected at acceptance and identify whether later rearrangement requires review.

7.16 The Lombard response as a feedback mechanism

People tend to increase vocal effort when background sound rises or communication becomes difficult; this Lombard response is not a fixed gain. It varies among individuals and can include changes in spectrum, articulation, duration, and speaking rate; a masking system that raises background may therefore cause occupants to speak more loudly, offsetting part of its intended privacy benefit; interior room acoustics and communication quality influence the response.[338]

A simple engineering model might assume source level increases by a fraction of the background increase; such a coefficient should be treated as population- and condition-dependent; if background rises 6 dB and talker level rises 3 dB, the net improvement in speech-to-background ratio is only 3 dB, before considering spectral changes. If amplification or sidetone helps occupants hear themselves and each other, the behavioural response may differ.

The design should first support clear internal communication at moderate vocal effort through suitable reverberation, seating distance, and electroacoustic coverage; masking outside or around the protected room should be controlled so that it reduces listener signal-to-noise ratio without causing excessive source escalation inside. Where masking is inside the room, its purpose and behavioural effect need particular scrutiny.

338 MB-0010. Acoustical Society of America, ANSI/ASA S3.5-1997.

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Operational trials can measure representative talker levels under several background states; ethical and privacy controls should avoid recording sensitive content; standard reading material or calibrated voice surrogates can be used; the result should inform source-model uncertainty, not be used to prescribe how individuals must speak unless an authority adopts an operational procedure.

7.17 Modulation, consonantal transients, and information-bearing time structure

Speech intelligibility depends upon temporal modulation and spectral detail. Vowels provide sustained energy, while consonants often contain brief bursts, frication, or rapid transitions. A steady noise with the same long-term spectrum does not carry this structure. Transmission paths, reverberation, background, and signal processing can reduce modulation even when average level changes little.[339]

The modulation transfer function describes how amplitude modulation at various rates is preserved from source to receiver; reverberation and noise reduce modulation depth. The Speech Transmission Index derives from modulation transfer across bands using a defined model; it is useful for speech-transmission quality but its application to privacy or secure-speech assessment must respect method scope, source assumptions, and receiving conditions; IEC 60268-16 provides the current international method framework for STI.[340]

Speech Intelligibility Index methods use band importance, audibility, and masking relationships to estimate intelligibility-related information.

339 MB-0235. ASTM International, ASTM E2638-24.
340 MB-0940. ISO 3382-2:2008, ASTM E2235-04.

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ANSI/ASA S3.5 remains a principal reference for SII; SII and STI are not interchangeable; they treat temporal and spectral effects differently and have different test signals and assumptions; neither is a governmental accreditation criterion merely because it returns a numerical value.[341]

Short consonantal peaks can exceed a long-term average by substantial margins; if a privacy assessment uses only averaged source and background, it may understate occasional audibility; a time-resolved calculation or conservative source crest factor can address this. The report should identify whether the conclusion concerns average connected speech, isolated words, names and numbers, or worst credible utterances.

7.18 STI measurement scope and limitations

STI measurement requires a defined test signal, source position, receiver position, level, background, and system state. Direct STI uses modulated noise or equivalent signals across octave bands; indirect methods derive modulation transfer from an impulse response and noise; installed public-address systems, room acoustics, and communication channels are common applications; a secure-room receiving location may be far below ordinary speech levels, so instrument dynamic range and background stability become critical.[342]

An STI value at one point does not describe all accessible positions; room modes, local leaks, and background variation create spatial differences; multiple positions and operating states are required; if the test signal is injected through the installed conference system, the result includes that

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system. If a standard source is used, it may not represent installed loudspeakers or talker directivity. The reference plane should be stated.

STI can be affected by non-speech-like distortions, nonlinear processing, echo control, codecs, and time variance; modern conferencing systems may contain automatic gain control, noise suppression, beamforming, and dereverberation; a test signal can trigger these algorithms differently from speech. The system should be placed in a defined mode, and both electroacoustic and direct speech paths may need assessment.

For privacy, a low STI may support reduced intelligibility under the tested conditions. It does not prove that isolated information cannot be recovered by a trained listener, recording, repeated exposure, or signal processing. The conclusion should use the metric's intended interpretation and retain qualitative limitations. ASTM E2638 provides a separate objective method oriented to speech privacy of a closed room, with its own scope and assumptions.[343]

7.19 SII, audibility margins, and band importance

SII estimates the proportion of speech information available to a listener from band-specific speech level, noise, hearing threshold, masking, and importance functions. The method can illuminate why a few bands dominate an otherwise reassuring broadband result. It also provides a disciplined alternative to treating all one-third-octave bands equally.[344]

A simplified conceptual form is

Equation 7.4

343 MB-0788. IEC 60268-16:2020.
344 MB-0010. Acoustical Society of America, ANSI/ASA S3.5-1997.

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$$SII = \sum_k I_k A_k ,$$

where I_k is the importance weight for band k and A_k is an audibility function between zero and one. The actual standard method contains detailed level distortion, masking, and threshold provisions. The simple expression should not be used as a substitute for the standard calculation.

Input speech spectra must match vocal effort and reference; a free-field speech spectrum at one metre is not the same as a room-average source level; receiving noise should represent the listener position and time state; hearing ability may differ from the normative listener. A security analysis may need conservative assumptions, but those assumptions should be explicit.

SII is sensitive to bands near audibility threshold. Measurement uncertainty and background variation can change A_k substantially. Monte Carlo propagation or scenario analysis is useful. The output should be presented with inputs and uncertainty rather than one exact score. Formal acceptance remains separate.

7.20 Room modes, modal transition, and source-receiver variability

Below the region of dense modal overlap, room response is governed by discrete modes; their frequencies depend upon geometry, while amplitudes depend upon boundary absorption and source and receiver positions; a source at a pressure node couples weakly to a mode; at an antinode it couples strongly. A receiver experiences the same spatial sensitivity; small movements can change low-frequency level by many decibels.[345]

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The Schroeder-frequency estimate

Equation 7.5

$$f_s \approx 2000\sqrt{\frac{T_{60}}{V}}$$

with T_{60} in seconds and V in cubic metres provides an approximate transition between distinct modal and more statistically diffuse behaviour. It is not a hard boundary. Irregular rooms, coupled volumes, non-uniform absorption, and localised sources blur the transition.

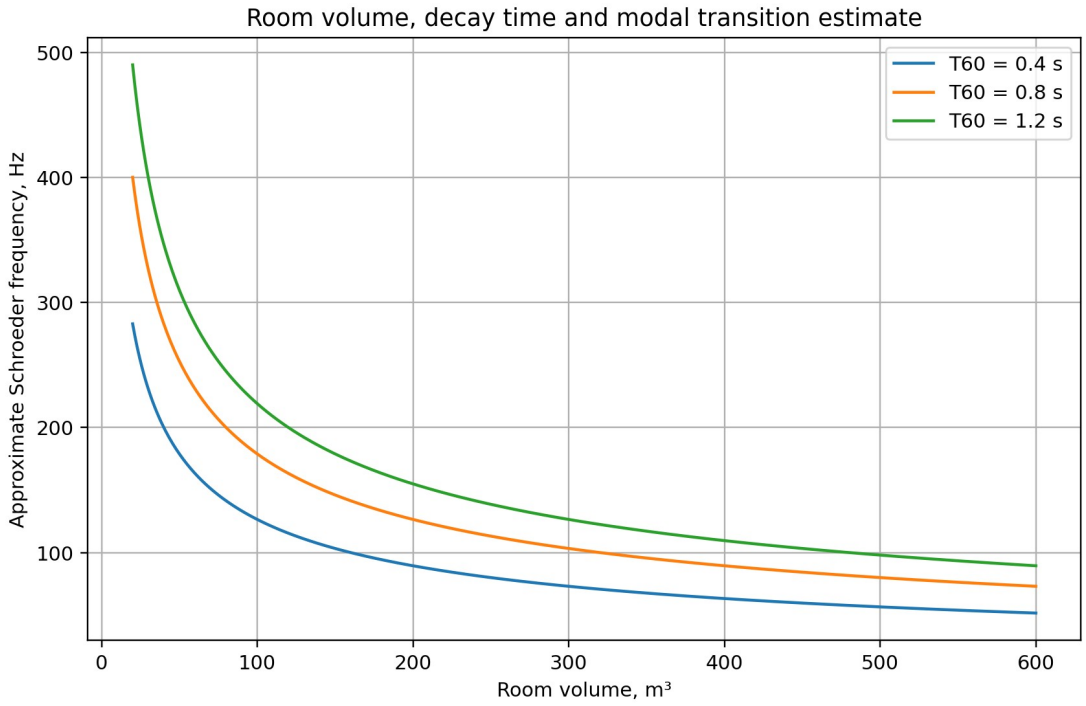

Figure 7-1. Approximate Schroeder frequency as a function of room volume and decay time. Author's original calculation.

A small, reverberant receiving space can have a high transition frequency, making one-third-octave averages less stable; ceiling voids and service cupboards are examples; testing should use multiple positions and, where standards permit, moving microphones or several source locations. Threat-

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informed points remain important because a listener may occupy a local maximum.

Modal analysis can also distinguish paths. A receiving peak that follows the room's modal pattern may arise from distributed radiation, while a local pressure concentration near a gap may show different spatial decay; time decay and source relocation provide further discrimination; the report should avoid assigning every peak to the wall without considering the receiving room.

7.21 Early reflections, late reverberation, and useful-to-detrimental energy

Speech clarity inside the protected room depends upon the balance between direct sound, early reflections, and late reverberant energy; early reflections within a suitable delay can support loudness and intelligibility; late reflections blur temporal detail and encourage increased vocal effort; the design objective is not maximum absorption. It is controlled decay, useful distribution, and suppression of harmful echoes while preserving acoustic comfort.[346]

Metrics such as clarity and definition can describe early-to-late energy ratios, but their relevance depends upon room use and source-receiver geometry; a boardroom, briefing theatre, and small interview room have different needs; secure-room interior design should be integrated with source containment. Absorptive treatment lowers reverberant build-up for a given source power, but hard finishes may be required for durability or security; treatments must not introduce concealed cavities, uncontrolled mounting points, or porous surfaces incompatible with the environment.

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A strong flutter echo between parallel surfaces can reduce communication quality without greatly changing T_{60}. Diffusion, angled surfaces, or selective absorption can address it. Large display walls and glazing are common sources. The treatment should not penetrate or bridge isolation assemblies. A heavy panel mounted through an independent lining into structural studs can create a new path.

Interior acoustics influence behaviour. If participants hear each other clearly, they may use lower vocal effort; if remote audio is uneven, some participants speak loudly; commissioning should therefore include coverage and room-response checks under occupied or representative furnishing conditions, alongside boundary tests.

7.22 Electroacoustic systems and algorithmic processing

Conference systems contain microphones, loudspeakers, digital signal processing, echo cancellation, automatic gain control, noise suppression, beamforming, codecs, and network interfaces. They can increase source level at boundaries and create unintended microphone paths. Their acoustic and security roles should be assessed together, with proper separation between public acoustic evidence and controlled technical-security requirements.[347]

Distributed ceiling loudspeakers can create a more uniform interior field but excite the ceiling and plenum; a soundbar near glazing can create local exposure. Table microphones and beamforming arrays can remain active or networked when not in use; speakerphones and displays can contain

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multiple transducers; the room state should define which systems are powered, muted, disconnected, or approved.

Automatic gain control changes source level according to input; a quiet talker may be amplified more than a loud one; echo cancellers inject or analyse test signals and adapt over time; noise suppression can alter standard STI or speech-shaped signals. Test protocols should include a controlled bypass or documented operational mode, plus the installed maximum setting credible under policy.

Remote codecs reduce and reconstruct speech using perceptual models; low-bitrate coding can remove information while preserving intelligibility, or produce artefacts that alter objective metrics; network delay and packet loss affect remote communication inside the room but may not change direct airborne leakage. The report should distinguish the acoustic source entering the room from the remote channel quality.

7.23 Receiving background as a distribution over time and access

Background sound is not one number. It varies by band, position, time, and operating state. A corridor may be loud during office hours and quiet at night. HVAC may cycle. Masking may be scheduled. Exterior traffic and weather vary. A receiving location inside a ceiling void or service riser can be much quieter than the occupied room below. The listener-access model determines which backgrounds matter.[348]

A monitoring programme can estimate distributions for each relevant state. Percentiles should be interpreted carefully. A low percentile may represent

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the quiet condition relevant to an adversary with patience, while a median describes typical use; if masking is an engineered control with supervision and alarms, its minimum compliant level may be credited. If it is incidental plant noise, it should not be treated as permanent protection.

Background spectra should be measured with the protected source absent or controlled; existing speech from other rooms can contaminate the record; tonal components can mask some bands poorly despite a high total level; time variation can create gaps between fan cycles. Short-time analysis reveals these windows.

The security conclusion should state the receiving background state. “Room provides privacy” is incomplete. A bounded statement might say that under the measured passive boundary and specified masking range, at defined accessible positions and source state, the objective metric met the decision criterion; that statement can be linked to monitoring and retest triggers.

7.24 Sound masking spectrum, uniformity, and system assurance

Sound masking raises background in selected bands to reduce speech-to-background ratio. It is not a substitute for adequate isolation because it can fail, drift, be disabled, or create behavioural effects. A robust design specifies spectrum, level range, spatial uniformity, temporal stability, zoning, controls, monitoring, and fault response. The room and adjoining spaces must be considered together.[349]

Masking spectra are usually shaped rather than white; excessive high-frequency energy can be objectionable, while excessive low-frequency

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energy consumes headroom and may propagate widely; the optimum depends upon speech spectrum, ambient environment, and comfort; a single A-weighted target is insufficient. One-third-octave commissioning data should be retained.

Uniformity should be assessed at a grid of occupied and accessible positions; a mean can hide quiet pockets; loudspeaker spacing, plenum conditions, ceiling absorption, partitions, and furniture affect distribution; direct-field and plenum systems behave differently. A system above a suspended ceiling can couple through the ceiling and shared plenum, so zoning and boundary design are critical.

System assurance includes calibration, locked controls, health monitoring, power resilience, and change management; a central controller may log level and faults, but independent field verification is needed; software updates and loudspeaker replacement can change spectrum; users should not have unrestricted adjustment if the system is credited as a security control. The authority should define alarm and response procedures.

7.25 Speech privacy probability and ASTM E2638 boundaries

ASTM E2638 provides an objective method for measuring the speech privacy afforded by a closed room under its stated conditions. The method relates room-to-room attenuation and receiving background to a privacy result. It is valuable because it connects construction and background to a listener-oriented outcome. Its scope and assumptions must be read carefully, and the result should not be relabelled as a governmental secure-room accreditation.[350]

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A probability framework recognises that speech level, listener conditions, and information content vary; the National Research Council Canada developed related approaches for rating speech privacy of enclosed rooms; such models can support design and comparison, but their input distributions and listener assumptions determine the output. A probability of intelligibility is not a guarantee that no word can ever be recovered.

The method should use the quietest relevant receiving locations and operating states defined by the threat model; door position, masking, HVAC, and furnishings must be recorded; if the room is tested with masking, the passive and active contributions should be separable. The result should include uncertainty and sensitivity to background.

A high privacy result may be appropriate for commercial confidentiality but still not satisfy a classified-use authority; conversely, an accredited facility may use controlled criteria not available in public sources; the manuscript should preserve this boundary and avoid inferring restricted thresholds.

7.26 Language, semantic context, and isolated critical information

Intelligibility tests often use standard words, sentences, or objective metrics; real protected speech contains names, numbers, acronyms, repeated topics, and contextual cues; a listener who knows the subject can infer information from fragments that would score poorly in a general word test; conversely, unfamiliar technical language may reduce comprehension. Security analysis should therefore avoid claiming that one score represents every content class.[351]

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Names and numbers can be especially consequential; they may be short, repeated, and distinguishable from rhythm or partial phonetic cues; a low average sentence score does not prove that a date, quantity, or surname cannot be recovered. The decision criterion should reflect the information risk defined by the authority.

Cross-language effects matter. A test corpus in one language may not represent phonetic distribution or listener expectation in another; objective metrics based on general speech importance remain useful, but validation and interpretation should acknowledge language; where the facility supports multilingual use, source spectra and content sensitivity may require broader assumptions.

No test should use actual classified or privileged content merely to be realistic. Standardised neutral material, speech-shaped signals, and approved phrases can provide evidence without exposing information. Recordings should be minimised and protected.

7.27 Listener access, duration, and assisted listening

A listener's opportunity depends upon location, distance, orientation, duration, and ability to use equipment. A passer-by in a corridor has a different opportunity from a person with prolonged authorised access to an adjoining office. A maintenance worker in a ceiling void, a device placed near a duct, or a recorder left overnight presents different receiving conditions. The threat model should identify credible access without drifting into unsupported operational speculation.[352]

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Duration improves the chance of encountering loud words, quiet background, or repeated information; a short commissioning sample may miss these states; long-term source and background distributions can inform risk; if access is tightly controlled and monitored, that control belongs to the security system but remains separate from acoustic isolation.

Assisted listening can include directional microphones, contact sensors, recording, filtering, and repeated playback; public acoustic testing need not reproduce every adversarial device, but it should avoid assuming an unaided listener when the threat model permits simple assistance. The authority determines the assessment boundary. Detailed site-specific vulnerabilities should be protected.

A receiving microphone used in testing should be positioned to represent the relevant access, not an arbitrary room centre; supplemental positions at doors, ducts, façades, service spaces, and structural surfaces may be necessary; the report should distinguish standardised positions from threat-informed ones.

7.28 Source protocol design and repeatability

A speech-security source protocol should state signal, spectrum, level, temporal structure, position, orientation, duration, and calibration. It should include pretest and post-test verification and define acceptable drift. If a human talker is used, the protocol should control distance, posture, text, vocal instruction, and repetitions, while recording source-room levels. Human trials are supplemental unless the method specifically requires them.[353]

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An electroacoustic surrogate can use speech-shaped noise, modulated test signals, or recorded standard speech; loudspeaker directivity and room interaction must be characterised; equalisation should aim at a defined field or reference point and should not conceal overload or excessive local level. The source chain, including file, player, interface, amplifier, loudspeaker, and limiter, should be documented.

Source level should be verified in each relevant band; a broadband setting can leave some bands too low for adequate receiving margin; if the source is increased to overcome background, linearity should be checked and operational relevance retained. The test should not drive rattles or nonlinearities absent in real use unless a separate diagnostic objective justifies it.

Repeatability is assessed through repeated runs, source repositioning, and stability checks. Variance should be reported. A protocol that returns substantially different results after a small source reset needs improved positioning or a wider uncertainty allowance.

7.29 Worked example: probabilistic receiving margin

Assume the source-room speech level in one band is normally distributed with mean 68 dB and standard deviation 3 dB; the measured apparent level difference is 48 dB with standard uncertainty 1.5 dB; receiving background is normally distributed with mean 23 dB and standard deviation 2 dB. For a first-order independent model, transmitted speech level has mean

$$\mu_{L_t} = 68 - 48 = 20\,dB$$

and standard deviation

$$\sigma_{L_t} = \sqrt{3^2 + 1.5^2} = 3.35\,dB.$$

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The speech-to-background margin $M = L_t - L_b$ has mean

$$\mu_M = 20 - 23 = -3\,dB$$

and standard deviation

$$\sigma_M = \sqrt{3.35^2 + 2^2} = 3.90\,dB.$$

If a simplified screening rule asks for the probability that $M > 0$, the standard normal value is $z = (0 - (-3))/3.90 = 0.77$. The upper-tail probability is about 0.22. This is not a probability of intelligibility. It is the probability that one band's instantaneous level exceeds background under assumed independent normal distributions. Band importance, temporal modulation, correlations, listener hearing, and multiple bands remain.

The example shows why a mean negative margin does not imply zero opportunity; it also shows the sensitivity to source and background variability; a deterministic calculation using only mean values would miss the upper tail; a real privacy model should use appropriate distributions and the governing standard or authority.

7.30 Door-operation transients and conversational exposure

Doors create both transmission paths and time-varying exposure. When a door opens, even briefly, passive isolation is replaced by an open acoustic connection. A sound lock reduces exposure only if door sequencing, vestibule absorption, access control, and user behaviour maintain separation. A room that performs well in steady closed-door testing can disclose speech during entry and exit.[354]

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The exposure depends upon opening duration, source activity, line of sight, vestibule geometry, and receiving access; a short opening during a loud utterance can dominate information risk despite negligible contribution to a long average; operational assessment should therefore include door cycles or procedural controls. The aim is not to calculate a universal “open-door rating,” but to identify whether the use pattern creates an unmitigated state.

Door closure also generates impact and seal noise; automatic bottoms engage, latches strike, and closers create vibration; these events can contaminate measurements and may trigger occupants to pause; in a test, door cycles should be marked. In operation, soft, reliable closing may improve both security and usability, provided seals fully engage.

A vestibule with absorptive finishes reduces reverberant build-up between leaves; if both doors are simultaneously open, the benefit collapses; interlocks may be appropriate in some contexts but must respect life safety and accessibility; the authority should define the operational control.

7.31 Multiple talkers, overlap, and collective vocal escalation

Meetings often contain several talkers, interruptions, laughter, and simultaneous speech; if sources are independent, their acoustic energies add. Two equally loud uncorrelated talkers raise average level by about 3 dB; four raise it by about 6 dB; overlap also changes temporal modulation and may reduce intelligibility for listeners inside and outside, but it can increase the chance that some information-bearing band exceeds background.[355]

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Collective meetings can produce vocal escalation. Participants speak over one another or compensate for distance; a single-talker source model may understate these states; an electroacoustic test can represent the aggregate spectrum and level, while scenario analysis can address overlap; the design should identify whether the room is intended for interviews, board meetings, briefings, or larger conferences.

Distributed source positions excite boundaries differently. Several talkers around a table create a more spatially diffuse source than one loudspeaker; a conference system may reinforce every seat through ceiling loudspeakers, increasing field uniformity and boundary exposure; testing should include the installed system and representative seating.

The privacy interpretation remains content-specific. Overlapping speech may reduce comprehension of each stream, yet names or numbers spoken clearly can still emerge. A conservative assessment should not assume that multi-talker babble always protects information.

7.32 Vocal effort monitoring without recording content

Source-state evidence can often be collected without retaining intelligible speech. One-third-octave levels, short-time overall levels, voice-activity indicators, and calibrated envelope statistics can characterise vocal effort while minimising content. Processing should occur under approved controls, and raw audio should be avoided if not necessary.[356]

A microphone inside the room can be positioned and calibrated to estimate room-average or local speech level; its signal may be processed in real time to store only levels and timestamps; the system’s privacy design should be

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reviewed because even temporary buffers or network transport can create records. A standalone instrument with controlled storage may be preferable.

Level-only data cannot distinguish every source or phonetic event; they are useful for validating assumed source distributions and identifying operational escalation; if a room consistently produces levels above design assumptions, interior acoustics, amplification, seating, or procedure should be reviewed. The result should not be used as covert personnel monitoring.

7.33 Interior acoustic design for moderate vocal effort

A secure room should permit participants to hear one another without raising their voices unnecessarily; appropriate reverberation, low internal noise, seating geometry, and electroacoustic coverage reduce effort; excessive absorption can make a room feel acoustically dead and encourage some talkers to project; excessive reverberation reduces clarity and encourages escalation. The optimum follows room volume and use.[357]

Ceiling treatment often supplies broad absorption, but secure construction may require a hard structural lid above; suspended absorptive ceilings can create plenums and service paths; the acoustical and security design should distinguish the interior finish from the isolation boundary. Wall panels should use controlled attachment details that do not bridge leaves or conceal uninspectable cavities.

Low internal mechanical noise improves communication but also reduces masking of speech inside the room; this is not necessarily adverse because the security boundary should contain sound; it illustrates why comfort

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criteria and receiving privacy are separate. Background outside the room, not merely inside, governs listener exposure.

A commissioning programme should measure decay, background, coverage, and source levels; occupied conditions or representative absorption should be used; a bare-room test before furniture can overstate reverberation and source levels; conversely, a fully occupied demonstration may understate the quiet unoccupied receiving condition.

7.34 Reverberation-time measurement and non-exponential decay

Reverberation time is commonly estimated from a decay curve over a specified range, extrapolated to 60 dB. Real rooms can show double-slope decay because of coupled volumes, non-uniform absorption, or hidden plenums. A single T_{60} value may conceal the early decay that affects speech and the late decay that indicates coupling.[358]

Impulse-response and interrupted-noise methods can be used under applicable standards. Source and receiver positions should sample the room. Background must permit an adequate decay range. Extrapolation from a short range increases sensitivity. The report should state whether T_{20}, T_{30}, early decay time, or another descriptor was used.

A coupled ceiling plenum may produce a late tail; a door recess or vestibule can create local decay; these features can also reveal leakage paths; decay analysis should therefore be inspected visually, not reduced automatically. If the slope changes, both regions and a physical explanation should be considered.

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7.35 Background noise criteria and their limited security meaning

Room Criteria, Noise Criteria, and related curves describe background-noise spectra for comfort and system design. They can help identify rumble, hiss, or tonal imbalance. They are not speech-security metrics. A room meeting a low background criterion may support excellent internal communication but reduce masking outside if adjoining spaces are equally quiet.[359]

The criterion should be named and applied according to its method; a single curve number can hide tonal components or low-frequency fluctuations; secure-room design should retain the spectrum and assess both source and receiving spaces; HVAC noise must be stable enough for comfort and any credited masking role, without speech-like modulation or excessive annoyance.

Where masking is intentional, it should be specified separately from incidental background; the operational minimum, not the commissioning average, governs; the system should be monitored if credited; a comfort criterion does not establish that minimum.

7.36 Exterior receiving positions and meteorological variability

Speech can leave through façades, roofs, windows, vents, and structural paths. Exterior assessment introduces wind, temperature gradients, traffic, wildlife, and changing ground reflection. Microphone windscreens and mounting affect results. A quiet exterior position at night can differ markedly from daytime conditions.[360]

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Source-to-exterior measurements should record weather and avoid conditions that invalidate the method; wind can generate microphone noise and change propagation; temperature gradients refract sound over longer distances; for near-façade positions, local leakage and reflection dominate, but the microphone should be placed and oriented consistently.

Access matters. A publicly accessible pavement, adjacent roof, courtyard, service ledge, or neighbouring window presents different opportunities. The assessment should remain within lawful public-source and site-authority boundaries. Detailed weak locations may require controlled reporting.

Façade elements often have different construction from internal partitions. Curtain-wall mullions, spandrels, trickle vents, and perimeter fire stopping require specific analysis. The direct wall rating does not describe them.

7.37 Hearing variability and conservative listener models

Listeners differ in hearing thresholds, language knowledge, attention, and training. A normative intelligibility metric represents a defined listener model, not every individual. Some listeners have hearing loss; others may use amplification or repeated playback. A security assessment should use the listener assumptions prescribed by the chosen method or authority and disclose them.[361]

Conservatism should be rational. Assuming perfect hearing, unlimited processing, and direct sensor access can produce an unrealistic worst case; assuming an unaided casual passer-by can understate risk; the threat model identifies credible access and capability; acoustic engineering supplies

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measurable transfer and receiving conditions; the authority selects the decision basis.

Listening tests require trained procedures, randomisation, sufficient material, and statistical analysis; they are vulnerable to learning and context; objective metrics are often preferable for routine engineering, with listening reserved for validation or specific questions; no listening test should use protected content.

7.38 Information classes and consequence-sensitive assessment

Not all conversations carry the same consequence. Commercial negotiation, medical consultation, legal privilege, diplomatic discussion, and classified briefing may require different authorities and risk tolerances. The acoustic physics is shared, but the decision criterion and record handling differ.[362]

A room may be suitable for ordinary confidentiality yet not authorised for classified use; the manuscript should avoid converting one jurisdiction's public terminology into another's accreditation category; the four-proposition model remains decisive: measured speech privacy is evidence, while formal authorisation is an institutional act.

Within one room, use can change. A space designed for routine meetings may later host sensitive briefings or amplified hybrid conferences; change management should review source levels, equipment, adjoining access, and authority; a label on a door does not update the construction.

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7.39 Training, user behaviour, and operational resilience

Users influence performance through door discipline, equipment settings, seating, vocal effort, and reporting of defects. Training should explain practical controls without disclosing unnecessary vulnerability detail. Users should know that doors must latch, masking faults must be reported, and unapproved devices or alterations require review.[363]

Training cannot compensate for defective construction. It should support a robust system, not demand unrealistic silence; procedures that are burdensome are more likely to be bypassed; sound locks, conference controls, and room booking should be designed for ordinary compliant use.

Maintenance staff and contractors require role-specific instruction; replacing a seal, drilling a wall, moving a loudspeaker, or adding a cable can change performance; permit and inspection processes should be clear; post-work testing should be proportionate to the change.

7.40 Worked example: source orientation and weakest-path margin

Assume a room-average source level at 2 kHz of 66 dB; a local directional increase of 5 dB occurs when a talker faces a glazed panel; the measured local source-to-receiver level difference through that path is 43 dB, and receiving background is 24 dB. The receiving speech level for the forward-facing state is

$$L_r = 66 + 5 - 43 = 28\,dB.$$

The band speech-to-background margin is therefore

$$M = 28 - 24 = +4\,dB.$$

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If the talker faces away and the local directional term is negative 3 dB, the predicted receiving level is 20 dB and the margin is negative 4 dB; the same construction produces an 8 dB range solely from orientation. A room-average test that does not capture the local source condition can miss the governing state.

This calculation does not determine intelligibility. It identifies a band and state that require an appropriate speech metric or remediation; uncertainty in directivity, level difference, and background should be propagated; the example supports source-position testing and operational layout review.

7.41 Chapter 7 evidence package

The chapter's methods require a source and receiver record: test signal, talker or loudspeaker, spectrum, level, directivity, position, orientation, temporal protocol, installed-system mode, room furnishings, decay, background distribution, microphone locations, listener-access assumptions, metric, uncertainty, and data-handling controls.[364]

Figures should preserve band values and time state; a single privacy score should link to its inputs; recordings, if any, should be minimised, encrypted, access-controlled, and disposed of according to authority. Neutral test material is preferred.

The report should state whether the result concerns detection, audibility, intelligibility, comprehension, probability of privacy, or formal acceptance. These terms should not be used interchangeably. The configuration and retest triggers should be explicit.

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7.42 Source sound-power and room-average speech level

A talker's acoustic power and the sound-pressure level observed in a room are related through room geometry, absorption, directivity, and distance; for a source in a reverberant enclosure, a common engineering expression combines direct and reverberant terms. It can be written conceptually as

Equation 7.6

$$L_p = L_W + 10\log_{10}\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right),$$

where L_W is source sound-power level, Q is directivity factor, r is source-receiver distance, and R is the room constant under the adopted formulation. The equation assumes a steady source and simplified field. It is not reliable in the modal region or very close to boundaries.[365]

The expression clarifies why the same talker produces different room levels. A small absorptive room can have lower reverberant build-up than a hard room. A receiver close to the talker sees a stronger direct term. A forward-facing direction changes Q. In a meeting, moving seats or adding absorption can alter boundary excitation even though talker power is unchanged.

Source power is difficult to measure for natural speech because the signal varies and the talker is not stationary; room-average level under a defined protocol is often more practical; the report should avoid converting it to power without a field model. An electroacoustic surrogate can be calibrated more readily, but directivity and modulation must be appropriate.

For design, several source states can be propagated through measured or predicted level differences; for testing, the source-room level should be

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measured simultaneously with receiving response; this avoids relying upon a nominal loudspeaker setting; source drift and room-state changes remain in the evidence record.

7.43 Privacy maps and spatial decision surfaces

A privacy map displays a metric or receiving margin across accessible positions. It can reveal quiet pockets, local leaks, and the effect of distance. The map should be based on a defined source state and background state. It should not mix measurements from different times or operating configurations without adjustment.[366]

The spatial grid should reflect threat access and acoustic variation; dense sampling is justified near doors, glazing, grilles, and junctions; wider sampling may suffice in diffuse regions; points should be shown on the map. Interpolation should not imply precision beyond the grid. A separate layer can show uncertainty or the range across source positions.

Decision surfaces can be probabilistic. At each point, the model may estimate the probability that a speech metric exceeds a criterion over source and background distributions; such maps are useful for comparing design options, but they are sensitive to assumptions; the publication should show representative inputs and not present the coloured boundary as a physical wall.

Maps can guide controlled zones. If a path is acceptable only beyond a distance, access control may supplement construction, subject to authority; the map should not be distributed more widely than necessary because it identifies relative vulnerabilities.

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7.44 Signal processing, enhancement, and evidentiary restraint

Recorded low-level speech-like signals can be filtered, averaged, beamformed, or enhanced. Processing may improve audibility, but it can also create artefacts and confirmation bias. A security assessment should specify the processing allowed by the threat model and preserve unprocessed data. Any enhanced demonstration should be accompanied by the exact algorithm and parameters.[367]

Linear filtering can improve signal-to-noise ratio when signal and noise occupy different bands; it cannot recover information that was never present above noise, though prior knowledge can make patterns seem meaningful; spectral subtraction and machine-learning enhancement can introduce speech-like artefacts. Their output should not be treated as verbatim evidence without validation on controlled material under comparable conditions.

Repeated utterances can be averaged if they are aligned and identical, improving uncorrelated noise; real protected speech is not repeated identically; a listener with prolonged access may benefit from context and repeated topics, but an engineering test should not assume coherent averaging of arbitrary conversation. Standardised repeated phrases can be used to assess a bounded capability.

Forensic audio principles require chain of custody, original-file preservation, processing logs, and clear distinction between enhancement for listening and quantitative measurement; the report should state whether any

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conclusion depends upon processed output or is supported by objective metrics.

7.45 Speech masking by non-stationary and informational backgrounds

Backgrounds differ in their masking effectiveness. Steady broadband noise masks through energetic overlap. Competing speech adds informational masking, which can reduce comprehension even when acoustic energy is similar. Music and intermittent machinery create time-frequency gaps. A single equivalent level cannot capture these differences.[368]

Engineered sound masking usually seeks a stable, unobtrusive spectrum rather than competing speech; its performance can be predicted more consistently; incidental office babble may provide strong masking at one moment and disappear the next; it should not be credited as a reliable control.

Temporal gaps matter. A modulated fan or cycling system may expose consonants during minima; short-time percentiles or modulation analysis can quantify fluctuation; if a masking system is credited, stability tolerances should limit these gaps; loudspeaker failures and zone imbalance should trigger alarms or inspections.

Informational masking should not be used to justify recording or broadcasting sensitive speech. Neutral masking signals are preferable. The metric and listener model should be chosen accordingly.

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7.46 Remote participation and hybrid conference states

Hybrid meetings introduce remote talkers, local loudspeakers, microphones, echo cancellation, and varying participant behaviour. Remote speech can be reproduced at levels higher than local conversation, particularly when users increase volume. Loudspeakers may be close to boundaries. The installed maximum and normal approved settings should be included in the source-state matrix.[369]

Remote participants can also cause local speakers to raise voices because of latency, poor intelligibility, or weak sidetone; the system’s automatic gain and noise suppression change during operation; testing should include representative calls or a controlled emulator, with network and software state recorded. A local test file played directly into the loudspeaker may bypass codec and control behaviour.

Microphone mute indicators do not necessarily remove power from all transducers; the technical-security review of devices is separate from acoustic isolation, but the room’s approved operating state should be clear; unapproved personal devices can alter both source and collection conditions.

The acoustical evidence should report local sound levels and spatial distribution. Network security and device accreditation remain separate domains, coordinated through the appropriate authority.

7.47 Case study: quiet service corridor beside a briefing room

Consider a briefing room separated from a service corridor by a high-rated wall containing a door and return-air path. Daytime corridor background

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averages 38 dB in speech-relevant bands because plant and activity are present. At night, the plant enters setback and background falls by 12 to 18 dB. The wall field remains strong, but local receiving maxima occur at the door head and return grille.[370]

A daytime broadband survey suggests generous privacy; a night survey with the same source identifies positive speech-to-background margins in two mid-frequency bands near the grille; coherence with the source confirms a transmission path; temporary duct treatment reduces those bands, while door perimeter treatment affects higher bands. The room contains two independent weaknesses.

The remediation combines a properly designed cross-talk silencer, improved door-head seal, and monitoring of masking in the corridor; the passive and active contributions are tested separately; source positions include the lectern and installed remote-conference loudspeaker; the final report states that performance is conditional on door closure and masking within its controlled range.

This composite case illustrates why time state, local positions, and path intervention are necessary. It does not prescribe a universal threshold or imply governmental accreditation.

7.48 Case study: amplified executive boardroom with glazing

An executive boardroom uses a large glazed wall and a ceiling audio system. The partition schedule cites a high laboratory rating, but no field requirement was established. During hybrid meetings, ceiling loudspeakers

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near the glazing operate 7 dB above ordinary conversation in several bands. A quiet adjacent office is accessible for long periods.[371]

Field measurements show that the glazing frame and a perimeter mullion dominate; the glass centre performs better than the frame; source orientation and loudspeaker zone create a 6 dB spread in receiving level; lowering the audio setting improves privacy but reduces remote intelligibility at one seat because coverage is uneven.

The redesign adds local loudspeaker coverage at lower level, improves frame seals, and adds secondary glazing with a deeper independent cavity. Interior absorption reduces reverberant build-up. The system is retested under ordinary and maximum approved settings; the case demonstrates that audiovisual design and envelope details must be integrated.

7.49 Decision uncertainty and guard bands for speech metrics

A speech metric near a criterion requires a decision rule. Measurement uncertainty, source variability, background variability, and spatial sampling all contribute. A simple guard band may require the measured privacy quantity, adjusted by expanded uncertainty, to remain on the acceptable side of the limit. The contract or authority should define the rule before testing.[372]

If y is a metric for which larger values are better and U is expanded uncertainty, a conservative acceptance rule may be

Equation 7.7

$$y - U \geq y_{lim}.$$

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This is an example, not a universal mandate. Some standards use different decision rules or do not include conformity assessment. The consequences of false acceptance and false rejection should be considered.

Uncertainty in bounded metrics such as STI or probabilities may be asymmetric; repeated measurements and Monte Carlo propagation can estimate the distribution; the report should state confidence level and coverage factor where an expanded uncertainty is used.

A failure within uncertainty is not resolved by rounding. It may require more measurement, remediation, or authority judgement. The technical record should make the ambiguity visible.

7.50 Speech spectra, octave-band reduction, and source normalisation

Speech spectra may be expressed as sound-pressure levels at a specified distance, room-average levels, or sound-power levels; these reference conditions are not interchangeable; a spectrum measured one metre in front of a talker contains directivity and near-field effects; a room-average spectrum contains reverberation. A sound-power spectrum seeks to describe the source independently of receiver position; the manuscript and test report should state the reference condition whenever speech data are used.[373]

Octave-band spectra are convenient but can conceal narrow weaknesses and consonantal energy; one-third-octave bands provide greater resolution and align with many building-acoustic measurements; narrowband data are useful for tones and modulation but can become spatially unstable in

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rooms. A layered record retains narrowband data, one-third-octave reduction, and the final metric.

Source normalisation can compare receiving levels to a measured source-room field; if the source-room spectrum changes among runs, receiving levels should not be compared directly; the level difference by band removes much of the source variation, subject to the source-room estimator being stable and representative. A local reference near the source and a spatial average answer different questions.

For human talkers, each utterance varies. Repetition and statistical treatment are needed. An electroacoustic surrogate provides repeatability, while human trials quantify the gap between surrogate and use; the final source model can combine both rather than pretending either is complete.

7.51 Temporal opportunity and extreme-value states

Security exposure can be governed by rare combinations: a loud word, a quiet receiving interval, a favourable source orientation, and a listener at a local maximum. Average analysis may not capture this joint extreme. An extreme-value or scenario approach can examine credible upper source and lower background states without assuming every variable simultaneously reaches an impossible maximum.[374]

Variables are correlated. A quiet night may coincide with reduced HVAC background but also lower occupancy and less speech; a formal briefing may produce louder speech and full mechanical operation; a masking failure may trigger an alarm and shorten exposure. The scenario matrix should preserve these dependencies.

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A conservative but credible design scenario can be defined by the authority; for example, raised speech at the lectern, maximum approved conference amplification, minimum controlled masking, closed doors, and the quietest accessible adjoining location; testing or modelling then focuses on that state. An absolute worst case with open doors and masking off may be addressed operationally rather than through the same acceptance metric.

Long-term monitoring can estimate distributions, but collecting speech-related data raises privacy and security concerns. Level-only statistics, source surrogates, and controlled trials are preferable. The report should identify what was observed and what was modelled.

7.52 Listening tests, experimental design, and statistical interpretation

Listening tests can validate whether a physical or objective metric corresponds to human performance under a defined condition. They require neutral material, controlled presentation, listener selection, randomisation, scoring, and statistical analysis. A casual demonstration in which an investigator “can hear words” is not a reproducible test.[375]

Open-set word tests ask listeners to report unrestricted words, while closed-set tests provide alternatives; closed sets can overstate performance because chance is higher and context is supplied. Sentence tests include semantic context. Numbers and names may require specialised material; the test should match the information proposition.

Listeners should not know the correct answers during a trial. Repeated material creates learning. Presentation order should be randomised, and

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source level and background should be controlled; hearing screening or documentation may be appropriate; a sufficient number of items and listeners is needed to estimate performance and variability.

Results should include confidence intervals and chance correction where relevant; a score above chance does not automatically imply operationally significant comprehension; conversely, a low average can hide occasional recovery of critical items; the authority determines the consequence threshold.

Recordings and answer sheets may be sensitive. They should use neutral content and controlled handling. Actual protected conversations should not be recorded for test convenience.

7.53 Worked example: Monte Carlo privacy screening

Consider five one-third-octave bands with source means of 64, 66, 68, 67, and 63 dB; apparent level differences are 45, 47, 50, 48, and 44 dB; receiving background means are 24, 23, 22, 22, and 23 dB. Assume source standard deviation 3 dB with correlation 0.8 across bands, level-difference uncertainty 1.5 dB independent by band, and background standard deviation 2 dB with correlation 0.5.

A Monte Carlo simulation draws correlated source and background spectra and level differences, then computes receiving margins; a simple screening event is defined as at least two adjacent bands exceeding background; the simulation might return an event probability near one third under these illustrative inputs. The exact result depends upon random seed and distributions; the purpose is methodological.

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The model does not calculate intelligibility. It identifies how often a spectral opportunity occurs; to estimate intelligibility, band importance, temporal modulation, hearing, and metric-specific rules must be added; sensitivity analysis may show that quiet-background variability dominates; the design response could then focus on passive isolation or controlled masking.

The simulation record should retain code, seed, input distributions, correlations, number of trials, and convergence check. A graphical distribution is more informative than one rounded probability.

7.54 Speech-security commissioning sequence

Commissioning should proceed from source and room verification to boundary and listener-oriented assessment; first, verify room geometry, finishes, doors, services, masking, and audiovisual state; second, measure interior background, reverberation, and source distribution; third, perform standardised field isolation tests; fourth, survey local weak paths. Fifth, apply the selected speech metric at accessible positions and credible source states. Sixth, test dependencies and fault states. Seventh, document limitations and retest triggers.[376]

The sequence prevents a privacy metric from hiding a construction defect; if a door gap is obvious, it should be repaired before relying on masking; it also prevents a strong wall test from obscuring an amplified source or quiet exterior position. Each step supplies evidence for a different proposition.

Acceptance meetings should include acoustics, architecture, mechanical and electrical services, security, operations, and the competent authority. Open

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findings should have owners and dates. Training and maintenance records should be delivered with the technical baseline.

7.55 Case study: legal consultation suite with intermittent masking

A composite legal consultation suite uses lightweight walls, solid-core doors, and corridor masking. Field level differences are adequate when doors latch, but the masking controller enters an energy-saving setback after business hours. Attorneys occasionally meet late, and the adjoining reception area becomes very quiet.[377]

Night testing shows that two bands have positive receiving margin near one door; the door bottom does not fully contact a slightly uneven threshold; daytime tests had concealed the weakness; the repair levels the threshold and replaces the automatic bottom. Masking controls are revised so that occupied late meetings maintain the approved minimum, with a visible fault indication.

The suite is not a classified facility, and the acceptance criterion is based on legal confidentiality and client policy; the case demonstrates the same four-proposition discipline: component evidence, installed field performance, occupied privacy under masking, and organisational acceptance remain separate.

7.56 Research limitations and unresolved questions

Public standards provide strong methods for sound insulation, room acoustics, STI, SII, and objective privacy. They do not disclose every governmental criterion for classified discussion spaces. The manuscript

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should not fill those gaps by inference. It can identify the public method and the boundary of public knowledge.[378]

Speech production data also have limitations. Populations, languages, vocal efforts, and modern hybrid systems continue to evolve; objective metrics simplify listener and context; machine-assisted enhancement changes practical capability but is difficult to bound without a defined threat model; these uncertainties favour robust passive design, controlled operations, and authority-led acceptance.

Research priorities include better probabilistic coupling of source, path, background, and listener; validated models for local directional exposure; long-term masking assurance; and transparent methods for comparing public national terminology without false equivalence.

7.57 Calibration of a speech-surrogate loudspeaker

A speech-surrogate source should be calibrated as a system, not merely set by amplifier voltage. The test file, player, interface, amplifier, equaliser, limiter, loudspeaker, mounting, and room determine the delivered spectrum. Calibration should establish band levels at the chosen reference condition and confirm that the source remains linear and stable over the test duration.[379]

A practical procedure begins with a known digital signal and fixed gain structure; the loudspeaker is warmed, then measured at a reference position and across the source-room sampling positions; equalisation may be applied to achieve a specified room-average speech-shaped spectrum,

378 MB-0781. Heinrich Kuttruff, Room Acoustics, 6th ed.
379 MB-0788. IEC 60268-16:2020.

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but filters should not demand excessive boost where the loudspeaker lacks capability. Limiter activity and harmonic distortion should be monitored.

The directivity of the calibrated source should be measured or taken from reliable data; if operational testing requires a forward talker surrogate, a directional device may be appropriate; if standard field isolation requires diffuse excitation, several source positions or an omnidirectional source may be used. One calibration cannot serve both without qualification.

Pretest and post-test checks should verify level and spectrum; a fixed reference microphone can monitor drift during runs; the source record should include serial numbers, positions, orientation, equalisation file, gain settings, and calibration uncertainty; this permits the same source state to be recreated after remediation.

7.58 Speech level difference versus room-to-room privacy

A band level difference between source and receiving rooms is an important intermediate quantity. It does not include receiving background or speech spectrum unless those are added. A high difference in one band can coexist with low privacy if other bands are weak. A room-to-room privacy metric combines the transmission relationship with source and receiver assumptions.[380]

The distinction matters in specifications. Requiring a field level difference creates a construction and room relationship; requiring an objective privacy result creates a system condition that may depend upon masking; both can be appropriate, but they allocate risk differently; a contractor responsible

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for the wall cannot control an owner-adjustable masking system unless the contract defines that responsibility.

Commissioning should report the passive level difference spectrum and the active background or masking spectrum separately, followed by the combined privacy metric. This allows later troubleshooting. If privacy declines, the record shows whether the boundary, background, or source state changed.

7.59 Time-varying background and minimum-window analysis

A background record can be divided into short windows and analysed by band. The minimum credible window, rather than the absolute mathematical minimum, may govern. The absolute minimum can be a microphone dropout or an unrepresentative transient pause. A credible window should satisfy duration, instrument health, and operating-state criteria defined before analysis.[381]

For each band, the distribution of windowed level can be summarised by percentiles and state labels; correlation among bands should be retained; a fan shutdown may lower several bands together; masking faults may affect one zone. The privacy calculation can then use state-specific backgrounds rather than assembling an impossible spectrum from the minimum of each band at different times.

Minimum-window analysis also supports monitoring. If controlled masking falls below its permitted range for longer than a set duration, an alarm or

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incident record can be generated; the control threshold and response belong to the authority and operational policy.

7.60 Case study: medical consultation room with shared plenum

A medical consultation room uses a full-height partition to the suspended ceiling but shares an open plenum with an adjacent staff room. The wall field and door provide moderate isolation. Conversation is intermittently intelligible near a return grille in the staff room when the air system is off. Daytime HVAC noise had previously masked the path.[382]

Investigation uses a speech-shaped source, local microphone scans, and temporary absorptive barriers in the plenum; coherence and level changes identify the over-partition plenum route; the remediation extends the barrier to the structural deck, seals service penetrations, and provides a lined transfer path designed for airflow and cross-talk control. Fire stopping and access are coordinated.

The final assessment uses the clinic’s confidentiality requirement, not a classified-facility criterion; passive field isolation and privacy under minimum HVAC background are both reported; the case demonstrates that a suspended ceiling is not an acoustic boundary unless designed and tested as one.

7.61 Case study: historic stone chamber with coupled cavities

A historic stone chamber is adapted for sensitive diplomatic meetings. The walls appear massive, but borescope and archival evidence reveal rubble cores, timber pockets, and former flues. A decorative internal lining creates

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cavities connected behind panelling. Local tests show strong leakage at a blocked flue and variable vibration near floor pockets.[383]

Heritage constraints prohibit extensive cutting. The design uses reversible independent linings in selected areas, sealed but inspectable flue treatments, a secondary inner door, and controlled service routes; source positions are kept away from vulnerable wall zones, and interior absorption reduces reverberant build-up. The work is documented so that future conservation changes can be assessed.

The case illustrates why visible stone thickness is not proof of uniform isolation; it also shows that operational and reversible measures can supplement construction where conservation limits intervention; formal use remains subject to the competent authority.

7.62 Worked example: masking failure sensitivity

A receiving position has transmitted speech levels of 22, 25, 27, 25, and 21 dB across five bands; the commissioned masking levels are 29, 29, 28, 27, and 25 dB; margins are therefore negative 7, negative 4, negative 1, negative 2, and negative 4 dB. If one masking loudspeaker fails, measured levels in the zone fall by 6 dB in the middle three bands; the new margins become negative 7, positive 2, positive 5, positive 4, and negative 4 dB.

A system that looked satisfactory by overall A-weighted level can therefore develop a speech-relevant quiet pocket. Monitoring only the controller output would miss a failed loudspeaker or open circuit. Field uniformity and fault detection are necessary if masking is credited.[384]

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The example does not calculate intelligibility. It identifies a state change that materially increases opportunity and should trigger the chosen privacy metric or incident response.

7.63 Room impulse responses and source-receiver transfer

A room impulse response contains the direct arrival, early reflections, late reverberation, and noise associated with a defined source and receiver. It can be measured using an impulsive source, maximum-length sequence, exponential sine sweep, or other method suited to the system. The chosen signal affects immunity to noise, separation of nonlinear distortion, and required source capability. A balloon burst or hand clap may illustrate decay, but it rarely provides the calibration and repeatability needed for high-isolation work.[385]

An exponential sweep is useful because the recorded response can be deconvolved to obtain a broad-band impulse response and, under appropriate processing, separate harmonic distortion components; the source and system must remain stable; a long sweep improves energy at low frequency but can be affected by time variance. Clock drift between playback and recording alters deconvolution; a common clock or measured resampling correction is desirable.

The impulse response can support reverberation metrics, clarity, STI by indirect method, and transfer analysis; each derived quantity has its own processing and scope; windowing the response to isolate one path may introduce spectral convolution and should be documented. An early window can examine direct leakage through a door before room reverberation

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dominates, while a later window may reveal coupled spaces; the window boundaries should follow arrival evidence rather than arbitrary convenience.

For a protected room, source and receiver positions should be tied to drawings; the response at one point is not a room property; multiple positions, source orientations, and operating states are required; the raw response should be retained so that alternative metrics can be computed without repeating a sensitive survey.

7.64 Speech transmission through apertures and ducts

Speech passing through a small opening or duct is spectrally shaped by aperture dimensions, end corrections, lining, bends, cross-sectional modes, and terminations. A narrow gap may transmit high frequencies less efficiently than a broad opening, while a duct can support low-order modes and carry mid-frequency information over distance. Grilles and silencers add attenuation and regenerated noise. The receiving sound is therefore not simply the source spectrum reduced by one constant.[386]

Below the first higher-order duct mode, plane-wave propagation may be a useful approximation; the cut-on frequencies depend upon cross-section; above them, modal patterns and bends complicate transfer; lining attenuation depends upon perimeter-to-area ratio, flow resistivity, length, and flow. A silencer selected from insertion-loss data must be evaluated for the actual duct size, flow, pressure drop, breakout, and flanking around its casing.

Cross-talk paths often connect rooms through return-air plenums or transfer ducts; a direct line of sight is adverse; bends, lined length, splitters,

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and separated terminals improve attenuation, but fire dampers, access doors, and maintenance conditions affect performance. Duct breakout can bypass an internal silencer if casing walls radiate into a ceiling void.

Speech assessment should measure or predict the path by band and include the receiving terminal or grille; a microphone directly inside the duct is a diagnostic position, not necessarily a listener location; where a device could gain access to the duct, the authority should define the threat model. Public-source analysis should not disclose site-specific access details beyond authorised reports.

7.65 Source-state taxonomy for room operation

A room can have several source states: unamplified conversation, raised conversation, formal presentation, hybrid conference, audiovisual playback, emergency announcement, and maintenance testing. Each has different level, spectrum, directivity, duration, and spatial distribution. A design that considers only ordinary conversation may be vulnerable during an approved amplified state.[387]

The source-state taxonomy should be created with users and system designers; each state receives an identifier, equipment configuration, maximum approved settings, representative source positions, and frequency spectrum; states that are prohibited can be controlled through software, physical limits, or procedure. The commissioning plan tests the credible governing states.

Audiovisual playback can contain music, film effects, or test signals with greater low-frequency content than speech; if such use is allowed, it may

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govern structural or direct transmission even if intelligibility is not the concern; the room may require separate operational limits for non-speech material. Emergency systems may be exempt from ordinary controls but should be considered in security procedures.

A source-state record also supports incident analysis; if information was allegedly overheard, equipment logs, room booking, and approved settings can be compared with the acoustic baseline; the engineer should avoid inferring content or behaviour beyond the records.

7.66 Measurement uncertainty for bounded speech metrics

Speech metrics such as STI and SII are bounded between zero and one, and privacy probabilities are bounded similarly. Their uncertainty can become asymmetric near the limits. Ordinary linear propagation may produce impossible values below zero or above one. Repeated measurements, bootstrap methods, and Monte Carlo simulation are more appropriate when spatial and temporal variability dominate.[388]

Uncertainty components include source calibration, source position, receiver position, background, impulse-response estimation, modulation transfer, band weighting, and algorithm implementation. Some are systematic. A loudspeaker directivity error affects several positions coherently; background variation may be correlated across bands; the uncertainty model should preserve these relations.

A metric can be repeatable yet biased if the source spectrum or algorithm is wrong; verification with a reference system or standard test case can expose

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implementation error; software version and settings should be recorded; independent calculation from exported band data is valuable for audit.

When the result is used for conformity, the decision rule should be agreed in advance; a measurement just inside the limit with large uncertainty is not strong evidence; more sampling, a better background margin, or remediation may be preferable to arguing about rounding.

7.67 Worked example: reverberation and source-level feedback

A boardroom of volume 240 m³ has equivalent absorption area 38 m² in the 1 kHz band. Sabine’s equation gives

$$T_{60} = 0.161(240)/38 = 1.02\,s.$$

A treatment adds 22 m² of equivalent absorption, increasing total A to 60 m² and reducing the ideal decay to

$$T_{60} = 0.161(240)/60 = 0.64\,s.$$

Assume the room is sufficiently diffuse for a first screening and that source power remains constant. The reverberant term in Equation 7.6 is approximately proportional to $1/R$, and room constant increases with absorption. A simplified estimate suggests room-average reverberant speech level may fall by roughly 2 dB. If improved clarity also reduces typical vocal effort by 2 dB, boundary excitation could fall by about 4 dB in that band.

This combined result is not guaranteed. Occupants may not change vocal effort, and the room may not be diffuse. Direct sound near listeners and boundaries remains. The treatment might alter source directivity through reflections. The example demonstrates a feedback path that should be

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measured during commissioning rather than credited as a fixed wall improvement.[389]

7.68 Worked example: multi-position privacy decision

A test measures an objective privacy quantity at six accessible positions; values are 0.84, 0.88, 0.91, 0.86, 0.79, and 0.90 under the chosen scale, where higher is better; standard uncertainties from repeat measurements are 0.02 at four positions and 0.04 at the two positions near a door and grille. Suppose the project decision rule requires the lower expanded-uncertainty bound with coverage factor two to exceed 0.80.

The lower bounds are 0.80, 0.84, 0.87, 0.82, 0.71, and 0.82; the first position lies exactly at the limit and the fifth fails; an arithmetic average of 0.86 would conceal the failed local position. The correct response is to investigate the fifth position and clarify how equality at the first is treated by the rule.

Temporary grille treatment raises the fifth measured value to 0.87 with standard uncertainty 0.03, giving lower bound 0.81; this supports the grille path and a permanent remediation; the test is then repeated in the final configuration; the example illustrates spatial weakest-path control, uncertainty, and pre-agreed decision rules. It does not define a universal privacy scale or threshold.[390]

7.69 Cumulative fragment recovery and consequence-weighted exposure

Speech-security assessment often treats one listening interval as though it were the entire exposure. Real access can be cumulative. A cleaner may pass

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the same corridor each evening, a neighbouring office may hear repeated meeting openings, or a recording device may collect many weak fragments that are later aligned. Words that are unintelligible in one interval can become recoverable when context, repetition, speaker familiarity, and independent documents are available. The assessment should therefore distinguish instantaneous intelligibility from cumulative information recovery.[391]

If the probability of recovering a particular fragment in exposure i is p_i, and the exposures are treated as independent for a first screening, the probability of at least one recovery is

Equation 7.8

$$P_{\geq 1} = 1 - \prod_{i=1}^{n} \left(1 - p_i\right).$$

For ten exposures each with $p_i = 0.08$, the screening probability is approximately $1 - \left(0.92\right)^{10} = 0.566$. The calculation does not establish a real adversary success rate. Independence is often false, p_i is difficult to estimate, and access conditions vary. It demonstrates why a low per-event probability can become material when exposure repeats.

Dependence can operate in both directions. The same persistent noise, geometry, and weak path may make outcomes strongly correlated, so repeated intervals add less information than the independent model predicts; conversely, changing talkers, source positions, door states, and background levels can expose different phonemes or frequency bands, making the combined record more informative. A credible model should

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therefore preserve state variables and avoid treating every sample as an identical Bernoulli trial.

Consequence is also uneven. Recovery of a common connective word may have negligible value, while a surname, code word, date, account number, location, or decision can be consequential even when the surrounding sentence remains obscure; a consequence-weighted assessment should identify information classes approved by the competent authority. It must not invent the protected content or record real classified speech merely to create a realistic test; neutral surrogates can represent names, numbers, short directives, and uncommon phonetic sequences.

Semantic redundancy changes the engineering problem; natural language permits listeners to infer missing material from grammar and context. Familiar projects, repeated agenda structures, displayed slides, or visible participant lists can further constrain possibilities; an objective metric based on audibility or modulation transfer does not directly quantify this external knowledge; the report should state whether the listener is assumed to be naïve, familiar with the speakers, aided by contextual documents, or able to replay a recording.[392]

Recording and signal processing can accumulate evidence unavailable to a live passer-by; time alignment, spectral subtraction, beamforming, dereverberation, source separation, and repeated averaging can improve selected fragments, although each method has limits and can create artefacts; a bounded test may include an approved recording at a defined accessible position, followed by documented processing that preserves the

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raw file and software settings. The result should not be generalised beyond the tested source, background, geometry, and processing chain.

A useful experimental design separates detection, phoneme recognition, word recognition, and critical-fragment recovery; multiple listeners can report forced-choice or open-response results under randomised trials; chance correction and confidence intervals are necessary; the test material should be balanced, non-sensitive, and sufficiently varied to prevent memorisation. A listener who repeatedly hears the same small vocabulary is measuring learning as well as acoustic transmission.

Operational controls can address cumulative exposure even when construction remains unchanged; limiting repeated access, changing meeting location, controlling door-open periods, maintaining masking, scheduling sensitive discussion away from predictable service intervals, and monitoring anomalous recording opportunities can reduce the number or quality of exposures. These controls are not substitutes for the boundary, but they are legitimate elements of a system-level risk treatment.

The final conclusion should state the exposure model. A result based on one short, unrecorded interval cannot support a claim about months of repeated access with recording and contextual knowledge. Equally, an extreme cumulative model should not be imposed without a credible access path. The engineering judgement lies in matching source states, listener capability, duration, repetition, consequence, and uncertainty to the authorised scenario.[393]

393 MB-0236. ASTM International, ASTM E2638-24.

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7.70 Chapter 7 glossary

Audibility. The condition in which a sound can be detected by a listener under stated hearing and background assumptions; it does not imply intelligibility.

Directivity factor. The ratio of acoustic intensity in a specified direction to that of an omnidirectional source radiating the same power.

Information masking. Reduction of speech understanding caused by competing meaningful or speech-like content beyond simple energetic overlap.

Lombard response. Behavioural change in vocal production, often including increased level, when background or communication difficulty rises.

Speech Intelligibility Index. A standardised spectral audibility model relating band importance and available speech information.

Speech Transmission Index. A standardised metric based principally on preservation of speech-relevant modulation across frequency bands.

Vocal effort. A defined or observed state of speech production associated with source level, spectrum, and behaviour.

Human speech is a variable, directional, temporally modulated source whose interaction with room modes, reverberation, background, masking, amplification, and listener access determines information exposure. Long-term spectra and single-number level differences are necessary but insufficient. Source distributions, local orientation, temporal structure, and

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receiving-state distributions can change the conclusion without any alteration to the wall.

STI, SII, and objective closed-room privacy methods provide disciplined metrics within their stated scope. They are not interchangeable and do not constitute governmental accreditation. A defensible assessment names the source model, metric, listener assumptions, background state, accessible positions, uncertainty, and limitations.

Interior acoustic design, sound masking, operational controls, and user training can support the boundary. They do not replace it. The complete evidence chain leads into Part III, where laboratory and field ratings, speech metrics, and decision uncertainty are compared explicitly.

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PART III. RATINGS, PRIVACY METRICS, AND UNCERTAINTY

Part III examines the intellectual and metrological passage from frequency-resolved acoustic observations to decisions about rooms. The passage is necessary because design drawings, procurement schedules, commissioning reports, and institutional authorities cannot operate efficiently on raw spectra alone. It is hazardous because every compression removes context. Sound Transmission Class, weighted sound-reduction indices, field level-difference classifications, speech-intelligibility metrics, and conformity statements each answer a bounded question. None is a universal certificate of secure speech.

The three chapters preserve a strict evidence hierarchy. Chapter 8 begins with laboratory transmission loss and explains how reference contours and weighting systems produce STC and R_w. It then follows those classifications into doors, glazing, services, composite boundaries, field substitutions, and contracts. Chapter 9 moves from completed room-pair measurements to speech consequence. It distinguishes room averages from local listener positions, field isolation from audibility, and speech degradation from recovery of one consequential token. Chapter 10 establishes the metrological discipline needed when those measurements approach an acceptance boundary. It treats uncertainty, covariance, nonlinear propagation, guard bands, consumer risk, producer risk, and the institutional separation between laboratory conformity and governmental accreditation.

The analysis uses current public metadata for ASTM, ISO, IEC, ANSI/ASA, ILAC, JCGM, Canadian, and United Kingdom sources, together with

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recognised technical monographs. Where a standard’s full text is not publicly reproduced, this volume relies upon lawful access, public scope information, and bounded technical synthesis. It does not invent controlled criteria or convert public engineering guidance into governmental accreditation requirements.[394]

The reader should retain four propositions throughout. A laboratory classification describes the tested specimen under a named method. A field result describes the configured room pair, including direct and flanking paths observed by the method. An occupied speech result describes recovery under a stated source, background, listener, and access model. Formal approval belongs to the competent authority. The chapters connect those propositions without merging them.[395]

394 MB-0757. ASTM International, ASTM E413-22, ISO 717-1:2020.
395 MB-0758. ASTM International, ASTM E90-23, ASTM E336-25a.

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Chapter 8. STC, Rw, Transmission Loss, and Single-Number Ratings

8.1 The purpose and danger of compression

A sound-insulation rating is a deliberate compression of evidence. The underlying observation is normally a frequency-resolved series of transmission-loss, level-difference, or apparent sound-reduction values; the rating procedure transforms that series into one number so that assemblies may be catalogued, specifications may be written, tenders may be compared, and completed work may be screened against an acceptance requirement. Compression is useful because a twenty-one-band spectrum is cumbersome in a door schedule and almost impossible to place in a room-data sheet without overwhelming the drawing; compression is dangerous because the removed information is often the information that explains failure; a rating may therefore be a competent administrative descriptor while remaining an incomplete physical description.[396]

The engineering question is not whether a rating is legitimate; it is what proposition the rating supports. A laboratory STC classification supports a proposition concerning the tested specimen, the prescribed frequency range, the receiving and source chambers, the mounting opening, the calculation rule, and the limitations of the governing method; an Rw value supports a related but not identical proposition under the ISO rating system. An apparent field classification supports a proposition concerning a completed separation in a building, with direct and flanking transmission combined in the measurement; none of those numbers, without further evidence, establishes that speech cannot be understood at an accessible

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receiving position; none establishes that a room has been accredited for classified use. The semantic discipline surrounding the number is therefore as important as the arithmetic that produces it.[397]

This chapter treats single-number ratings as controlled abstractions; it explains the construction of the abstraction, the aspects of the frequency curve that survive, the aspects that disappear, and the ways in which the result may be misapplied; the treatment is intentionally comparative. American STC terminology, ISO Rw terminology, field descriptors, speech-privacy metrics, and contractual language occupy different places in the evidence chain; a secure-room specification that writes these terms as synonyms creates uncertainty before the first stud, block, or door frame reaches the site.

The most consequential error is to treat a rating as a material property; gypsum board does not possess an STC; concrete masonry does not possess an Rw; a door leaf does not possess a universal rating independent of frame, seals, size, hardware preparation, and installation. The classification belongs to the tested or measured assembly in its stated configuration. Even the phrase “STC 55 wall” is incomplete until the specification identifies the leaves, board types, framing, cavity, absorptive fill, fasteners, perimeter condition, penetrations, test method, laboratory report, and whether the requirement concerns a laboratory specimen or the completed field boundary; the omitted nouns are where most costly disputes begin.

397 MB-0702. ASTM International, ASTM E90-23, ASTM E336-25a.

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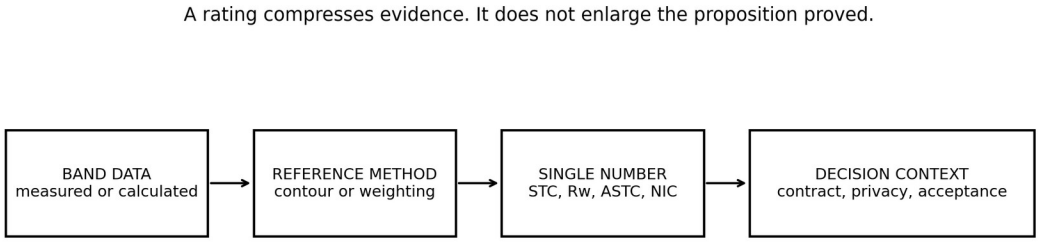

Figure 8-2. Rating evidence chain. Author's original diagram. A classification begins with frequency-band evidence, passes through a defined weighting method, and acquires contractual or security meaning only when the decision context is stated.

8.2 Frequency-resolved transmission loss as the primary evidence

For a laboratory specimen, airborne sound transmission loss in a frequency band may be represented as

Equation 8.1

$$TL(f) = 10\log_{10}\left(\frac{W_i(f)}{W_t(f)}\right) = -10\log_{10}\tau(f),$$

where $TL(f)$ is the band transmission loss in decibels, $W_i(f)$ is incident acoustic power, $W_t(f)$ is transmitted acoustic power, and $\tau(f)$ is the band power-transmission coefficient. The expression is conceptually simple. The measurement is not. Incident and transmitted powers are inferred through room averages, specimen area, receiving-room absorption, source stability, background correction, and the assumptions of the test method. The reported curve is consequently a result of both the specimen and the measurement model.[398]

398 MB-0713. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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A frequency curve reveals mechanisms that a single number conceals. A stiffness-controlled rise at low frequency can indicate panel or cavity behaviour; a narrow trough can indicate a resonance, a frame condition, a panel coincidence region, an opening, or a laboratory limitation; a gradual mass-controlled slope may be interrupted by leaves, ties, studs, glazing laminates, or door hardware. A plateau can indicate leakage or a dominant weak path. A curve that appears satisfactory from 500 Hz upwards may remain weak in bands carrying substantial male speech energy or amplified conference-room programme; for this reason, any design decision involving high vocal effort, loudspeakers, duct-borne transmission, lightweight double-leaf walls, or massive structural flanking should retain the band data.[399]

The minimum reported band range is method-dependent; a contract should not assume that every quoted STC or Rw result was derived from identical lower and upper limits; nor should a designer infer unmeasured low-frequency performance from the slope of the classified range. Extrapolation is especially unreliable near mass-air-mass resonance, panel resonance, coincidence, structural modes, and leakage-controlled plateaux; if the risk assessment identifies octave bands below the classification range as material, those bands must be measured or modelled under an expressly stated supplemental procedure; they cannot be conjured from the headline rating.

Band values are logarithmic. A 5 dB improvement in one band does not mean that the whole assembly has improved by 5 dB, because the rating procedure applies a reference curve, weighting rule, or deficit limitation

399 MB-0714. Carl Hopkins, Sound Insulation.

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across a range of bands. Conversely, a one-band defect can be operationally important even when it does not move the final rating; the reason is physical rather than bureaucratic; a listener receives the residual spectrum that actually crosses the boundary; human recognition can exploit sparse but information-rich fragments; a classification algorithm cannot know whether the weak band carries a surname, a number, or a repeated phrase.

Worked example 8.1. From transmission coefficient to band loss

Suppose the measured power-transmission coefficient at 500 Hz is $\tau = 2.0 \times 10^{-5}$. Equation 8.1 gives

$$TL = -10 \log_{10}\left(2.0 \times 10^{-5}\right) = 47.0\,dB.$$

If a construction change reduces the coefficient to 8.0×10^{-6}, the new loss is

$$TL = -10 \log_{10}\left(8.0 \times 10^{-6}\right) = 51.0\,dB.$$

The physical change is a 60 per cent reduction in transmitted power, yet the logarithmic result is a 4.0 dB improvement. The calculation is dimensionally valid because τ is dimensionless. It does not establish the change in STC or Rw because the rating depends upon the entire curve. It also does not establish field improvement because a flanking path may remain unchanged.

8.3 ASTM STC classification and the reference-contour idea

Sound Transmission Class is assigned under ASTM E413 to a transmission-loss curve obtained by an applicable laboratory method, most commonly ASTM E90 for building partitions and elements; the classification uses a prescribed reference contour and shifting rule; the procedure is not a simple arithmetic average. It evaluates the relationship between measured band

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values and a reference shape, subject to limits on unfavourable deviations; the number assigned to the shifted contour becomes the classification; the contour therefore gives greater interpretive structure than a mean, but it still suppresses the original band-by-band evidence.[400]

The classification range and reference shape express an intended use; they were developed to provide a practical rating of airborne sound insulation for common building separations; they were not designed as a universal measure of every threat spectrum, every listener, every low-frequency mechanism, or every secure-room operating condition. The standard itself is a classification procedure; it does not convert an assembly into an accredited secure boundary; it does not determine whether a discussion is intelligible outside; it does not replace a project-specific acceptance rule.

The distinction between contour deficiency and operational deficiency is fundamental; a measured band may lie below the shifted reference contour and contribute to the allowed deficiency total; another weak band may lie outside the classification range and contribute nothing to the rating. A third band may satisfy the contour yet remain the dominant transmitted speech band because all other bands are stronger; the classification result is thus a statement within the rating algorithm, not a complete description of the residual signal.

Rounding also matters. Band results, room averages, reverberation corrections, and the final contour position can place an assembly near an integer boundary; a nominal change of one decibel can alter the classification even when the underlying uncertainty is comparable with that

400 MB-0721. ASTM International, ASTM E413-22, ASTM E90-23.

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change. A report that presents STC 50 and STC 51 as categorically different without uncertainty, repeatability, or specimen information creates a false precision; procurement language should avoid bonuses, penalties, or accreditation claims that hinge upon a one-point difference unless the decision rule has been declared in advance.

Worked example 8.2. Simplified reference-contour fitting

Consider the following illustrative one-third-octave-band losses over a reduced teaching range: 125 Hz, 32 dB; 160 Hz, 35 dB; 200 Hz, 38 dB; 250 Hz, 42 dB; 315 Hz, 45 dB; 400 Hz, 48 dB; 500 Hz, 51 dB; 630 Hz, 53 dB; 800 Hz, 55 dB; 1000 Hz, 57 dB; 1250 Hz, 58 dB; 1600 Hz, 60 dB; 2000 Hz, 62 dB; 2500 Hz, 64 dB; 3150 Hz, 65 dB; 4000 Hz, 66 dB. Suppose an illustrative reference contour is shifted until the sum of measured shortfalls reaches but does not exceed the method’s permitted total, and no single shortfall exceeds its permitted limit; if the next 1 dB upward shift would violate either rule, the lower shift governs.

This is deliberately not a substitute for the complete ASTM calculation. It demonstrates the logic. The assigned class is controlled by the distribution of unfavourable deviations rather than the arithmetic mean; a high surplus at 2000 Hz cannot automatically cancel an excessive shortfall at 125 Hz; the calculation must use the current standard’s complete contour, band range, deficiency definitions, and rounding provisions. A spreadsheet should be validated against hand calculations and version-controlled before it is used for acceptance.

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8.4 Rw and the ISO 717-1 framework

ISO 717-1 provides a single-number rating framework for airborne sound insulation based upon frequency-dependent measurements made under applicable ISO laboratory or field procedures. The weighted sound reduction index, R_w, is associated with laboratory sound reduction. Apparent and standardised descriptors apply to field conditions. The ISO framework also provides spectrum adaptation terms intended to improve the relationship between the single number and selected source spectra. These terms are not decorative suffixes. They are evidence that one weighted number cannot represent all source spectra equally well.[401]

A common professional mistake is to translate STC and Rw by memory as though one were a metric version of the other; the rating curves, ranges, terminology, reference quantities, and associated field metrics differ; numerical values may be close for some ordinary partitions, but closeness is not equivalence. A specification should select the rating system appropriate to the jurisdiction, source documents, test methods, and acceptance process; where a multinational project requires both systems, the report should present each result under its own method and avoid an undocumented conversion.

Spectrum adaptation terms, commonly denoted C and C_{tr} in the ISO framework, modify the weighted result for defined reference spectra. Their value is greatest when the source spectrum differs from the assumptions implicit in the basic rating. A wall may have a respectable R_w but a materially lower combined value when a low-frequency-weighted spectrum is applied.

401 MB-0722. International Organization for Standardization, ISO 717-1:2020, ISO 10140-2:2021.

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That difference is not a defect in the standard. It is a warning that the bare weighted number is not source-neutral.

The adaptation-term concept is particularly relevant to secure rooms; normal conversational speech, raised speech, amplified conference audio, ventilation noise, urban traffic, and mechanical plant do not share the same spectrum; the source may also change during an incident. A room designed around ordinary speech can be challenged by a participant leaning towards a door, speaking loudly during disagreement, or replaying recorded audio through a soundbar; the acoustic basis of design should identify the controlling source states and choose the reported metrics accordingly.

ISO field measurements also distinguish between quantities normalised to receiving-room absorption and those standardised to a reference reverberation time; these are not interchangeable corrections. One changes the result by reference to equivalent absorption area; the other by reference to decay time; the selected descriptor should match the intended comparison; a test report that presents a weighted field result without its underlying quantity, source-room volume, receiving-room volume, decay data, and normalisation basis leaves the reader unable to reconstruct the result.

8.5 Laboratory ratings, field classifications, and the flanking question

ASTM E90 is a laboratory transmission-loss method; its controlled chambers and specimen opening are designed to suppress paths other than transmission through the specimen; ASTM E336 addresses airborne sound attenuation between rooms in buildings and therefore observes the performance of the completed separation in its actual surroundings. The

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latter can include direct transmission, junction transmission, ceilings, floors, façades, ducts, doors, and other flanking paths; ASTM E413 may then be used to classify certain laboratory or field curves, but the metric name must reveal which curve was classified.[402]

The distinction is more than nomenclature. A laboratory specimen may perform exceptionally while the completed room fails because the wall terminates at a suspended ceiling, a return-air plenum connects adjacent rooms, a door undercut remains open, a steel column bypasses the partition, or a cable tray was installed after the test. Conversely, a field result may be limited by the receiving-room background or available source level before the boundary reaches its true performance; a lower field number does not by itself identify the failed construction; it identifies the performance of the tested room pair under the method and conditions.

ASTM E336-25a uses several distinct quantities and classifications, including level-reduction and normalised or apparent descriptors; these are not interchangeable merely because each is expressed in decibels; a raw level difference depends upon the receiving-room absorption and volume; a normalised result adjusts to a specified reference. An apparent transmission-loss result incorporates specimen area and receiving-room absorption under the field model; the reporting language must state the quantity before the number.[403]

A secure-room commissioning plan should therefore retain at least three layers of evidence; the first is laboratory evidence for proprietary or prescriptive assemblies; the second is field evidence for the completed

402 MB-0724. ASTM International, ASTM E90-23, ASTM E336-25a.
403 MB-0723. ASTM International, ASTM E336-25a, ASTM E2235-04.

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boundary and accessible receiving locations; the third is occupied-condition evidence linking residual speech to background, masking, listener access, and the defined security criterion. The layers may use different methods; their results should be connected through an explicit evidence map rather than collapsed into one headline number.

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Table 8-1. Principal rating families and bounded propositions

Descriptor	Typical evidence source	Primary proposition supported	Principal limitation
Band transmission loss	Laboratory specimen test	Frequency-dependent direct transmission of the tested specimen	Does not include ordinary building flanking
STC	ASTM classification of an applicable curve	Reference-contour classification under ASTM E413	Conceals curve shape and does not prove speech security
Rw	ISO classification of laboratory sound-reduction data	Weighted laboratory sound-reduction index	Not numerically interchangeable with STC by assumption
ASTC or apparent weighted field result	Completed room-pair test	Combined direct and flanking performance under the field method	Does not identify individual paths without diagnostics
NIC or level-reduction classification	Field level differences	Room-to-room attenuation under stated conditions	Depends upon receiving-room conditions and is not a material property
Speech privacy metric	Residual speech and background under a speech method	Probability or degree of audibility or intelligibility for a stated listener model	Does not confer governmental accreditation

8.6 Why equal ratings can represent unequal risk

Two assemblies can receive the same single-number classification while exhibiting different band curves; one may have moderate, even performance; another may be strong in the middle and high bands but weak at low frequency. A third may contain a narrow leakage-controlled trough that happens not to move the contour; in ordinary office planning, the classifications may still provide useful comparative information; in a room intended for sensitive discussion, the differences can be material because speech effort, listener position, background sound, and repeated exposure can exploit the residual spectrum.[404]

The comparison in Figure 8-1 uses two deliberately simplified curves. Assembly A provides stronger low-frequency performance but lower high-

404 MB-0725. ASTM International, ASTM E2638-24.

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frequency values. Assembly B rises sharply from weak low bands and then exceeds Assembly A. A single-number procedure centred on the prescribed range may place them close together. A person selecting only by rating would miss the low-frequency contrast. The correct response is not to reject ratings. It is to retain the curves whenever the design question depends upon source spectrum or mechanism.

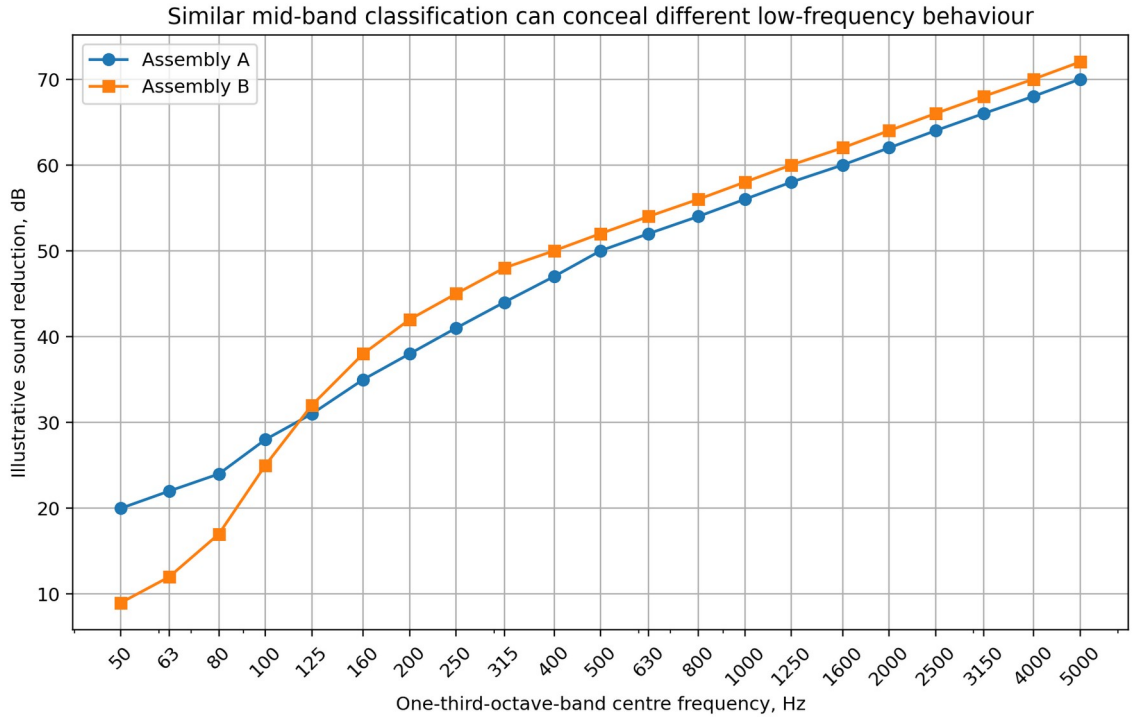

Figure 8-1. Frequency curves and single-number concealment. Author's original plot using illustrative data. Similar mid-band classification can conceal markedly different low-frequency transmission.

Low-frequency weakness has several causes. In double-leaf gypsum construction, mass-air-mass resonance can produce a broad depression; in concrete or masonry rooms, a structural slab, column, or rigid service connection can carry low-frequency vibration around the nominal boundary; in doors, leaf bending and seal compression can interact with the frame; in glazing, panel dimensions, laminate, cavity, and frame leakage shape the

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result; a rating that does not preserve those distinctions cannot support a mechanism-specific remedy.

High-frequency weakness also matters. Small gaps, unsealed perimeter joints, hardware penetrations, and thin duct liners can produce leakage at bands where consonant information is concentrated; a residual high-frequency fragment may not sound loud, yet it can improve recognition of names or technical terms when combined with lower-frequency rhythm and context. The secure-room analysis should therefore avoid an exclusive fascination with low frequency; the point is frequency resolution, not a universal presumption that one end of the spectrum always governs.

The rating may also conceal temporal behaviour; a door seal that seats only when the latch is fully thrown, a pressure-dependent transfer grille, or an intermittent fan can change the residual spectrum between test runs; a static classification measured in one state cannot describe the distribution of states. Commissioning must therefore define normal, worst credible, and degraded configurations.

8.7 Composite boundaries and the arithmetic of weak elements

A room boundary is commonly composite; a wall contains a door, glazing, outlets, penetrations, and junctions; if the elements transmit independently over their respective areas, the area-weighted composite transmission coefficient is

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Equation 8.2

$$\tau_c(f)=\frac{\sum_{i=1}^{n} S_i 10^{-R_i(f)/10}}{\sum_{i=1}^{n} S_i},$$

and the corresponding composite reduction is

Equation 8.3

$$R_c(f)=-10\log_{10}\tau_c(f),$$

where S_i is the area of element i and $R_i(f)$ is its band sound reduction. This first-order model is useful because it exposes the logarithmic dominance of weak elements. It is not a complete field model because edge transmission, interaction, frame paths, and flanking are omitted.[405]

Worked example 8.3. A high-rated wall with a modest door

A 22 m² boundary contains a 20 m² wall with a 60 dB band loss and a 2 m² door with a 30 dB band loss. The wall transmission coefficient is 10^{-6}. The door coefficient is 10^{-3}. Equation 8.2 gives

$$\tau_c=\frac{20\left(10^{-6}\right)+2\left(10^{-3}\right)}{22}=9.18\times10^{-5}.$$

Therefore,

$$R_c=-10\log_{10}\left(9.18\times10^{-5}\right)=40.4\,dB.$$

The 30 dB door occupies only 9.1 per cent of the area, yet the composite boundary is approximately 40 dB, not something close to the 60 dB wall; increasing the wall from 60 to 65 dB changes the composite result by less

405 MB-0726. Carl Hopkins, ISO 12354-1:2017.

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than a tenth of a decibel. The rational design action is to improve the door system or add a sound lock, not to buy a heavier wall.

The calculation in Figure 8-3 generalises the weak-element effect. As wall performance rises, the composite result asymptotically approaches the limit imposed by the door. The curves are band-specific and assume independent area transmission. Real doors often perform worse after installation because of frame, seal, threshold, hardware and operational defects. The figure is therefore an explanatory model, not a product prediction.

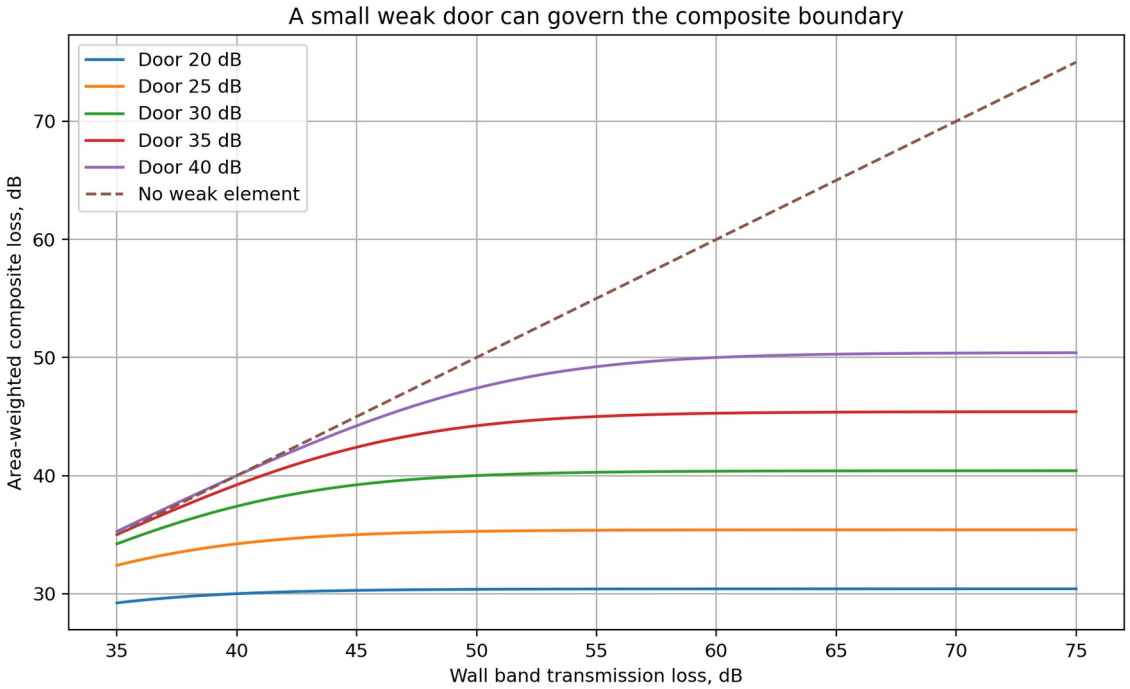

Figure 8-3. Composite weak-element effect. Author's original calculation. A 2 m² door in a 22 m² boundary can govern the composite result even when the surrounding wall is improved substantially.

The same arithmetic applies to glazing and intentional openings, but not all weak paths have a meaningful surface area; a crack, conduit, or duct may behave as an aperture or waveguide rather than a simple panel; its contribution must be measured or modelled through an appropriate transfer function. Assigning it a fictitious STC can disguise the mechanism.

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8.8 Component ratings and system ratings

Doors, operable partitions, access panels, glazing, silencers, and ceiling systems are often supplied with rating data. Each product class has its own specimen conventions and failure mechanisms; a door-set result belongs to the complete tested set, including leaf, frame, seals, threshold, hardware preparation, size, and mounting; a glazing result belongs to the pane build-up, dimensions, edge support, airspace, frame, and sealant. A silencer insertion-loss result belongs to its test arrangement, airflow condition, pressure drop, and end reflection assumptions; these results cannot be inserted into a room specification as interchangeable “STC items.”[406]

The terms “acoustic door” and “soundproof glass” are commercial descriptions, not measurements; the submittal must identify the applicable standard, laboratory, report number, specimen dimensions, rating, frequency curve, hardware, seals, and deviations from the tested configuration; if the proposed field installation differs, the design team should assess the direction and magnitude of the change. A larger leaf, closer cut-out, drop seal, electromagnetic lock, card-reader conduit, or transfer grille may materially alter the result.

Ceiling Attenuation Class and other ceiling-plenum metrics describe specific paths and test configurations; they do not establish the isolation of a room whose partition stops at the ceiling; likewise, an impact rating addresses impact transmission, not airborne speech. Outdoor-indoor ratings address façade exposure, not room-to-room privacy; the presence of a decibel value and an integer class does not make two metrics commensurate.

406 MB-0727. ASTM International, ASTM E413-22, ISO 717-1:2020.

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A useful submittal review asks four questions; first, what physical quantity was measured? Second, what specimen was measured? Third, what calculation produced the single number? Fourth, how does the proposed installation differ? The reviewer should not begin with the catalogue number; the catalogue number is the conclusion of an evidence chain that must be reconstructed.

8.9 The contractual life of a rating

Ratings acquire legal and commercial force through specifications; a requirement such as “provide partitions with STC 55” is defective because it does not identify the evidence expected at design, submittal, installation, or acceptance; a robust requirement distinguishes a laboratory basis-of-design from field acceptance. It states the governing standard and edition, the required band data, the maximum permitted substitutions, the treatment of doors and services, the receiving locations, the acceptance statistic, and the decision rule; it also states whether the requirement applies to each boundary, an average, or the worst accessible point.[407]

The contract should address uncertainty before testing; if the nominal requirement is ASTC 50, does a measured result of 50 pass without regard to uncertainty? Is a guard band required? Is retesting permitted? Who selects the test positions? What happens when the instrument background limits several bands? Does a result below the rating but above a speech-privacy criterion constitute acceptance? These questions are not testing details. They allocate risk.

407 MB-0728. ASTM International, ASTM E413-22, ISO 717-1:2020.

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Specifications should distinguish “shall” from “target.” A target is a design aspiration. A shall requirement is a contractual obligation; if the consultant writes a high rating as a target and later treats it as mandatory, the contractor may reasonably object; if the consultant writes an ambitious mandatory field value without assessing source capability, room volume, background, and available remedies, the owner may purchase a dispute rather than an acoustic boundary.

The submittal schedule should require raw or tabulated band results, not only a certificate showing a classification; reports should be legible, traceable, and complete enough to compare the tested specimen with the proposed work; a marketing summary is not a test report. A laboratory letter without specimen drawings is not an adequate construction record.

8.10 Rounding, uncertainty, and classification stability

Single-number ratings are integer outputs derived from continuous and uncertain inputs. The source and receiving levels, decay time, area, background correction, microphone positions, source stability, and analysis software all contribute uncertainty; the contour or weighting calculation can amplify small changes when the result lies near a shift boundary; an integer classification should therefore be accompanied by the underlying curve and an uncertainty statement appropriate to the method and decision.[408]

Repeatability within one laboratory is not the same as reproducibility among laboratories; specimen construction adds another component. Two nominally identical gypsum walls may differ because of board density, fastener torque, stud alignment, cavity fill, sealant, workmanship, curing,

408 MB-0703. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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and mounting; a published rating is not a deterministic constant for every future specimen; the design should use a margin that reflects both measurement uncertainty and construction variability.

Classification stability can be tested by perturbation; the analyst can add and subtract plausible band uncertainties, recompute the rating, and observe how often the class changes; this is not a replacement for the governing uncertainty procedure, but it reveals fragility; a classification that changes under a 0.3 dB shift in one influential band should not be presented as a sharp boundary between acceptable and unacceptable physical performance.

The report should avoid false decimals; STC 50.7 is not a standard classification merely because software produced a decimal intermediate; the underlying band data may be reported to appropriate precision, but the final class follows the standard; conversely, an integer result should not be mistaken for exactness. The reporting note should identify the method's resolution and the decision rule.

8.11 Forensic interpretation of ratings

In dispute or incident analysis, the first task is to separate the documents; the design drawing may show a partition type; the specification may require a laboratory class; the product submittal may cite a report; the as-built wall may differ. The field test may measure an apparent result. The security authority may have accepted the room for a different reason. These records are not interchangeable. A forensic opinion should identify which proposition each record supports and where the chain breaks.[409]

409 MB-0704. ASTM International, ASTM E413-22, ISO 717-1:2020.

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A low field classification does not prove that the wall leaf is defective; the result may be governed by a door, plenum, slab, duct, column, or receiving-room background; a high laboratory rating does not exonerate the installation; it proves only the laboratory specimen. A passing occupied speech test does not prove every boundary path; the background or masking may have concealed a weakness during the test; a narrow conclusion is stronger than a dramatic one.

The examiner should preserve raw spectra, source states, room geometry, decay data, photographs, door positions, HVAC states, and access conditions; recalculation should use the edition of the method specified or applicable at the time; if a later standard changes terminology or procedure, the report should explain the difference rather than silently reclassifying the historic result.

Where proprietary reports are incomplete, the examiner may need to state that the rating cannot be verified; the absence of a specimen drawing, seal schedule, or laboratory identity is an evidentiary limitation; it should not be repaired through catalogue inference.

8.12 Design rules derived from the rating analysis

The practical rules are concise. Retain frequency curves. Name the quantity before the number; identify laboratory and field propositions separately. Use source-spectrum terms where applicable. Do not convert STC and Rw by habit. Require complete specimen evidence. Treat doors, glazing, services, and flanking as system elements; State the acceptance rule before testing;

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preserve uncertainty and raw data; never imply that a single-number rating establishes secure speech or accreditation.[410]

These rules do not diminish the value of classification. They restore it. A rating used within its method is a compact and defensible descriptor; a rating used outside its method is a slogan; the difference lies in the surrounding evidence.

8.13 Frequency range, source spectra, and the low-band problem

The lowest classified band is not the lowest frequency at which a room can transmit useful information; this point is elementary in physics and frequently neglected in procurement; a participant’s voice contains fundamental-frequency energy, harmonics, temporal envelope, and prosodic modulation. The fundamental of an adult male speaker often lies below the central part of an insulation classification range, while vowels and voiced consonants extend through it; a loudspeaker can add still lower programme energy, equalisation, and cabinet or table vibration; mechanical plant can modulate the receiving environment. A rating that begins above the most troublesome structural or cavity resonance may therefore remain administratively correct while leaving the dominant diagnostic mechanism unclassified.

Supplemental low-frequency measurements are valuable when the rooms are large enough, the source system can excite the bands, and the receiving background permits a credible result; they are not automatically more accurate merely because they extend lower. At long wavelengths, rooms support sparse modes, source location becomes influential, microphone

410 MB-0705. ASTM International, ASTM E413-22, ISO 717-1:2020.

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spatial variance grows, and the assumption of diffuse fields weakens; a 50 Hz result obtained from one source and one microphone position can be less representative than a carefully averaged 100 Hz result. The test plan must balance operational relevance against metrological validity.[411]

The report should distinguish three categories; classified bands are those used by the named rating procedure; supplemental measured bands are reported under an identified extension or project procedure but do not enter the classification unless the method expressly permits it; extrapolated bands are analytical predictions rather than measurements. A table that places all three in one column without status labels invites misuse.

A useful design record presents the source spectrum alongside the insulation curve; for ordinary speech, the spectrum should represent the selected vocal effort and talker population; for amplified rooms, the loudspeaker’s maximum permitted programme and limiter state should be considered. The residual receiving spectrum is obtained by subtracting the path attenuation from the source spectrum in each band, then comparing it with background or masking; this operation reveals why a rating alone cannot decide speech privacy.

Low-frequency deficiencies are often expensive to correct after construction because they arise from global dimensions, structural continuity, or coupled leaves rather than local sealant; the rating review should therefore occur before wall depth, slab isolation, plant location, and room geometry are fixed; a late request to “add five STC points” may be physically meaningless if the actual problem is a 63 Hz flanking path through a concrete slab.

411 MB-0706. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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8.14 The reference spectrum hidden inside a rating

Every weighting scheme embodies a comparison shape; the reference contour is not a neutral mathematical convenience; it encodes assumptions about which parts of the spectrum should influence the single number and by how much; the assumptions may be entirely reasonable for the method's intended building-acoustics use. They remain assumptions. A security engineer should ask whether the controlling source and listener problem resembles the spectrum implicit in the rating.

STC and R_w are commonly compared through tables of typical differences. Such tables can be helpful at concept stage, but they cannot support a contractual conversion. The difference between the ratings varies with curve shape. A heavy homogeneous wall, a lightweight double-leaf wall, laminated glazing, and a door-set may not preserve the same numerical relationship. If a project team receives an STC report for an R_w specification, the proper response is to obtain or calculate the required classification from eligible band data, using the correct method, rather than add or subtract a remembered constant.

The same principle applies to spectrum adaptation; an adaptation term is not a universal penalty for "traffic" or "low frequency." It is calculated from defined reference spectra and the measured sound-reduction data; the result must be reported with the weighted index in the form prescribed by the standard. Removing the sign, changing the source spectrum, or quoting only the combined number can obscure its meaning.[412]

412 MB-0707. International Organization for Standardization, ISO 717-1:2020.

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For secure-room design, source-spectrum analysis should not be limited to one nominal talker; a practical matrix may include normal conversation, raised voice, maximum credible unamplified effort, conferencing loudspeaker output, and equipment-generated audio; each state should be linked to an operational control; if the room's security depends upon a limiter, policy should prevent its bypass; if it depends upon a masking system, the commissioning record should include failure alarms and degraded-mode instructions.

The design team should resist the temptation to invent a proprietary "secure STC" by changing weights without validation; a project-specific risk index can be useful, but it must be described as a decision aid, not a consensus classification; its source spectra, band importance, listener model, uncertainty, and validation set must be disclosed; otherwise, the new number simply creates another layer of compression whose limitations are harder to see.

8.15 Curve shape as a diagnostic signature

An insulation curve can be read diagnostically. The interpretation is not automatic, because different mechanisms can produce similar shapes, but the curve narrows the hypotheses; a broad low-frequency depression in a double-leaf wall suggests coupled resonance or structural interaction; a localised mid-frequency trough may correspond to panel resonance, a cavity dimension, or a frame member. A gradual high-frequency flattening can indicate leakage; an abrupt change after a construction modification may reveal that one path has been suppressed and another has become dominant.[413]

413 MB-0708. ASTM International, ASTM E413-22, ISO 717-1:2020.

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The diagnostic process should compare the measured curve with controlled state changes; close and latch the door; seal a suspected gap temporarily with a reversible material. Stop the fan. Change source position. Measure the plenum. Add mass to a panel. Observe whether the predicted bands change; a mechanism is strengthened when the response follows a physical perturbation; it is weakened when the curve remains unchanged.

Intensity scans, near-field sound-pressure maps, structural vibration measurements, and transfer functions can supplement the rating curve; their purpose is not to generate more attractive graphics; it is to separate paths; a door perimeter may radiate strongly at high frequency while the leaf controls the mid-band; a steel beam may carry low-frequency vibration to the receiving room; a duct may show a narrow tonal path; each remedy should target the demonstrated path.

Curve comparison requires consistent conditions. A before-and-after plot is misleading if the source room, receiving absorption, background, source position, door state, or analysis bandwidth changed; the report should show the raw observations and corrections, not merely the final classification; if one band was censored by background, it should not be displayed as an ordinary measured value.

A useful forensic figure overlays four curves: the laboratory specimen, the field boundary, the close-range diagnostic path, and the post-remediation field result; the differences reveal where the design departed from the specimen and whether the repair altered the governing mechanism. The classification can be displayed beside the curves, but it should not replace them.

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8.16 Openings, seals, and the non-linearity of leakage

Air leakage and acoustic leakage are related but not identical; a small opening that passes little steady airflow can transmit sound efficiently at wavelengths much larger than the gap. Its behaviour depends upon geometry, depth, lining, end correction, pressure distribution, and frequency; a continuous perimeter crack around a door can be more consequential than one local opening of the same area because it couples a large pressure field to the receiving side.[414]

The effect of leakage is logarithmic. Consider a nominal 15 m² partition with 60 dB band loss. A total open area of 100 cm², only 0.067 per cent of the wall area, is assigned an illustrative zero-loss aperture in a simple area model. The wall coefficient is 10^{-6} and the aperture coefficient is approximately one. The composite coefficient is roughly 6.68×10^{-4}, corresponding to only 31.8 dB. The model neglects aperture impedance and is therefore conservative in some configurations, but it demonstrates why a pencil-width gap can destroy a high-rated boundary.

Seal performance is state-dependent. Compression seals require sufficient closing force and uniform frame alignment; automatic bottoms depend upon adjustment, floor level, and debris. Astragals depend upon leaf sequence. Fire-rated hardware can limit available seal arrangements; electromagnetic locks, panic hardware, hinges, closers, and card-reader wiring create additional paths; the rated door-set should be reviewed as an operating mechanism, not as a slab.

414 MB-0709. Carl Hopkins, ASTM E90-23.

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Field classification can expose leakage but may not locate it; diagnostic listening or scanning should occur with the test signal active and under controlled access; temporary sealing can identify the contribution, but the temporary material must not be mistaken for a permanent compliant repair. Fire, egress, accessibility, smoke, and security requirements remain controlling.

The maintenance plan should include seal inspection and functional testing; a door that passed at commissioning may degrade through hinge wear, warped leaves, carpet replacement, threshold damage, or closer adjustment; configuration control is part of acoustic performance because the rating is conditional upon the physical state.

8.17 Classification of variable and operable systems

Operable partitions, demountable walls, movable acoustic panels, and large doors introduce repeatability as a central performance variable. The result depends not only upon material construction but upon closure sequence, panel alignment, top and bottom seals, floor tracks, storage handling, and operator practice; a single laboratory rating obtained from a carefully installed specimen may not represent the distribution of field states.[415]

Acceptance testing should include repeated opening and closing cycles by ordinary users; the purpose is to observe whether the result is robust to realistic operation; if the first closure yields 49 dB, the second 44 dB, and the third 48 dB, the mean alone conceals a security-relevant low state. The specification may need a minimum-of-replicates rule rather than an average.

415 MB-0710. ASTM International, ASTM E413-22, ISO 717-1:2020.

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Variable systems also complicate room classification. A conference suite may combine two rooms into one and later divide them; HVAC zoning, masking, audiovisual systems, and access control change with the partition state; a high partition rating cannot compensate for a common return plenum or an active loudspeaker on the receiving side. Commissioning should test each authorised configuration.

Demountable systems require special scrutiny at head, base, and intersections; raised floors and suspended ceilings can bypass the panel; reconfiguration creates new joints and service penetrations; the as-built record should identify panel types and permitted layouts. A later facilities team should not assume that a modular wall may be moved without acoustic recommissioning.

The rating report should describe specimen width, height, panel count, joint count, closure force, and operator procedure; a result for a small specimen with few joints may not transfer to a long field installation; the uncertainty budget should include operational variability where the acceptance proposition concerns repeated use.

8.18 Ratings in predictive design models

Design models use laboratory data to estimate building performance. ISO 12354-1 and related engineering methods combine direct sound reduction with flanking transmission through junctions and structural elements; the resulting apparent performance is not a simple subtraction of a universal “field loss.” It depends upon geometry, junction type, material properties,

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element dimensions, structural coupling, and the completeness of the path model.[416]

A common rule of thumb assumes that field performance will be five points below laboratory rating; such a margin may be useful as a preliminary allowance, but it is not a physical law; a well-detailed isolated boundary can approach its laboratory basis in some bands. A poor junction can lose far more; a concrete slab can dominate low-frequency flanking while the wall remains intact; prediction should identify paths rather than hide them inside an arbitrary deduction.

Model inputs should retain frequency dependence. Entering only STC or R_w into a model cannot reproduce resonance, coincidence, or path crossovers. If software accepts only single numbers, it is unsuitable for detailed secure-room analysis. The analyst should use band data and document source provenance.

Calibration of the model against field measurements is valuable, but it must avoid circularity; adjusting every uncertain parameter until the model matches one room can produce a numerically perfect but non-predictive fit; parameters should be constrained by drawings, measurements, and material data. The calibrated model should then be tested against a second configuration or location.

Sensitivity analysis identifies which inputs matter; if changing wall sound reduction by 10 dB alters apparent performance by only 0.5 dB, the wall is not governing; if changing a junction vibration-reduction index shifts the low

416 MB-0711. International Organization for Standardization, ISO 12354-1:2017, ISO 10848-1:2017.

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bands materially, the design should focus on structural isolation. This is a more rational use of ratings than choosing the highest catalogue number.

8.19 Rating evidence in submittals and substitutions

A submittal should permit an independent reviewer to compare the proposed assembly with the tested assembly; the minimum record includes the complete test report, specimen drawing, materials, dimensions, mass per area, framing, fasteners, cavity treatment, perimeter mounting, openings, laboratory identity, standard edition, date, band data, and classification. Redacted proprietary reports may be acceptable only if the redaction does not remove the evidence needed for comparison.[417]

Substitution review should use a difference register; changing one gypsum-board brand may be immaterial if density, stiffness, thickness, edge, and certification remain equivalent; changing from independent double studs to staggered studs is not equivalent; moving resilient clips to the other side, changing channel spacing, omitting cavity insulation, substituting a door size, or adding a card-reader conduit can alter the mechanism. The contractor’s statement that the product is “equal or better STC” is not sufficient.

The reviewer should distinguish classification equality from assembly equivalence; two products may both show STC 55 while having different curves, fire ratings, structural capacity, durability, seal systems, and tested dimensions; the project requirement may depend upon those differences. A substitution decision should therefore address the whole performance specification.

417 MB-0712. ASTM International, ASTM E413-22, ISO 717-1:2020.

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Laboratory reports should be checked for extensions and engineering judgements; a test report documents what was tested; an assessment letter may infer performance for a variant; such inference can be legitimate, but its basis and limitations should be explicit. The document should not be relabelled as a test.

A secure-room project may also require control of report distribution; detailed construction reports can reveal boundary design; the source register should identify handling requirements without converting public or commercial data into a classified status; evidence governance and technical validity are separate questions.

8.20 Worked comparison of equal classifications

Consider two hypothetical wall curves that both satisfy the same teaching classification. Assembly A has losses of 25, 29, 34, 39, 44, 49, 53, 56, 58, 60, 62, 64, 66, 68, 70, and 72 dB from 125 Hz to 4000 Hz; assembly B has 17, 24, 34, 42, 48, 52, 55, 57, 59, 61, 63, 65, 67, 69, 71, and 73 dB. The mid and upper bands of B are stronger, but its first two bands are weaker.[418]

Suppose a normal-speech source spectrum at the wall is 68, 70, 72, 72, 71, 69, 66, 63, 60, 57, 54, 51, 48, 45, 42, and 39 dB; subtracting the path loss gives the residual spectra; at 125 Hz, A yields 43 dB and B yields 51 dB. The corresponding 160 Hz values are 41 dB and 46 dB; above 500 Hz, B is generally one to three decibels quieter.

If the receiving background is low and the boundary is accessible, B may present greater low-frequency audibility despite its strong upper bands; if the background is dominated by low-frequency ventilation, the difference

418 MB-0715. ASTM International, ASTM E413-22, ISO 717-1:2020.

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may be less consequential, while A’s weaker mid bands may govern consonant recognition. The rating cannot decide between them. The source and background spectra are needed.

The example also demonstrates why “higher in most bands” is not a complete design rule; the relevant result is the residual signal relative to the receiving condition and listener task; a secure-room analysis should therefore maintain a band-by-band consequence model at least through design and commissioning.

8.21 Composite case study. Boardroom boundary with wall, door, glass, and plenum

A hypothetical executive boardroom is separated from a controlled corridor by 28 m^2 of double-stud gypsum wall, a 2.2 m^2 single door, 4.5 m^2 of laminated glazing, and a ceiling plenum connecting to an adjacent office. The wall has a laboratory classification substantially above the door and glazing; the design team initially records the wall class as the room’s acoustic-security value.

A band model shows that the door controls 250 Hz to 1000 Hz, glazing controls 1250 Hz to 3150 Hz, and the plenum controls several higher bands when the return fan is off; the wall is not controlling any speech band; increasing board layers changes the predicted room-to-corridor result negligibly; a vestibule, improved glazing frame, and ducted return with a silencer produce meaningful improvement.

During commissioning, the corridor background is 8 dB higher with the air system operating; the occupied-condition speech test appears satisfactory in that state; when the fan cycles off, consonant fragments become audible

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near the ceiling; the field attenuation curve is unchanged; the receiving background changed. The case demonstrates that rating evidence and occupied security evidence are different layers.

The acceptance record therefore contains four documents: laboratory reports for wall, door, and glazing; a field room-to-room measurement; a plenum diagnostic test; and an occupied speech assessment under fan-on and fan-off states; the authority decides whether the operational control on the ventilation system is acceptable. No one number replaces the package.

This case also illustrates the value of design-stage composite modelling; had the team focused upon the complete boundary rather than the wall rating, the vestibule and return path could have been included before construction; the cost of early analysis is small compared with rebuilding a finished corridor.

8.22 Specimen size, mounting opening, and laboratory boundary conditions

A laboratory rating is conditional upon the specimen opening and mounting. Panel dimensions affect modal density, bending-wave behaviour, coincidence, edge restraint, and joint count; a small door or glazing specimen may not reproduce the deflection, hardware, or seal length of a larger field unit; a wall tested between massive laboratory chambers experiences boundary conditions unlike a partition attached to flexible decks, façades, or raised floors.[419]

The report should therefore include specimen dimensions and mounting details; a rating certificate without them is insufficient for comparison;

419 MB-0718. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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gypsum walls require stud spacing, gauge, track attachment, board orientation, screw spacing, joint treatment, cavity insulation, and perimeter seal; masonry requires unit density, grout pattern, mortar, finish, and curing; glazing requires glass build-up, frame, bite, gasket, and sealant. Door sets require every hardware penetration and seal.

Laboratory openings can introduce their own flanking or masking limits; accredited methods control these effects, but high-performance specimens may approach the facility limit; the report should disclose limiting background, flanking checks, and qualified ranges where available; a plateau at high loss may reflect the facility rather than the specimen.

Field substitutions often change scale. A 2.0 m by 0.9 m tested door may be proposed at 2.4 m by 1.2 m; the perimeter-to-area ratio changes, leaf stiffness changes, and hardware may differ; the rating cannot be transferred by area alone. An engineering assessment should identify whether a new test is required.

8.23 Interlaboratory reproducibility and the myth of the exact catalogue number

Two competent laboratories can obtain different curves for nominally identical specimens; differences arise from specimen construction, material batches, mounting, chamber fields, instrumentation, analysis, and method reproducibility; the published integer is therefore not an immutable product constant.[420]

Manufacturers may test several specimens and publish the best result; this is not necessarily improper if the report is accurate, but the designer should

420 MB-0719. International Organization for Standardization, ISO 12999-1:2020, ISO/IEC 17025:2017.

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know whether the value is typical, minimum, or maximum observed; a robust specification can require a tested assembly plus a design margin and field acceptance, rather than assuming catalogue equality.

Interlaboratory data are valuable for uncertainty and reliability; if comparable specimens vary by three points among laboratories, a one-point contractual distinction between products is weak; the review should focus on curve shape, construction, quality controls, and field evidence.

The exact integer can also change when a standard edition changes; a revised classification rule, band treatment, or terminology may alter the reported number without physical change; historic reports should be interpreted under their stated edition; a current project should use the current specified edition and avoid silently re-rating old data unless the underlying bands are available.

8.24 One-number selection for different construction families

Homogeneous heavy walls, lightweight framed walls, doors, glazing, and duct systems fail differently; a single rating has different diagnostic sufficiency for each family; a dense concrete wall may have a relatively smooth mass-controlled curve while a double-leaf wall has resonance and coincidence features; a door may be leakage-controlled. Glazing may show panel and frame effects; a duct path is not adequately represented by a wall rating.

For heavy walls, source and field flanking can dominate once direct transmission becomes strong; the laboratory number may have diminishing design value unless junctions are modelled; for lightweight walls, the detailed leaf, frame, cavity, and resilience are essential. Two nominal STC

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values do not reveal whether one assembly has a fragile resonance near speech bands.

For doors and glazing, complete system reports are necessary; a leaf or pane classification without frame and seal evidence should not be accepted; for silencers, insertion loss, generated noise, pressure drop, airflow, and breakout are the relevant quantities. Calling a silencer “STC 50” would be category error.

The metric schedule should therefore be component-specific. The room-performance schedule then assembles component and path evidence into field and occupied criteria.

8.25 Façade and exterior metrics

Outdoor-indoor transmission class and façade sound-insulation metrics address environmental sources and exterior-to-interior transmission; they can inform secure rooms near public access, roofs, courtyards, or adjacent buildings; they are not substitutes for room-to-room classifications.

Exterior source fields differ from diffuse laboratory fields; traffic, aircraft, voices, and loudspeakers have direction, distance, ground effects, and atmospheric conditions; façade geometry and reflections matter; windows, vents, and curtain walls often govern.

A secure-room façade assessment should identify credible exterior listener positions as well as exterior source threats; preventing exterior noise intrusion and preventing interior speech radiation are reciprocal in a linear passive system, but background, directivity, and access differ. A façade with good environmental rating may still contain local leakage at mullions or vents.

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The report should state the applicable metric and source direction. An OITC value cannot be inserted into an internal-wall STC schedule without explanation.

8.26 Ceiling, plenum, and impact metrics that are often confused

Ceiling attenuation class concerns transmission through a ceiling-plenum-ceiling path under a particular test arrangement; impact insulation class concerns impact excitation of floors; room criteria and noise criteria concern background; none is a direct substitute for airborne room-to-room isolation.[421]

The confusion arises because all produce decibel-like ratings. A project schedule may list STC, CAC, IIC, NC, and NRC in adjacent columns. The acronyms look commensurate. Their measurands are not.

A suspended ceiling with high CAC can contribute to office privacy where partitions stop at the ceiling, but a secure room should ordinarily control the plenum and boundary explicitly; ceiling tiles are removable and services penetrate them. A high CAC result does not address duct cross-talk, cable trays, or access.

Impact performance matters when footsteps or equipment vibration create masking or interfere with testing, and when structure-borne paths can carry speech-related vibration. It remains a different excitation and metric.

The specification should define each acronym on first use and identify the assembly or path to which it applies. Ambiguous rating schedules are a predictable source of construction error.

421 MB-0720. Marshall Long, Architectural Acoustics.

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8.27 Rating databases and evidence quality

Online databases and manufacturer compilations make ratings easy to search; they also detach numbers from reports; a responsible database record should retain the source laboratory, report number, date, standard, specimen, curve, and limitations.

Duplicate records can create false confidence; the same report may be republished by a distributor, manufacturer, and association; counting three web pages as three independent tests is incorrect.

Search filters can also hide configuration; “double stud, STC 60” may return assemblies with different board density, stud depth, cavity, insulation, and resilient elements; the designer should retrieve the original report.

Data provenance should be part of the project source register; where only a summary is available, classify it as a lead rather than controlling evidence; do not infer missing band data from the class.

A local project database can improve consistency if it stores full metadata and checksums. It should not become a repository of orphaned ratings.

8.28 Probabilistic design margin

Design margin addresses the chance that the completed work will underperform the nominal design. It can be based on predicted field mean, construction variability, measurement uncertainty, and required reliability.

Suppose a model predicts an apparent class equivalent of 54, construction variability has standard deviation 2 points, and acceptance requires at least 50; under a simplified normal model, the margin is two standard deviations and the probability of falling below 50 is about 2.3 per cent. If uncertainty of field measurement is also material, decision risk must be added separately.

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This calculation is illustrative because classifications are discrete and distributions may not be normal. It nevertheless shows why a margin should be justified rather than arbitrary.

A very high nominal wall rating does not create system margin if a door governs. Margin analysis must be path-based. Investment should increase the weakest path and reduce variability.

Quality assurance can reduce variability. Mock-ups, trained installers, inspection hold points, seal testing, and as-built records may be more valuable than another board layer.

8.29 Rating requirements in design-build and performance contracts

Performance specifications give the contractor freedom to choose assemblies while holding an outcome. Prescriptive specifications define construction. Secure rooms often require a hybrid. Critical details are prescribed, while field performance is verified.

A pure performance requirement can fail when the contractor cannot test until late construction. Remedies may be disruptive. A pure prescriptive requirement can fail when the prescribed assembly is undermined by site junctions; the contract should include early mock-ups and predictive review.

Design-build responsibility should be clear. Who selects the field metric? Who models flanking? Who supplies source power for acceptance? Who pays for retest? Who controls post-test changes? Silence creates adversarial interpretation.

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The acceptance criterion should apply to named room pairs and positions; an average across rooms can hide a failed high-consequence boundary; sampling rules should be defined.

8.30 Rating statements in professional reports

A good statement includes the metric, method, edition, configuration, result, uncertainty or limitation, and proposition; for example: “The completed separation between Conference Room A and Corridor C achieved ASTC 51 under the stated field method with both vestibule doors latched and masking disabled; the result represents combined direct and flanking performance of the tested room pair and does not by itself establish speech unintelligibility or accreditation.”

A poor statement says: “The room is STC 51 and secure.” It misnames the object, hides the method, and overstates the conclusion.

Professional language should also avoid “soundproof.” No ordinary room is absolutely impermeable to sound. “High-isolation,” “field-tested,” and “met the specified criterion” are more precise.

Where a result is limited, state the limit. “At least 58 dB in the 1000 Hz band due to receiving background” is more honest than a fabricated 60 dB.

8.31 Historical ratings and changing expectations

Older buildings may have been designed under earlier standards, terminology, and privacy expectations. Historic reports can be technically valuable but should not be treated as current compliance evidence without review.

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Materials and workmanship also change. Traditional plaster on lath, heavy timber, clay tile, and dense masonry can behave differently from modern systems. A historic rating may not document hidden conditions.

Security expectations evolve with listener technology, building use, and organisational risk. A room accepted decades ago may require reassessment after tenant change, digital conferencing, lower backgrounds, or new public access.

The forensic record should preserve historical context while applying current decision authority. It should not rewrite the past or assume grandfathering.

8.32 Rating-focused inspection checklist

Before relying upon a rating, the reviewer should verify the exact metric; standard and edition; laboratory or field status; complete curve; specimen or room geometry; material and installation match; doors, glazing, services, and flanking; background limitations; uncertainty; decision rule; and accreditation boundary.

The checklist is deliberately short because each item opens a substantial evidence inquiry. Its function is to prevent the headline number from bypassing professional judgement.

A rating that survives this review is valuable; it becomes one traceable link in the design and acceptance chain; a rating that cannot survive should remain a research lead, not a controlling requirement.

8.33 Rating curves for gypsum-board systems

Gypsum-board assemblies illustrate why the curve matters; a single stud wall with boards fixed to both sides is mechanically coupled through the

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studs; a staggered-stud wall reduces some coupling but shares tracks; a double-stud wall can provide deeper decoupling but introduces a mass-air-mass resonance and can be short-circuited by bridging. Resilient channels or clips change the connection stiffness and damping; equal laboratory classes can therefore arise from different mechanisms and different fragility.

The low-band curve should be examined against cavity depth and leaf masses; a resonance near the lower classified bands can control the rating; adding board to one leaf may shift or deepen features; unequal leaves can separate coincidence effects. Cavity absorption reduces resonance severity but does not substitute for depth or decoupling.

The high bands reveal leakage and short circuits; back-to-back boxes, screws contacting framing, unsealed heads, and service penetrations can flatten the curve; a field class below the laboratory basis may not identify which defect occurred, but the spectral difference guides inspection.

A design schedule should therefore include the laboratory curve and critical details. Writing only “STC 60 double stud” permits substitutions that preserve a catalogue class while changing resonance, fire rating, and robustness.

8.34 Rating curves for masonry and concrete

Massive walls often show high direct airborne reduction, but their field result can be limited by flanking and openings; hollow masonry can contain cell resonances and leakage through joints; grouting, parging, plaster, and linings alter mass, sealing, and damping. Concrete density and thickness are only part of the system.

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A laboratory rating for a masonry panel built carefully in a test opening may overstate a field wall with incomplete head joints, electrical boxes, control joints, lintels, and slab continuity; the field curve may show a broad limit rather than a local trough because several paths contribute.

When direct wall performance is far above doors and services, pursuing a higher wall class is irrational; the rating analysis should identify the crossover where another path governs; structural vibration measurements may be needed for low-frequency flanking.

Massive construction also challenges measurement dynamic range; background-limited bands should be reported as bounds; a high integer rating based on censored data should be interpreted cautiously.

8.35 Rating curves for glazing

Glazing performance depends on pane mass, thickness, laminate, cavity, pane spacing, frame, gasket, and perimeter; symmetrical double glazing can exhibit coupled resonances. Laminates add damping. Large panes have lower modes and greater deflection; frame leakage can dominate high bands.

A tested insulating glass unit does not establish the performance of a curtain-wall bay; mullions, anchors, spandrels, vents, and adjacent panels create paths; a secure-room window should be reviewed as a façade subsystem.

The rating curve can reveal coincidence and cavity features; a single-number comparison between two glazing systems may conceal a weak speech band; source-spectrum adaptation and exterior listener geometry should be considered.

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Field replacement glass can change performance even when nominal thickness is retained; tempering, laminate, pane dimensions, and frame work matter; post-replacement testing may be required.

8.36 Rating curves for door sets

Door-set curves are frequently leakage-controlled. The leaf may be capable of higher loss than the perimeter; seals create a high-frequency limit, while leaf bending and core construction shape lower bands; hardware penetrations and thresholds add local paths.

A field door result should be measured with the specified latch and closer state. A door held only by the closer may not achieve the tested compression. Repeated closures reveal variability.

The perimeter length relative to area makes size important; a larger door has more area but not proportionally more perimeter, which can improve leakage ratio, while leaf deflection and hardware may worsen. Transfer by intuition is unsafe.

A sound lock should be assessed as two door sets plus vestibule; its improvement depends on the weaker door, separation, absorption, and simultaneous opening; adding ratings arithmetically is incorrect.

8.37 Rating curves for service penetrations

A penetration is not normally classified in isolation because its effect depends on host assembly and installation; putty pads, sleeves, fire stops, pipe insulation, cable fill, and annular seals shape transmission; a tested fire-stop system may not have acoustic evidence, and an acoustic seal may not satisfy fire requirements.

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Penetration schedules should identify host wall, opening size, service, sleeve, seal, fire rating, acoustic detail, inspection, and change control. The room-level field test then captures combined effects.

A cluster of small penetrations can create a larger effective path; cable changes after commissioning can disturb seals; the rating is conditional upon maintenance.

8.38 Sensitivity of composite results to area estimates

Composite calculations depend upon area. Door and glazing dimensions are usually known; crack and penetration areas are not; an assumed aperture area can dominate the prediction, so sensitivity analysis is necessary.

If the assumed effective crack area varies by a factor of ten, its contribution changes by 10 dB in a simple open-area model; the uncertainty is too large for precise prediction. Diagnostic measurement is more valuable.

For known panels, area measurement uncertainty is modest; for complex frames and joints, a path-specific model may be required; the report should distinguish measured, drawn, and assumed areas.

8.39 Frequency-dependent specification schedules

A project can specify minimum band values in addition to a single-number rating; this preserves control of critical low or speech bands; the schedule should be achievable and linked to a test method.

Band minima can create measurement difficulties at high isolation; guard bands and lower bounds should be addressed; excessive prescriptive bands can also restrict legitimate designs; the schedule should follow the source and risk model.

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A common approach is a principal class plus minimum values in selected low bands and a field acceptance metric; occupied speech testing then addresses consequence; each layer has a purpose.

8.40 Rating and fire-resistance coordination

Acoustic and fire tests measure different propositions; an assembly with strong sound insulation may not have the required fire resistance; a fire-rated wall may have modest acoustic performance. Substitutions can affect both.

Gypsum layers, stud gauge, insulation, joints, sealants, deflection heads, doors, and penetrations are part of fire listings; acoustic modifications must not invalidate them; the design should use compatible tested or assessed systems.

Fire-stop products can shrink, harden, or bridge resilient assemblies; acoustic details should be reviewed with fire engineers; the field rating reflects the final combined condition.

8.41 Rating and structural-movement coordination

Deflection heads, seismic joints, expansion joints, and building drift require movement; rigid acoustic sealing can crack or restrain the joint; flexible systems must preserve both movement and attenuation.

A laboratory wall without movement joints may not represent a tall field partition; the head detail can govern leakage; classification evidence should be supplemented by detail-specific assessment and field testing.

Movement over time can degrade seals. Lifecycle inspection should target these locations.

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8.42 Rating and accessibility requirements

Door seals and closers increase opening force; thresholds can create trip or wheelchair barriers; acoustic performance must be coordinated with accessibility and egress.

An automatic bottom may preserve a flush threshold but requires adjustment; a vestibule can improve isolation but adds doors and manoeuvring space; the design should not solve acoustics by creating unlawful access.

The accepted door configuration is the configuration that occupants can actually use. A door that remains propped open because it is difficult to operate has no meaningful rating in service.

8.43 Rating and sustainability claims

Low-carbon materials, recycled content, demountability, and reduced mass can influence acoustic design; sustainability claims should not replace performance evidence; lightweight systems may achieve high ratings through decoupling but can be workmanship-sensitive.

Reuse of existing masonry or concrete can provide mass, while new independent linings improve isolation. The embodied-carbon benefit should be balanced against depth, materials, and durability.

A life-cycle assessment should include remediation risk. A marginal assembly that requires later reconstruction can have higher environmental cost than a robust initial design.

8.44 Rating-focused design review workshop

A multidisciplinary workshop can review each boundary; the acoustician presents curves and predictions. The architect presents details. Structural

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and mechanical engineers identify flanking and services; security personnel define listener access and operations. The contractor addresses buildability.

The workshop should mark every path on drawings; ratings are then assigned to evidence, not to coloured walls alone; unresolved paths become action items.

This process is more effective than circulating a rating schedule without explanation. It converts the single number back into a system design.

8.45 Model specification language

A model clause may require: laboratory evidence under the named standard and edition; full band results; exact specimen construction; field testing under the named method; minimum single-number and selected band values; doors, glazing, and services included; masking disabled unless otherwise stated; uncertainty and decision rule; and retest after remediation.

The clause should also state that laboratory classification does not constitute field acceptance or security accreditation. This protects all parties from semantic overreach.

8.46 Final chapter synthesis

The rating is a map legend, not the landscape; it allows rapid comparison when its metric, method, and specimen are known; it becomes misleading when detached from the curve and system.

A secure-room professional should be fluent in ratings while remaining suspicious of unqualified integers; the correct habit is to ask what was measured, how it was compressed, what was omitted, and what decision the number is being asked to support.

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8.47 The role of test reports in design reasoning

A complete test report is not merely evidence for a submittal. It is a design document. The curve, specimen drawing, photographs, mounting, and observations reveal how the assembly achieved its rating; they permit the designer to identify fragile details and compare the field construction.

The report should be read before details are finalised; if the tested wall used continuous sealant at both faces, a project detail showing interrupted sealant is not equivalent; if the door report used a particular automatic bottom and threshold, changing hardware requires review.

Notes in reports can be consequential; a laboratory may record visible leakage, specimen damage, unusual curing, or facility limitations; marketing summaries often omit these notes.

The design file should preserve the original report rather than a web link alone. Web content changes. A checksum and source register establish provenance.

8.48 Negative evidence and absent ratings

The absence of a rating does not prove poor performance; it means the proposed claim lacks that evidence; a bespoke masonry wall, historic stone boundary, or unusual room-within-room system may require prediction and field testing rather than a catalogue report.

Conversely, the presence of a rating does not prove suitability; the tested configuration may differ materially; evidence quality should be assessed independently of the number.

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A project can proceed with a performance specification and mock-up when proprietary evidence is unavailable. The risk, test timing, and remediation path should be explicit.

8.49 Rating selection for retrofit work

Existing buildings rarely match laboratory assemblies; hidden construction, voids, penetrations, and junctions create uncertainty; a retrofit target should be based on site investigation and field baseline, not an assumed existing STC.

Adding an independent lining can improve direct transmission, but the field gain may be limited by doors, floors, ceilings, and services. A before-and-after band measurement helps separate improvement.

Historic fabric may restrict invasive work; reversible linings and secondary glazing can be assessed through mock-ups; the rating schedule should not require destructive equivalence with new construction where conservation governs.

8.50 Rating selection for room-within-room construction

A room within a room uses independent walls, ceiling, and floor to reduce airborne and structure-borne transmission. Its performance depends on complete decoupling, ventilation, doors, penetrations, and isolation mounts.

Adding inner-wall and outer-wall ratings is not valid; the cavities interact, flanking and mount paths matter, and intermediate room response affects transmission; frequency-dependent modelling and mock-up evidence are required.

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The inner shell can also trap sound and increase source levels; interior absorption is part of source control; a high shell rating does not remove the need for occupied privacy testing.

8.51 Rating effects of resilient-system short circuits

Resilient channels and clips are intended to reduce mechanical coupling. Screws into studs, rigid blocking, cabinets, conduits, skirting, ceiling grids, and perimeter contact can short-circuit the system.

The field curve may lose mid and low-band performance broadly; one short circuit can influence a large area; inspection before board closure and controlled fastening are more effective than forensic repair.

A laboratory rating assumes the tested resilient configuration; the project should require installer training, inspection, and photographic records; the rating alone cannot ensure workmanship.

8.52 Rating effects of cavity absorption

Porous cavity absorption reduces standing-wave energy and damps mass-air-mass resonance; its effect depends on flow resistivity, thickness, placement, and cavity fill; more material is not always better if it creates rigid bridging or compresses against leaves.

Laboratory reports should identify insulation type and density; substitution by nominal R-value is not an acoustic equivalence; fire and moisture requirements also apply.

Cavity absorption usually improves curve smoothness more than it changes fundamental low-frequency limits. The rating should be interpreted with the complete assembly.

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8.53 Rating effects of damping compounds and constrained layers

Viscoelastic damping between boards can reduce panel response and coincidence-related weakness. Performance depends on compound properties, coverage, temperature, cure, board type, and fastening.

Manufacturer ratings may be configuration-specific. Field application thickness and cure are difficult to verify after closure. Quality control should include batch, application, and photographic records.

Damping is not a substitute for sealing or decoupling. A leakage-controlled wall will not benefit materially until openings are corrected.

8.54 Rating effects of unequal leaves

Using unequal leaf masses can separate coincidence features and alter coupled response. The strategy is often beneficial in double-leaf walls and glazing.

The result is frequency-dependent. Adding mass to only one side can shift resonances and affect structural support. Fire and load requirements must be checked.

A single-number improvement may be modest while the curve becomes more robust in a critical band. This is another reason to retain spectra.

8.55 Rating effects of framing material

Wood and light-gauge steel studs have different stiffness, damping, and connection behaviour; steel studs can flex and reduce coupling in some configurations; heavier gauges can increase stiffness and change performance; wood introduces different fastener and structural paths.

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A report for one stud type should not be transferred to another; gauge, depth, spacing, and bridging matter; the field detail should match the evidence.

8.56 Rating effects of perimeter conditions

A partition can be strong through its field and weak at head, base, and ends. Deflection tracks, slab irregularity, perimeter sealant, façade intersections, and columns govern.

Laboratory mounting may use massive, sealed boundaries; field details need equivalent acoustic continuity while allowing movement; the rating submittal should be reviewed beside junction details.

8.57 Rating under partial-height and shared-plenum construction

A partition stopping at a suspended ceiling cannot be represented by the wall’s full-height STC alone. Ceiling transmission, plenum absorption, ductwork, and adjacent partitions form the path.

Office systems may use ceiling attenuation metrics, but high-security rooms generally require more complete boundaries. Where partial height is unavoidable, the field criterion and accessible plenum must be addressed explicitly.

8.58 Rating and occupant-generated structural excitation

Speech is airborne, but loudspeakers, table impacts, and equipment can excite structure. A wall rating does not address vibration travelling through slabs or frames.

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Conference tables coupled to floor boxes and walls can transmit audio from embedded speakers. Structural-path testing may be needed. The rating schedule should not imply coverage.

8.59 Rating changes after penetration work

Post-occupancy cabling and maintenance commonly degrade boundaries; a small new conduit can bypass seals; a removed ceiling tile can open a plenum path; a replacement door can alter the weakest element.

Configuration control should require approved details, inspection, and targeted retest. The original rating remains historical evidence, not a permanent property.

8.60 Procurement comparison matrix

Table 8-2. Evidence needed when comparing nominally equal-rated products

Product class	Minimum comparison evidence	Common hidden difference	Field verification emphasis
Gypsum partition	Full curve, stud and board schedule, cavity, fasteners, perimeter	Resilient short circuit or different board mass	Junctions, boxes, head and base
Door set	Complete set report, dimensions, seals, hardware	Leaf-only claim or different threshold	Repeated closure and perimeter scan
Glazing	Pane build-up, dimensions, frame and seals	Different pane area or frame	Mullions and perimeter leakage
Operable partition	Panel count, joints, closure procedure	Laboratory closure not reproducible	Minimum over repeated cycles
Silencer	Insertion loss, airflow, generated noise, pressure drop	Different velocity or end condition	Cross-talk and breakout under operation

8.61 Rating evidence and professional responsibility

The designer is responsible for selecting appropriate evidence, not merely collecting certificates; the contractor is responsible for building and documenting the specified configuration; the laboratory is responsible for competent testing; the authority is responsible for use decisions.

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Clear roles prevent a rating from being asked to perform work outside its scope; a certificate cannot cure a defective detail; a field test cannot rewrite a laboratory report. Accreditation cannot be self-declared.

8.62 Rating evidence for penetrated fire barriers

A secure boundary is often also a fire or smoke barrier. Penetrations must satisfy both systems. An acoustically dense putty that is not listed for the fire assembly cannot be used merely because it reduces leakage; a fire-stop system with a large rigid collar can create structural coupling or leave an acoustic weakness.

The evidence package should identify the host assembly, fire-resistance listing, penetration system, acoustic test evidence where available, annular dimensions, service fill, backing, sealant depth, and inspection; if no combined test exists, the design team should use compatible listed systems and verify field performance.

The room rating belongs to the completed penetrated boundary; product claims for sealant alone are not sufficient; later cable changes must remain within the listed and acoustically controlled configuration.

8.63 Rating evidence for ventilation silencers

Silencers are characterised principally by insertion loss, generated noise, pressure loss, and airflow conditions; their band performance can be combined with duct path models; a wall-style STC is not the appropriate descriptor.

The submittal should identify dimensions, length, baffle configuration, lining, test airflow, face velocity, insertion-loss bands, self-noise, and

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pressure drop. A silencer installed with different transitions or too close to a fan may perform differently.

Breakout from the silencer casing and adjoining duct can bypass internal attenuation; the field test should include the complete route; a high insertion-loss unit cannot correct an unlined transfer grille opening through the wall.

8.64 Rating evidence for raised floors

Raised floors can create a shared cavity beneath partitions; floor panels, stringers, pedestals, cable openings, and underfloor air distribution influence transmission; a wall rating measured on a solid base does not represent this path.

Secure-room details may extend partitions to the structural slab, isolate the floor cavity, or provide tested barriers. Access panels and future cabling remain vulnerabilities.

Field testing should include the underfloor path. A local source and receiver in the cavity can support diagnosis, while the room-level metric provides acceptance evidence.

8.65 Rating evidence for suspended ceilings and roof spaces

A full-height wall should connect acoustically to the structural deck; suspended ceilings and roof spaces can bypass partial-height partitions; deck profiles, insulation, purlins, ducts, and access hatches complicate continuity.

The wall’s laboratory class is only one input; head-of-wall details, deck flute closures, movement accommodation, and fire stopping require evidence; a roof can also radiate to exterior listener positions.

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Inspection before ceiling closure is critical. A field rating after finishes can identify failure but make repair costly.

8.66 Rating evidence for operable glazing and windows

Operable windows add seals, latches, drains, vents, and variable closure; a fixed glazing rating does not apply; repeated operation should be tested.

Drainage paths and trickle vents can govern. Security hardware may alter compression. A window that is permitted to open during ordinary use creates an operational state with no closed-boundary rating.

The acceptance record should distinguish fixed, closed-operable, and open states. Controls and alarms may be needed for sensitive discussion.

8.67 Rating and cross-laminated timber systems

Mass-timber buildings introduce panel joints, lightweight floor build-ups, junctions, and structural continuity. Direct panel mass can provide useful attenuation, but flanking through slabs and connections can govern.

A conventional gypsum wall rating does not describe a mass-timber room. Junction prediction, independent linings, floating floors, and field mock-ups may be needed.

Fire and moisture design constrain details. The rating evidence should identify the complete assembly rather than the timber panel alone.

8.68 Rating and modular volumetric construction

Factory-built modules can improve quality control, but module-to-module joints, transport damage, service connections, and site assembly determine field performance. A tested module wall does not establish the intermodule boundary.

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Factory acoustic tests can provide early evidence; site acceptance should target joints and penetrations; repeated module types support statistical quality control if the population is defined.

8.69 Rating and historic plaster construction

Traditional plaster on lath can provide substantial mass and damping, but cracks, keys, voids, timber framing, and later repairs create variability. A modern gypsum rating should not be assigned by visual similarity.

Field baseline measurement, borescope inspection, and local opening can identify construction; independent linings may preserve historic fabric; the rating target should be linked to conservation constraints.

8.70 Rating and acoustic metamaterials or novel products

Novel products may claim high performance from resonant or structured mechanisms; their benefits are often narrow-band and configuration-dependent; a single class can conceal the useful and weak bands.

Independent full-curve testing, environmental durability, fire performance, manufacturing tolerance, and field robustness are required. Extraordinary claims deserve ordinary evidentiary discipline.

A product should not be selected because its marketing language resembles security terminology. The test report and mechanism govern.

8.71 Rating change from workmanship defects

Workmanship defects can produce non-proportional losses. A missing bead of perimeter sealant, one bridged resilient channel, or an unlatched door can reduce performance far more than the defect’s area suggests.

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Quality control should focus on high-leverage details; checklists, hold points, installer training, and photographs reduce risk; random end-of-project testing alone may discover problems too late.

A defect report should identify the physical condition and measured effect where possible. It should not assign a generic “minus five STC” penalty.

8.72 Rating and ageing

Sealants harden, gaskets compress, hinges wear, and panels crack. Moisture changes materials. Building movement opens joints. The commissioned rating is a baseline, not a permanent guarantee.

Maintenance schedules should target components whose degradation changes leakage. Periodic screening can identify drift. Any significant alteration triggers retest.

The lifecycle record should preserve replacement products and configurations. An apparently equivalent gasket may perform differently.

8.73 Rating in acoustically coupled suites

Suites may contain several rooms connected by doors, vestibules, return paths, or shared construction. The effective isolation from one room to an exterior listener can involve multiple sequential and parallel paths.

Adding room-to-room ratings is generally invalid because intermediate room absorption and path interaction matter. A network model using band transmission coefficients is more appropriate.

Field testing can isolate links and test the end-to-end path. The security use may depend on all intermediate doors being closed.

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8.74 Rating and temporary construction conditions

During construction, unfinished joints, open ceilings, temporary doors, and active trades make final ratings meaningless. Early testing can still diagnose mock-ups or specific paths if the condition is recorded.

A preliminary pass should not be represented as final acceptance; conversely, waiting until all finishes are complete can delay repair; the commissioning plan should stage tests.

8.75 Rating as a communication tool

Ratings succeed when every participant understands their bounded meaning; the architect sees an assembly requirement; the contractor sees evidence and workmanship; the acoustician sees a compressed curve. The security authority sees one input to use approval.

A short explanatory note on drawings and specifications can prevent years of confusion. It should define laboratory, field, occupied, and accreditation propositions and direct readers to the detailed criteria.

The professional obligation is not to abandon simple numbers. It is to prevent simplicity from becoming false certainty.

8.76 Integrated rating case study. Courtroom consultation suite

A hypothetical courthouse consultation suite contains two attorney rooms separated from a public corridor and from each other; the design documents specify “STC 55 walls” without distinguishing laboratory and field requirements; the walls are double-stud gypsum assemblies supported by strong laboratory evidence; each room has a solid-core door with perimeter

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seals, a transfer-air route above the ceiling, and power and data boxes serving audiovisual equipment.

Submittal review initially focuses on the wall certificates; the acoustic consultant reconstructs the evidence chain and finds that the proposed door report covers a smaller leaf with different hardware, while the transfer path has no insertion-loss evidence. A composite band calculation predicts that wall upgrades would not materially alter the room-to-corridor result; the design is revised to use a tested door set and ducted return with a cross-talk silencer; partitions extend to the deck, and outlet boxes are separated.

The first field test produces a respectable room-average classification but a local high-frequency peak near the latch jamb; repeated closures vary by 4 dB; inspection finds insufficient latch engagement under corridor pressure; adjustment improves the minimum repeated result and reduces speech-token recovery at the accessible listener position.

The final dossier contains the laboratory wall report, door-set report, silencer data, field curve, repeated door-state results, occupied speech assessment, uncertainty, and authority disposition; no document states that the room is “STC 55”; instead, each number is attached to its assembly or room-pair proposition.

The case demonstrates several rating principles; first, the strongest component does not define the room; second, component evidence must match configuration; third, field averaging can conceal a local weak path; fourth, operational variability can be greater than instrument uncertainty; fifth, occupied privacy requires a consequence test. The headline rating

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remains useful, but only after the complete system has been designed and verified.

8.77 Integrated rating case study. Historic stone diplomatic room

A hypothetical diplomatic residence contains a meeting room bounded by 600 mm stone walls, timber floors, a fireplace, sash windows, and a panelled door; visible mass encourages an assumption of excellent isolation. No historic acoustic records exist.

Baseline field testing shows strong mid-band wall performance but weak low-frequency transfer to the room below and high-frequency leakage at the fireplace flue and windows; the wall mass is not the governing path; conservation restrictions prohibit destructive alteration of the stone and joinery.

The design uses a reversible independent inner lining on selected walls, secondary glazing in independent frames, a sealed but inspectable flue treatment, and a floating floor zone; the door receives a conservation-compatible internal secondary door to create a small sound lock. The field curve improves unevenly, with the largest gains at the previously identified paths.

No attempt is made to assign an assumed laboratory STC to the stone; the evidence consists of baseline and post-remediation field curves, structural diagnostics, drawings, and occupied speech tests; the result is reported as performance of the configured historic room. Formal use remains with the competent authority.

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The case shows that visible thickness is not a rating and that bespoke historic construction may require field evidence rather than product classification; it also shows why a curve supports conservation decisions more effectively than a single integer. The engineer can target reversible work at demonstrated mechanisms instead of adding unnecessary material to already strong stone walls.

8.78 Comparative design exercise. Selecting among three nominal STC 55 partitions

A design team is offered three nominal STC 55 gypsum partitions; assembly X uses one row of light-gauge studs, two layers of dense board on each side, and cavity insulation; assembly Y uses staggered studs on a common track with unequal leaves; assembly Z uses independent double studs with fewer board layers; the catalogue classes are equal, but the engineering choices are not.

Assembly X is thin and economical; its common studs provide a direct mechanical path, and the heavy leaves place demands on fasteners and structure; its curve is relatively smooth through the mid-band but shows a coincidence-related depression; assembly Y reduces stud coupling while retaining one track. Its asymmetrical leaves separate some resonant features, yet common head and base details can bridge the system; assembly Z provides the greatest nominal decoupling and cavity depth, but its mass-air-mass resonance lies in a lower band and its performance is highly sensitive to bridging by blocking, services, and intersecting construction.

The conference-room threat model includes ordinary speech, maximum unamplified effort, and local loudspeaker programme; the receiving corridor

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is quiet after hours; the design team overlays source spectra, laboratory curves, predicted flanking, door performance, and background; assembly X is weakest in a critical consonant band; assembly Y performs more evenly. Assembly Z is strongest overall but offers little system benefit because the door and slab flanking govern below 500 Hz.

The team selects Assembly Y, upgrades the door system, extends the partition to the deck, and isolates the return-air path; this choice is not “lower quality” than selecting the deepest wall; it is a system optimisation based on residual spectra and path dominance. A larger budget for Assembly Z would have purchased unused direct-wall performance while leaving the actual weak paths unchanged.

The submittal requires the complete test report, board and stud properties, cavity insulation, fasteners, and perimeter details; a first-of-type field test is performed before repetitive construction; the result confirms the predicted curve within the stated uncertainty; a local threshold weakness is corrected before finishes are repeated.

The exercise demonstrates that nominal rating equality creates a starting set, not a final selection; curve shape, field robustness, space, fire resistance, structure, services, workmanship, cost, and system paths decide suitability; the correct professional question is not “which wall has the highest STC?” It is “which complete design most reliably satisfies the field and occupied criteria under credible states?”

8.79 Rating reconciliation record for multinational projects

A multinational project may receive American laboratory reports, ISO product data, British design terminology, and Canadian operational

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guidance; the project should not force them into one undocumented rating; it should create a reconciliation record.

The record lists every metric, source standard, edition, frequency range, test condition, field or laboratory status, and intended use; where band data permit, the required classification is calculated directly under the appropriate method; where data are incomplete, the limitation is stated. No fixed conversion is used as controlling evidence.

The reconciliation also identifies language differences; “sound reduction index,” “transmission loss,” “level difference,” “normalised difference,” and “apparent” quantities are not interchangeable; contract schedules should preserve official terminology and provide plain-language definitions.

This record becomes part of design review and commissioning. It prevents a contractor from substituting an STC certificate for an R_w requirement, and it prevents an authority from reading a field class as a laboratory property. It also makes future standard changes easier to trace because the original band data and calculation remain available.

A cross-jurisdiction comparison can still be useful; it may show that two systems place similar assemblies in similar broad categories; such comparison is explanatory rather than contractual; the final acceptance statement remains tied to the specified method and competent authority.

8.80 Classification stability under band censoring, rounded values, and laboratory limits

A single-number rating can appear stable even when the underlying evidence is not equally complete; the first source of apparent stability is rounding. One-third-octave transmission-loss values are often reported to a

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stated precision, while the classification rule operates upon deficiencies from a reference contour; a small change in several bands may leave the integer result unchanged, yet materially alter the margin to the next classification or the shape of the residual spectrum. The second source is censoring. When receiving-room levels approach the background or the test suite reaches its usable dynamic range, the reported result may become a lower bound rather than an ordinary point estimate; a lower bound can support a limited statement about minimum demonstrated performance, but it cannot be silently treated as an exact value in regression, product comparison, or speech-risk calculation.[422]

This distinction matters most when two products have the same catalogue number but different evidentiary depth; product A may have uncensored values across the classification range, repeated measurements, and a complete specimen description; product B may have several lower-bound bands, sparse construction records, or a report whose receiving-room background correction is close to the method limit. Both may carry the same integer classification; they are not equally informative; the designer should therefore review the curve, the measurement limits, the report notes, and the specimen schedule before deciding that the products are interchangeable.

Classification stability also depends upon the direction of uncertainty; an uncertainty interval centred well inside one integer class may leave the reported class highly stable; the same interval centred close to a contour transition may make the adjacent class plausible. This does not require abandoning single-number ratings; it requires distinguishing the published

422 MB-0716. ASTM International, ASTM E90-23, ASTM E413-22.

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classification from the confidence with which the underlying curve and specimen support a project decision; a procurement schedule can state the required class while also requiring complete band data, identification of lower bounds, and sufficient laboratory information to permit a competent review.

A practical review can be organised in three layers; the first asks whether the classification was calculated under the named method and edition; the second asks whether each band entered the procedure as a measured value, a corrected value, or a lower bound. The third asks whether the tested specimen matches the proposed construction in mass, dimensions, framing, joints, seals, hardware, mounting, and operating state; these questions prevent an integer result from concealing differences in evidence quality.

Consider an illustrative wall for which the nominal classification remains unchanged after a 2 dB reduction at 125 Hz and a 1 dB reduction at 160 Hz; the arithmetic classification may be stable because the governing contour deficiencies occur elsewhere. Yet the altered low-band curve may change the result of a room-to-room speech analysis when amplified programme sound, a low-frequency talker spectrum, or a structural bypass places unusual weight on those bands; the rating has not become false; its bounded proposition has remained the same, while the project consequence has changed; that is precisely why curve retention is indispensable.

Interlaboratory comparison demands the same restraint; differences may arise from specimen construction, conditioning, room geometry, mounting, edge treatment, background conditions, and ordinary measurement

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variation. A small numerical difference between two reports should not be described as a product advantage unless the specimens and methods are sufficiently comparable and the difference is large relative to the combined evidence uncertainty; where exact comparability cannot be established, the appropriate conclusion is not that one result is superior. It is that the reports demonstrate performance for different tested configurations.[423]

The final engineering record should retain the original report, any correspondence clarifying censored bands or specimen details, the designer's comparison memorandum, and the acceptance rationale; if a later field result is weaker than expected, these records permit the investigation to distinguish an optimistic design assumption from a workmanship defect, a flanking path, or a changed operational state. Without them, the project has only a catalogue integer and a dispute.

8.81 Chapter conclusions

Single-number ratings are indispensable to building-acoustics practice because they convert a complex spectrum into a form that can be scheduled, compared, and enforced; their authority ends at the boundary of the method; the rating belongs to the tested or measured configuration. It does not erase frequency dependence, flanking, openings, operating state, uncertainty, speech consequence, or the authority required for secure use.

A rigorous project therefore retains the full curve, verifies the source report, models composite and flanking paths, specifies field acceptance separately, and tests occupied conditions against credible source and listener states; the better the rating is understood, the less likely it is to be misused. The

423 MB-0717. ASTM International, ASTM E90-23, ISO 10140-2:2021.

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governing professional discipline is not scepticism about standards; it is precision about the proposition each standard permits the engineer to make.

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Chapter 8 Glossary

Apparent Sound Transmission Class (ASTC). An ASTM field classification derived from an apparent transmission-loss curve, incorporating the combined performance observed between rooms under the applicable field method.

Classification curve. A prescribed reference shape or weighting framework shifted or applied to frequency-band data to obtain a single-number result.

Composite transmission coefficient. The area-weighted ratio of total transmitted acoustic power to incident acoustic power for a boundary containing more than one element, subject to the assumptions of the model.

Contour deficiency. The amount by which a measured band value lies below a shifted reference contour under a classification rule.

Direct transmission. Acoustic energy transmitted through the nominal separating element rather than around it through flanking structures or services.

Field classification. A single-number result derived from measurements in the completed building rather than a controlled laboratory specimen.

Noise Isolation Class (NIC). An ASTM classification associated with measured room-to-room level reduction under the applicable method and conditions.

Reference contour. The standardised frequency shape used in a classification procedure.

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Spectrum adaptation term. An ISO 717-1 adjustment used with a weighted result to reflect defined source-spectrum characteristics.

Sound Transmission Class (STC). The ASTM E413 classification applied to an eligible transmission-loss curve. It is not a material property or a secure-room accreditation.

Transmission coefficient, τ. The dimensionless ratio of transmitted to incident acoustic power in a defined frequency band.

Transmission loss, TL. Ten times the base-ten logarithm of incident acoustic power divided by transmitted acoustic power for the defined specimen and method.

Weighted sound reduction index, R_w. The ISO 717-1 single-number rating associated with laboratory airborne sound-reduction data.

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Chapter 9. Field Isolation, Speech Intelligibility, Audibility, and Privacy Metrics

9.1 The field problem begins where the laboratory specimen ends

A secure discussion occurs in a building, not in a test opening between idealised chambers; the field problem includes the actual source room, the actual receiving spaces, every accessible listener position, the installed doors and services, structural flanking, background sound, and the states in which the facility can operate. Field isolation is therefore a system result; it may be described by level difference, normalised level difference, standardised level difference, apparent sound reduction, or a classification derived from one of those curves; the chosen quantity must correspond to the proposition being tested.[424]

The simplest observation is the band level difference

Equation 9.1

$$D(f)=L_1(f)-L_2(f),$$

where $L_1(f)$ is the spatially averaged source-room level and $L_2(f)$ is the spatially averaged receiving-room level. The quantity is useful and direct. It is also conditional upon the rooms. If the receiving room contains little absorption, its reverberant level rises and D falls. If furnishings or occupants add absorption, D can increase without any change in the separating construction. A raw level difference is consequently not a portable material property.

424 MB-0729. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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Normalisation and standardisation address this dependence in different ways; an absorption-normalised quantity references an equivalent absorption area; a reverberation-standardised quantity references a decay time; an apparent sound-reduction quantity additionally uses separating area under its model; these corrections improve comparability when their assumptions are met, but they do not remove flanking or transform field evidence into laboratory evidence. The report must preserve the measured room state and the correction applied.

Field testing also encounters background limitation; the receiving level may be close to ventilation noise, traffic, electrical hum, or instrument self-noise; logarithmic subtraction becomes sensitive when source-on and background levels are close; some bands may permit a correction, some may be lower bounds, and some may be unreportable. A clean single-number result should not conceal censored bands.

The purpose of field measurement should be stated before the source is energised; a design-verification test asks whether the completed room pair satisfies a defined metric; a diagnostic test seeks the dominant path; a speech-security assessment asks whether information can be recovered by a stated listener under stated conditions. One test can inform another, but the source, sampling, processing, and decision rule may differ.

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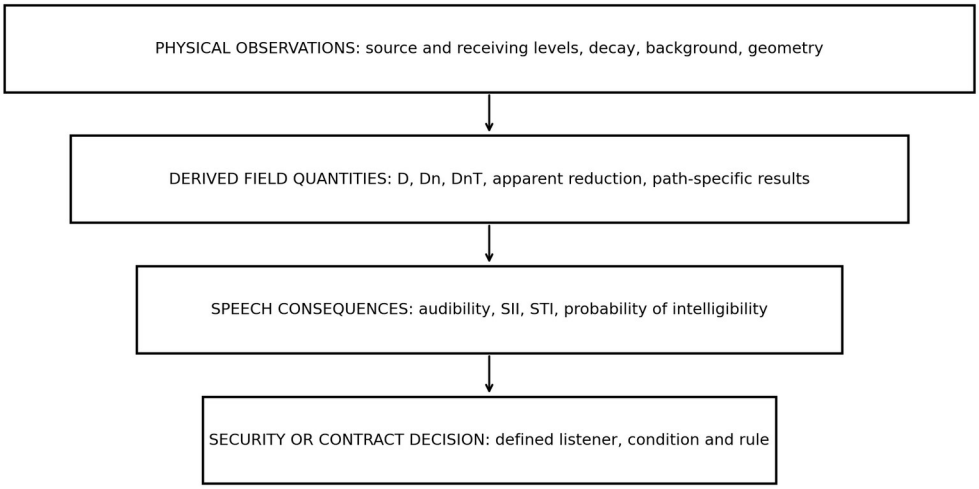

Figure 9-1. Metric hierarchy. Author's original diagram. Physical observations are transformed into field quantities, speech consequences, and finally a bounded decision. Each transformation adds assumptions.

9.2 Spatial averaging, source positions, and room state

Room-to-room measurements estimate spatially varying fields. Source-room modes, receiving-room modes, directivity, boundaries, furnishings, and openings produce local maxima and minima; a microphone placed in one null can overstate isolation; a position near a reflecting corner can understate it; governing field methods therefore prescribe multiple source and microphone positions, separation distances, and averaging procedures.[425]

The arithmetic must follow the method. Energetic averaging of levels is not the same as averaging decibels. If n positions produce levels L_i, the energetic mean is

425 MB-0740. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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Equation 9.2

$$\overline{L} = 10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^{n} 10^{L_i/10} \right).$$

This preserves mean-square pressure. An arithmetic mean of decibel values can be close when the spread is small, but the methods should not be mixed without justification.

Source placement should excite the room broadly rather than favour one path or mode; a loudspeaker pressed against the tested wall can produce an unrepresentative local field; a source near a corner can increase low-frequency output and excite particular modes; multiple positions reduce dependence on one configuration; for diagnostic work, deliberate source changes are valuable because path sensitivity is evidence.

Room state must be controlled. Doors, cupboards, curtains, operable partitions, ceiling hatches, ventilation, masking, and furnishings can change both field and background; a receiving room tested empty may have a longer decay than the occupied room; a corridor tested at night may have lower background than during normal use; the report should list the state and, where the decision concerns operation, test credible operating extremes.

The receiving location in a speech-security assessment is not necessarily the room-average position used for a building-acoustics metric; an accessible listener may place an ear near a door jamb, ceiling grille, shared wall, window, or service penetration; a spatial average can dilute a local vulnerability; the test programme therefore needs both representative averages and threat-informed local positions.

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Worked example 9.1. Energetic averaging

Five receiving positions produce 31, 34, 29, 36, and 32 dB in a one-third-octave band. The arithmetic mean is 32.4 dB. The energetic mean is

$$\overline{L} = 10\log_{10}\left[\frac{10^{3.1}+10^{3.4}+10^{2.9}+10^{3.6}+10^{3.2}}{5}\right] = 33.1\,dB.$$

The 0.7 dB difference is not dramatic here, but the energetic mean is the physically appropriate average; the example assumes equal weighting and valid positions; it says nothing about whether the loudest accessible point should govern a security decision.

9.3 Level difference, normalised difference, and standardised difference

The normalised level difference can be written in the general form

Equation 9.3

$$D_n(f) = D(f) + 10\log_{10}\left(\frac{A(f)}{A_0}\right),$$

where $A(f)$ is equivalent absorption area in the receiving room and A_0 is the reference absorption area. The standardised level difference is commonly expressed as

Equation 9.4

$$D_{nT}(f) = D(f) + 10\log_{10}\left(\frac{T(f)}{T_0}\right),$$

where $T(f)$ is receiving-room reverberation time and T_0 is a reference time. Exact definitions and symbols must follow the governing standard. The equations show that the correction is frequency-dependent because absorption and decay vary by band.[426]

426 MB-0749. International Organization for Standardization, ISO 16283-1:2014, ISO 3382-2:2008.

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The sign of the correction often confuses practitioners. A long receiving decay raises the receiving level and reduces raw D. Standardising to a shorter reference condition adds a positive correction. A highly absorptive receiving room may produce a large raw difference; normalisation removes some of that advantage. The purpose is comparison, not reward or penalty.

Apparent sound reduction incorporates separating area and receiving absorption, conceptually resembling laboratory reduction while retaining field paths. The adjective “apparent” is essential. It signals that the result may include flanking; removing the adjective overstates what was measured.

A specification should not mix $D_{nT,w}$, R'_w, ASTC, and NIC in one numeric threshold without a crosswalk grounded in actual room geometry and method. Each quantity responds differently to room volume, absorption, area, and source-receiving configuration. A design team that wants a common internal performance target may use one principal field metric and report others as supplemental.

Worked example 9.2. Standardising a field difference

A measured band difference is 48 dB. Receiving-room decay is 0.80 s. The reference decay is 0.50 s. Equation 9.4 gives

$$D_{nT} = 48 + 10\log_{10}(0.80/0.50) = 50.0\,dB.$$

The correction is 2.0 dB. If the decay-time standard uncertainty is 0.06 s, its sensitivity contribution is approximately

$$u_T = \left|\frac{10}{\ln 10}\frac{1}{T}\right|(0.06) = 0.33\,dB.$$

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The result is not a wall property. It is the standardised difference for the tested room pair and band.

9.4 Speech as a non-stationary, directional source

Speech is not pink noise. It varies by talker, language, phoneme, emotion, posture, orientation, distance, and vocal effort; its short-term peaks carry information; its long-term average spectrum is useful for prediction, but a security assessment should not assume that an average prevents recovery of brief high-level fragments; a raised phrase spoken towards a door can dominate a meeting-hour average.[427]

Talker directivity changes with frequency. Low-frequency voiced energy radiates relatively broadly; higher-frequency consonant energy is more directional and is influenced by head orientation; a participant facing glazing or a door can create a stronger incident spectrum at that boundary than the room-average field suggests. Table shape, seating, microphones, loudspeakers, and reflective finishes modify the field further.

Vocal effort is behavioural. People increase level when background rises, when speaking across a large table, during conflict, or when a remote participant is difficult to hear; this Lombard response can partly defeat masking intended to reduce intelligibility; a masking system that is raised without considering talker behaviour may yield less improvement than predicted and create fatigue.

A source protocol should define at least normal and maximum credible effort; recorded speech offers repeatability but may not reproduce directivity or behaviour; a trained live talker offers natural articulation but

427 MB-0750. ASTM International, ASTM E2638-24.

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introduces variability; a loudspeaker can deliver a calibrated spectrum but is not a human mouth. The choice depends upon the proposition.

For ordinary field insulation, broadband noise remains efficient because it provides stable energy across bands; for occupied speech security, speech-like sources, calibrated talkers, or both may be needed; the report should not label a broadband attenuation result as speech unintelligibility without a consequence model.

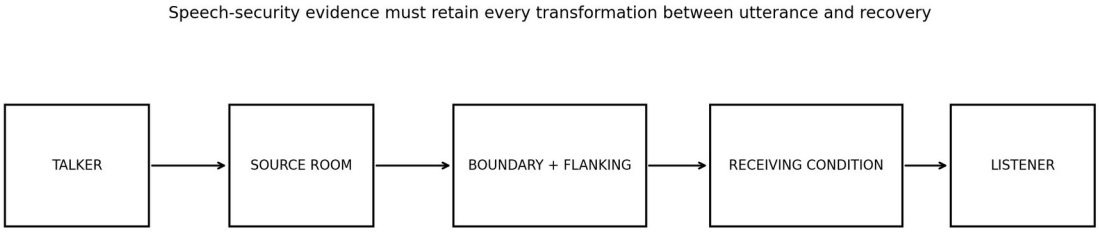

Figure 9-3. Speech-recovery chain. Author's original diagram. The utterance is transformed by the source room, boundary, flanking paths, receiving condition, and listener before information is recovered.

9.5 Audibility, recognition, intelligibility, and understanding

Audibility is the detection that a sound is present. Recognition identifies a sound class or familiar pattern. Intelligibility concerns recovery of speech content. Understanding adds language, context, and cognition; these are related but not interchangeable; a listener may hear speech without understanding words; a listener may recover a name from a fragment without understanding the sentence; a security criterion should identify the prohibited outcome.[428]

428 MB-0752. ANSI/ASA S3.5-1997, IEC 60268-16:2020.

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Signal-to-noise ratio is a starting point, not a complete speech metric; speech and background vary by frequency and time; the listener integrates bands with different importance; reverberation and distortion can reduce modulation; familiar context can increase recovery; repeated exposure can accumulate fragments.

The Speech Intelligibility Index estimates intelligibility-related audibility through frequency-band importance and disturbance; it is useful for communication systems and can inform privacy analysis when its assumptions are respected; the Speech Transmission Index estimates the preservation of speech-envelope modulation through a transmission channel; it is sensitive to reverberation, noise, and nonlinear effects under its method. Neither is a secure-room accreditation metric by itself.[429]

Word-score testing provides direct evidence for a defined corpus, talker, listener group, and condition; it also introduces training, language, hearing, scoring, and ethical considerations. The words chosen matter. Technical names and numbers may be more consequential than phonetically balanced common words; a room can pass an average word score while permitting recovery of rare high-consequence items.

A conservative security analysis may therefore combine objective metrics with bounded human listening trials; objective metrics improve repeatability and diagnosis; human trials test the consequence; the authority should define the criterion and the listener model before the result is known.

429 MB-0751. ANSI/ASA S3.5-1997, IEC 60268-16:2020.

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9.6 Closed-room speech privacy and probability

ASTM E2638 provides a method for evaluating speech privacy of closed rooms using the sound insulation of the room boundary and the receiving-side background; its framework recognises that privacy is probabilistic rather than a binary property; it addresses the likelihood of speech audibility or intelligibility under defined conditions and does not itself prescribe universal acceptance criteria.[430]

The probability perspective is essential. Talker level is a distribution. Background is a distribution. Listener acuity varies. Position matters. A room may be private for ordinary conversation but vulnerable during rare maximum effort; a criterion based on a percentile can address that variability, but the selected percentile embodies policy.

The illustrative curves in Figure 9-2 show that the same physical speech-to-background margin can yield different probabilities when listener capability or exposure changes. The curves are not standard thresholds. A favourable listener close to the boundary may recover content at a margin that defeats an ordinary passer-by. The threat model should identify which listener is relevant.

430 MB-0753. ASTM International, ASTM E2638-24.

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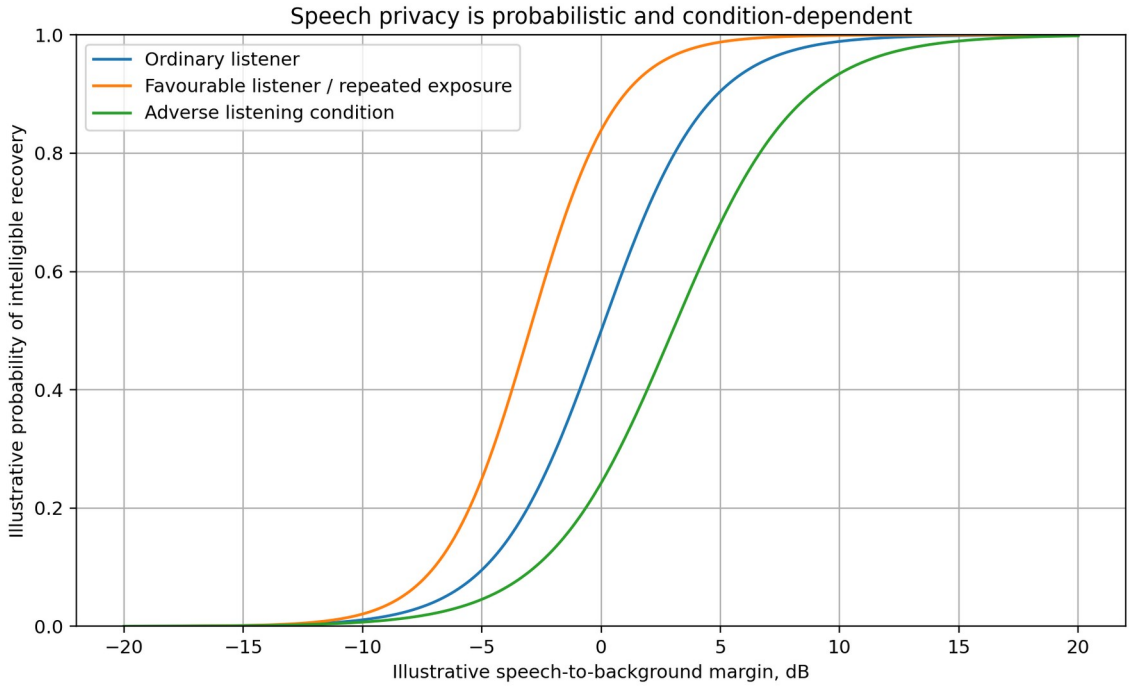

Figure 9-2. Illustrative intelligibility probability. Author's original plot. The curves are explanatory only and are not standard acceptance thresholds.

Privacy terminology requires care. "Confidential privacy," "normal privacy," and similar commercial labels may come from office-acoustics systems with specific assumptions; they should not be imported into classified-discussion work without definition; the project should state the physical and operational criterion directly.

A result should also distinguish boundary listening from contact listening; ASTM E2638's public scope concerns unaided listeners not touching the boundary; a contact transducer, stethoscope, laser vibrometer, microphone in a duct, or electronic device changes the threat; acoustic construction remains useful, but the test proposition changes.

9.7 Background sound, masking, and state dependence

Background sound reduces the audibility of transmitted speech when its spectrum overlaps the residual speech; it can arise naturally from HVAC, urban activity, adjacent occupancy, or equipment; it can be introduced

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deliberately through a masking system; the relevant quantity is the receiving spectrum at the listener position during the protected condition.[431]

A single A-weighted level is insufficient. Two backgrounds with the same dBA can mask speech differently; a low-frequency rumble may contribute heavily to total level while offering little masking of consonant bands; a broadband masking spectrum can reduce intelligibility more effectively, but excessive high-frequency energy causes annoyance and may encourage louder speech.

Masking uniformity matters. A room or corridor average can hide quiet zones near doors, corners, grilles, or workstation partitions; commissioning should map the accessible area and record spatial variation. Temporal stability also matters. A system that changes with occupancy or scheduling may leave quiet intervals.

The masking system is an active security dependency; it requires power, control, fault monitoring, tamper protection, maintenance, and configuration management; if privacy fails when masking stops, the operational plan should define the response; a silent failure is particularly dangerous because occupants may not notice gradual drift.

HVAC background is less controllable. Fans cycle, dampers move, and night modes reduce airflow; a room that appears private during daytime operation can become vulnerable after hours; testing should include the lowest credible background state unless policy guarantees a minimum.

431 MB-0754. ASTM International, ASTM E2638-24.

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Worked example 9.3. Band speech-to-background margin

At an accessible receiving position, residual speech levels in the 500, 1000, and 2000 Hz bands are 31, 28, and 24 dB; background levels are 29, 25, and 20 dB; the band margins are 2, 3, and 4 dB. Raising masking by 3 dB in each band changes the margins to -1, 0, and 1 dB; this likely reduces audibility, but it does not prove zero intelligibility; the result must be evaluated with the selected speech metric and listener model.

9.8 Reverberation, receiving-room absorption, and listener geometry

Receiving-room reverberation affects both field metrics and speech perception; a long decay raises steady broadband levels but can smear speech modulation; a short decay lowers reverberant build-up but can make direct leakage more localised; the net effect on privacy depends upon path geometry, listener position, and background.[432]

A corridor is not acoustically equivalent to an office; long corridors support axial propagation and reflections; stairwells can carry sound between floors; ceiling voids can create shallow, highly reflective spaces; exterior locations may be dominated by façade radiation and environmental noise; each receiving environment needs an appropriate model.

Equivalent absorption area can be estimated from decay and volume under diffuse assumptions; at low frequency or in irregular rooms, the estimate may be unstable; the test report should not apply a reverberation correction blindly where the decay curve is non-linear, interrupted, or background-limited.

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432 MB-0755. Heinrich Kuttruff, ISO 3382-2:2008, IEC 60268-16:2020.

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Listener geometry includes ear height, distance from boundary, orientation, and legal access; a person may not be permitted to stand inside a controlled plenum, but maintenance access may exist; an exterior listener may approach a window; a neighbouring tenant may place furniture against a shared wall. The threat assessment should map credible positions rather than assume the room centre.

Close listening can differ from room-average measurements because the direct field near a leak decays with distance before the room field dominates; a local vulnerability may therefore be obvious at 0.1 m and negligible at 2 m; the security decision should use the closest credible access distance.

9.9 Repeated exposure and cumulative information recovery

A meeting is a sequence, not one sentence; even when individual phrases are rarely intelligible, a listener can accumulate context. Names recur. Numbers are repeated. Participants correct each other. Presentation slides may synchronise with fragments; a privacy assessment based upon one brief trial can understate cumulative exposure.[433]

The probability of at least one recovery event increases with opportunities. If independent utterances each have probability p of yielding a sensitive fragment, the probability of at least one event in n opportunities is

Equation 9.5

$$P_{\geq 1} = 1 - (1 - p)^{n}.$$

433 MB-0756. ASTM International, ASTM E2638-24.

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The independence assumption is often false, but the equation demonstrates accumulation. If $p=0.01$ and $n=100$, then $P_{\geq 1}=0.634$. A one-per-cent event is not negligible over a long meeting.

Context makes events dependent. Once a listener recognises a project name, later fragments become easier to interpret; familiarity with voices and agenda increases recovery; conversely, changing background and interruptions can reduce it; a high-consequence assessment should consider duration, repetition, and context.

Operational controls can reduce exposure. Avoiding repetition of sensitive numbers, disabling room loudspeakers, managing seating, limiting meeting duration, and checking masking state can complement construction; these controls should not be used to excuse a defective boundary, but they recognise that security is a system.

Human trials should avoid disclosing real classified content; standardised speech material, code words, or synthetic content can test recovery; the protocol should protect listener privacy and hearing, record language competence, and prevent coaching.

9.10 Source and receiver calibration for speech tests

A speech test requires more than playing a recording at an arbitrary volume; the source level, spectrum, directivity, distance, and room position must be calibrated; if a loudspeaker is used, its equalisation and maximum linear output should be recorded; if a live talker is used, level monitoring and repeated phrases can quantify variability.[434]

434 MB-0730. ASTM International, ASTM E2638-24.

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The reference level may be measured at a defined distance in a free field, at the talker position in the room, or as a spatial room average; these are different source descriptors; the selected descriptor should connect to the prediction model and be reproducible.

Receiving microphones require acoustic calibration and adequate self-noise; human listeners require documented position, hearing assumptions, and scoring; a binaural recording can preserve spatial cues, but playback calibration is complex; a monaural microphone may under-represent directional listening.

The speech corpus should include phonetic balance and high-consequence formats such as names, alphanumeric strings, dates, and short commands; scores should be reported by category; a room that blocks ordinary sentences but leaks digits may still be unacceptable.

Playback and scoring should be blinded where practical; the listener should not know the script; multiple listeners permit an estimate of variability; the report should avoid extrapolating beyond the tested language and population.

9.11 Field diagnosis when the privacy result is poor

A poor speech-privacy result requires path diagnosis before remediation; raising masking may improve the immediate consequence but leave a serious construction defect; adding wall layers may fail if a door or duct governs; the diagnostic sequence should move from non-invasive state changes to targeted measurements.[435]

435 MB-0731. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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First verify source and background. Then compare room-average and close-range positions; operate doors, fans, dampers, and masking; inspect penetrations and ceiling spaces; use a broadband source to map band-specific leakage. Apply temporary reversible seals. Measure structural vibration where low-frequency energy persists.

The residual spectrum guides the tools; high-frequency leakage near a frame suggests seals or gaps; broadband transfer through a grille suggests duct or plenum; low-frequency coherence between slabs suggests structural flanking; a narrow tone may originate in equipment rather than speech transmission.

Documentation should preserve failed states. Repairs made before photographs or raw data are collected can destroy evidence; in litigation or security incident work, chain of custody and change control may be necessary; the report should distinguish susceptibility, observed performance, and proven compromise.

Remediation should be verified under the original condition and credible adverse states; a post-repair classification alone may not show that speech consequence improved if background changed; the same source protocol and listener positions should be repeated.

9.12 Comparative case study. Three rooms with the same field class

Three hypothetical conference rooms each receive an apparent field class of 48. Room A has a uniform boundary and a steady 35 dBA corridor background; room B has a door-jamb leak producing a local high-frequency

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path, while its corridor background is 40 dBA; room C has strong airborne isolation but a low-frequency structural path to a quiet office below.[436]

The equal class does not imply equal privacy; room A may provide consistent ordinary privacy; room B may appear satisfactory in room-average measurements but permit local consonant recovery at the jamb when the corridor is quiet; room C may transmit rhythm and low-frequency voiced content to the office below, particularly at night.

The appropriate follow-up differs. Room A needs operational verification. Room B needs close-range mapping and door repair; room C needs structural mobility and path analysis; applying one standard wall upgrade to all three would waste resources.

The case shows why acceptance should include both a principal field metric and threat-informed diagnostics. The field class remains useful. It simply cannot carry the entire decision.

9.13 Legal, evidentiary, and accreditation boundaries

A field measurement can be technically competent yet legally insufficient for a contractual claim if the method, edition, acceptance rule, or authorised witness was not defined; it can be contractually passing yet insufficient for a security authority whose criteria are controlled; it can demonstrate poor privacy without proving that information was actually intercepted.[437]

Expert reports should separate fact, calculation, inference, and policy; the measured levels and room states are facts; the derived metric is a calculation under a method; the path diagnosis is an inference supported by

436 MB-0732. International Organization for Standardization, ISO 3382-2:2008, ASTM E2235-04.
437 MB-0733. ASTM International, ASTM E2638-24, ASTM E336-25a.

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perturbation; the accreditation consequence belongs to the competent authority.

The term “failed secure room” should be avoided unless the applicable authority has made that determination; a more precise statement may be that the tested room did not satisfy a specified field metric, or that intelligible speech was recovered at an accessible position under the test protocol.

Public standards should not be presented as controlled governmental criteria; where public guidance describes functional goals, it can inform design and testing; it cannot substitute for unavailable accreditation requirements.

9.14 Background correction, censoring, and lower bounds

The receiving observation contains transmitted test signal and background. If the two are uncorrelated, a corrected signal level may be calculated by logarithmic subtraction:

Equation 9.6

$$L_s = 10 \log_{10}\left(10^{L_{s+b}/10} - 10^{L_b/10}\right),$$

where L_{s+b} is the source-on receiving level and L_b is background. The equation becomes increasingly sensitive as the difference narrows. When source-on exceeds background by 10 dB, the correction is about 0.46 dB. At 3 dB, the correction is about 3.0 dB. At 1 dB, the corrected result is more than 6 dB below source-on and is highly uncertain. Governing methods therefore place limits on correction and reporting.[438]

438 MB-0734. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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A band that cannot be separated from background should not be filled with the background value, zero, or an invented estimate; it commonly yields a lower bound on attenuation. If the source room is 95 dB and the receiving source-on level is indistinguishable from 25 dB background, the path attenuation is at least about 70 dB under the configuration, not exactly 70 dB; the inequality should survive into tables, curves, classifications, and decisions.

Censored bands create classification problems. Some methods prescribe how limited values are treated; a software package may silently use the limiting value and produce a class; the report must disclose the limitation and assess whether the class is stable; a high-isolation room can appear neatly classified only because the instrument or background prevented observation of its true performance.

The remedy is not always a louder source; source-room limits, loudspeaker distortion, neighbour disturbance, hearing safety, and structural excitation constrain level; increasing source power can activate nonlinear rattles or flanking paths that do not represent ordinary speech, although those paths may still be relevant to amplified use. Testing can also move to a quieter period, reduce background, use synchronous techniques, or report a lower bound.

Background is not purely additive. A fan or masking system can change pressure balance, grille impedance, damper state, and talker behaviour; turning it off may alter the path as well as the noise; the test record should identify such coupling.

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Worked example 9.4. Background-limited receiving band

The source-on receiving level is 27.0 dB and background is 25.5 dB. Equation 9.6 gives

$$L_s = 10 \log_{10}\left(10^{2.70} - 10^{2.55}\right) = 21.7\,dB.$$

If each input has standard uncertainty 0.5 dB, the corrected level uncertainty is much larger because the subtraction is ill-conditioned; the result may exceed the method's correction limit; the defensible report is likely a lower bound on attenuation rather than a precise corrected band.

9.15 Reverberation correction is not a cosmetic adjustment

Decay time enters field metrics because the receiving room stores acoustic energy; the standardised correction assumes that the measured decay represents the relevant average energy-loss process; multi-slope decay, strong modes, coupled rooms, open doors, active noise control, and time-varying ventilation can violate that simplification.

A decay curve should be inspected, not merely reduced by software. Early decay may differ from late decay. A ceiling plenum can create a coupled volume. A large upholstered room can be non-diffuse. At low frequency, individual modes produce position-dependent decay. The reported T_{20} or T_{30} should include fit range, correlation, position spread, and background margin.[439]

The correction can change after occupancy; furniture, people, documents, wall finishes, and curtains add absorption; a field result measured in a bare room may not represent the occupied raw level difference; standardisation

439 MB-0735. ASTM International, ASTM E2235-04, ISO 3382-2:2008.

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improves comparison, but occupied speech consequence still depends upon actual room state.

In small rooms, reverberation time can be short enough that measurement is difficult; the excitation must provide adequate dynamic range; interrupted noise, integrated impulse response, and other methods have different sensitivities; the analyst should follow the applicable standard and retain decay traces.

The security report should distinguish the standardised quantity from the actual receiving level. A room can have an excellent $D_{nT,w}$ while a quiet receiving room permits audibility. Conversely, a modest standardised value may coexist with strong privacy under stable masking. Both facts can be true.

9.16 Source-level distributions and percentile design

A single source level represents a point in a behavioural distribution; talkers differ by sex, age, culture, hearing, language, emotional state, and task; the same talker varies over a meeting; a design based upon the median ordinary voice will not control the rare maximum effort that may carry the most sensitive statement.[440]

A probabilistic source model can use percentiles; the basis of design may select, for example, a high percentile of unamplified vocal effort at a defined distance and orientation; the exact percentile is a policy choice linked to consequence; the source data, population, measurement method, and uncertainty should be recorded; a value copied from a general handbook without these details is not a defensible security source.

440 MB-0736. ASTM International, ASTM E2638-24, ASTM E336-25a.

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Amplification changes the distribution. A conferencing system may apply automatic gain, compression, echo cancellation, and equalisation; remote participants can drive loudspeaker output; a software update may alter behaviour; the source state should include maximum configured output and failure modes.

Speech peaks and long-term average levels serve different purposes; long-term spectra support energy predictions; peaks affect audibility of short fragments; percentile levels over short windows can describe variability; a test that averages over fifteen minutes may hide a one-second disclosure.

The source protocol should include orientation. A participant facing a boundary can increase high-frequency incident energy compared with facing away; seating plans and table positions can be operational controls, but the design should not rely upon perfect behaviour.

9.17 SII as an audibility-weighted model

The Speech Intelligibility Index combines band audibility with band-importance functions and corrections for disturbance; conceptually, it asks how much of the speech information spectrum remains available; it is more informative than a broadband signal-to-noise ratio because not every band contributes equally; it remains a model whose validity depends upon source spectrum, level, hearing, distortion, and task.[441]

For privacy work, SII can be used inversely; a low predicted SII suggests limited intelligibility; the interpretation should not simply reverse communication-quality categories; a threshold suitable for classroom

441 MB-0737. ANSI/ASA S3.5-1997.

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understanding is not automatically a threshold for preventing recovery of one word; security consequence can attach to sparse information.

The model requires careful treatment of speech level at the listener; if residual speech is estimated from room-average attenuation but the listener stands near a leak, SII will be optimistic; background and masking spectra must be measured at the same position and state; hearing acuity and binaural advantage may require conservative assumptions.

Band importance varies by speech material; standard functions are based upon defined corpora and tasks; names, digits, spelling alphabets, and technical abbreviations may have different information distributions; a project-specific listening trial can validate whether the chosen SII interpretation is conservative.

SII does not represent context accumulation directly; a low value for one utterance may still permit repeated recovery; it also does not describe electronic enhancement, contact sensing, or recording and post-processing unless those are part of the listener model.

9.18 STI as a transmission-channel measure

The Speech Transmission Index evaluates how well amplitude modulation in speech-relevant bands survives the channel; reverberation, noise, echoes, and some nonlinear effects reduce modulation transfer; STI is valuable in public-address and room-acoustic design; in privacy analysis it can quantify degradation, but it does not by itself prove that sensitive words cannot be recovered.[442]

442 MB-0738. International Electrotechnical Commission, IEC 60268-16:2020.

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A wall-plus-room path is not always a linear time-invariant channel; doors move, fans cycle, masking changes, and the listener shifts position; STI measured in one state is conditional; electronic conferencing equipment can apply nonlinear processing outside the assumptions of a test signal.

STI test signals require controlled source level and spectrum; a result can be biased by background, clipping, automatic gain control, or insufficient test duration; the report should identify the measurement method, equipment, positions, and uncertainty.

The distinction between speech quality and security consequence is again central; STI categories developed for communication do not automatically map to security categories; a poor STI can still allow recognition of repeated names or digits; a very low result under broadband masking may improve privacy, but the masking dependency must be governed.

A combined analysis can use STI to describe channel degradation and a targeted listening test to evaluate high-consequence recovery; the two sources of evidence should agree in direction; if they conflict, the discrepancy requires investigation rather than averaging.

9.19 Human listening trials and experimental design

Human trials convert physical transmission into observed recovery; they are powerful and easy to misuse; the trial needs a defined question, ethical handling, calibrated playback or live source, listener qualifications, randomisation, blinding, scoring, and statistical treatment.[443]

Listeners should not know the script. Familiarity increases guessing. Repeated exposure to the same corpus creates learning; multiple lists or

443 MB-0739. ASTM International, ASTM E2638-24, ASTM E336-25a.

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randomised tokens reduce this effect; the source should include speech classes relevant to the room, such as ordinary sentences, names, numbers, and alphanumeric strings.

The listener population must match the threat model; ordinary hearing, favourable hearing, language fluency, and professional listening experience produce different results; the report should not conceal that one exceptional listener recovered more than the group average; for a high-consequence boundary, the maximum credible recovery may govern.

Playback trials using recordings permit standardisation, but the recording chain can remove spatial and binaural cues. Headphone level must be calibrated. Processing such as noise reduction should be documented; live trials preserve room cues but are less repeatable.

Statistical confidence matters. Ten trials with zero recoveries do not prove zero probability; under a simple binomial model, the upper confidence bound remains substantial; sample size should be selected before testing; the report should give counts and intervals, not only percentages.

Real sensitive information should not be used; synthetic material can reproduce phonetic and structural difficulty; the test corpus and results may themselves be security-sensitive because they reveal boundary performance. Handling should be defined.

Worked example 9.5. Zero observed recoveries

Suppose 60 independent tokens are presented and none is correctly recovered. The rule-of-three approximation gives an upper 95 per cent confidence bound of approximately $3/60 = 0.05$ for the event probability. Zero observations therefore support “less than about five per cent under the

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tested conditions," not "impossible." Independence and identical probability are simplifying assumptions.

9.20 Masking-system design as a controlled dependency

A masking system can convert a marginal boundary into an acceptable occupied condition, but only if it is treated as part of the security system; the design needs spectral targets, minimum and maximum levels, spatial uniformity, temporal stability, zoning, control access, fault indication, power continuity, maintenance, and verification.[444]

The spectrum should be shaped to the residual speech and occupied comfort; excess low-frequency energy wastes acoustic power and may cause vibration; excess high-frequency energy produces hiss and fatigue; the target should be specified in bands, not only dBA.

Loudspeaker spacing and ceiling geometry affect uniformity; above-ceiling systems can leak into adjacent rooms or ducts. Direct-field systems create gradients. Commissioning should map both protected and accessible spaces; quiet pockets near the boundary are important.

Automatic level control can respond to changing background, but it introduces sensors, algorithms, latency, and failure modes; a controller that reduces masking during quiet periods may do the opposite of what security requires; any adaptive function should be tested under adverse states.

Masking may interact with fire alarms, public address, hearing assistance, and occupational comfort. It cannot obstruct emergency communication. The design requires coordination rather than unilateral acoustic optimisation.

444 MB-0741. ASTM International, ASTM E2638-24.

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The operational procedure should define what happens on failure; meetings may stop, move, or reduce sensitivity; a light or monitoring system can indicate status; reliance upon an inaudible or unnoticed system state is poor governance.

9.21 Accessible positions and spatial threat mapping

A room boundary should be mapped against credible access. The corridor side of a door, an adjoining office, a ceiling void, a mechanical room, a façade ledge, a roof, a service riser, and the floor below may present different paths and backgrounds; the map should include temporary access by maintenance personnel and future tenants.[445]

Distances should be measured. The difference between 0.1 m and 1 m can be large near a local leak; a person can lean towards a grille or place an object against a wall; the threat model may exclude destructive or electronic enhancement, but the exclusion should be explicit.

Spatial surveys can use a coarse room grid plus fine scans at suspected paths; heat maps are useful if their interpolation does not imply unmeasured precision; raw position data should remain available.

Exterior positions require weather control. Wind noise, façade reflection, traffic, and source directivity affect results; night testing can reduce background but may not represent daytime operations; multiple states may be needed.

Access can change through construction. A secure room may later share a wall with a new tenant; a plenum may become accessible through a corridor hatch; the lifecycle review should update the map.

445 MB-0742. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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9.22 Contact, optical, and electronic listening boundaries

Architectural speech-privacy methods generally assume airborne listening; contact transducers, laser vibrometry, microphone placement inside services, and compromised electronic devices create different channels; a room that prevents unaided airborne intelligibility may remain vulnerable to these methods.[446]

The acoustic design should still reduce surface vibration and accessible radiation where practicable; independent linings, damping, structural isolation, glazing design, and service control can reduce susceptibility; TSCM and electronic-security measures address other channels.

Testing should not imply coverage beyond the method; a report may state that no intelligible unaided airborne speech was recovered at designated accessible positions; it should not state that the room is “bug proof.”

Controlled criteria for particular threats may not be public; the public monograph should identify the boundary and defer to the competent authority; it should not reconstruct unavailable thresholds.

9.23 Operational state matrix

A useful commissioning schedule tests combinations rather than one ideal state; the matrix can include door open, door closed but unlatched, door latched, vestibule occupied, HVAC high, HVAC low, masking on, masking off, audiovisual system active, and adjacent room occupied; not every combination requires a full standard test. Screening identifies controlling states, followed by formal measurement.[447]

446 MB-0743. ASTM International, ASTM E2638-24, ASTM E336-25a.
447 MB-0744. ASTM International, ASTM E2638-24, ASTM E336-25a.

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The matrix should distinguish authorised from unauthorised states; a door-open condition may be operationally prohibited, yet it still matters for alarms and human factors; an HVAC-off state may occur during maintenance; a masking-off state may occur during power failure.

Results can be classified as normal, degraded, and prohibited; the operating procedure should link to these states; a room whose privacy depends upon two doors being closed needs indicators or discipline.

A state matrix also improves forensic response; if a later complaint arises, investigators can reproduce the relevant condition; without it, a passing commissioning report may describe a state that no longer exists.

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Table 9-1. Example occupied-condition state matrix

State	Door system	HVAC	Masking	Principal evidence	Operational disposition
Normal	Both vestibule doors interlocked and closed	Normal occupied mode	Verified on	Field metric plus speech test	Authorised for designated discussion
Low-background	Doors closed	Night or reduced-flow mode	On	Speech test at accessible positions	Authorised only if criterion remains satisfied
Masking failure	Doors closed	Normal	Off	Screening and alarm verification	Degraded; follow authority procedure
Maintenance	One boundary opened or ceiling accessed	Variable	Variable	No privacy claim	Prohibited for sensitive discussion
Emergency	Egress overrides interlock	Emergency mode	Variable	Life-safety control governs	Discussion stops or relocates

9.24 Integrated calculation. From source spectrum to receiving consequence

A simplified three-band model uses source levels of 72, 69, and 63 dB at 500, 1000, and 2000 Hz; path attenuation is 46, 49, and 52 dB; residual speech is therefore 26, 20, and 11 dB; background is 24, 18, and 9 dB; the margins are 2, 2, and 2 dB.[448]

If a door-jamb repair improves only the 1000 and 2000 Hz bands by 8 dB, the residual becomes 26, 12, and 3 dB; the 500 Hz margin remains 2 dB, while upper bands fall well below background; intelligibility may decrease substantially because consonant information is reduced, even though low-frequency audibility remains.

448 MB-0745. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

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If masking instead raises every background band by 5 dB, margins become -3 dB in all bands; the consequence improves, but the boundary has not; a masking failure restores the previous condition; the evidence package should record both strategies.

The example is intentionally sparse. A real calculation uses more bands, appropriate speech spectra, room and listener models, uncertainty, and temporal variability; it nevertheless shows why source, path, and background must remain separate vectors until the consequence calculation.

9.25 Commissioning report architecture for speech privacy

A defensible report begins with authority and scope. It identifies the rooms, boundaries, accessible positions, operational states, source protocol, field metric, speech metric, decision rule, exclusions, and limitations.[449]

The methods section records instruments, serial numbers, calibration, source positions, microphone positions, room dimensions, temperature, humidity, decay, background, masking, HVAC, doors, and audiovisual state. Drawings and photographs locate every point.

Results include band data, corrections, uncertainty, classifications, speech scores, and state comparisons. Lower bounds are identified. Figures distinguish room-average and local positions.

Interpretation separates laboratory, field, occupied, and accreditation propositions; it identifies dominant paths only where diagnostics support them; recommendations target mechanisms and include retest conditions.

449 MB-0746. ASTM International, ASTM E2638-24.

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Appendices preserve raw files, processing settings, calibration certificates, scripts, and chain of custody. The report should be readable without private explanation from the original examiner.

9.26 Speech spectra, band importance, and residual-information analysis

A residual speech spectrum is not interpreted by equal weighting of all bands; vowels carry energy, syllabic rhythm, and voicing cues; consonants often carry lower energy but high lexical information; fricatives and plosives can be localised in upper bands; nasals and voiced consonants provide lower-frequency structure. The listener combines these cues with language and context.

A privacy analysis should therefore report both energetic and information-weighted views; the energetic view identifies dominant transmitted power and physical mechanisms; the information view estimates which speech cues remain; SII supplies one established weighting framework, but specialised material may require listening validation.

Band importance also depends upon what is protected; a telephone number, surname, chemical formula, military designation, and ordinary sentence have different redundancy; digits are limited vocabulary and can be recovered from partial cues; a rare surname may be recognised from context; acronyms can be highly distinctive.

The design team should not invent arbitrary importance weights without documenting their basis. A project-specific consequence matrix can supplement standard metrics by identifying high-value content classes and operational controls.

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A useful residual plot shows source, path attenuation, receiving speech, background, and speech-to-background margin by band. This allows the reviewer to see whether a claimed privacy improvement came from the boundary or from background.

9.27 Temporal metrics and short-duration disclosures

Most building-acoustics tests use time-averaged levels; sensitive speech can occur in short bursts; a participant may state a password, date, or decision in less than one second; long averaging dilutes the event.

Short-time spectra, percentile levels, and event detection can supplement averages; the time resolution must balance spectral resolution; a 125 ms window resolves syllabic dynamics but has coarser low-frequency resolution than a long FFT.

The receiving background may also be intermittent; a door slam can mask one phrase while a fan-off interval exposes the next; time-frequency analysis reveals alignment between speech and quiet windows.

For privacy trials, event-based scoring is more relevant than meeting-average signal-to-noise ratio. The report can identify the maximum recoverable fragment and the conditions under which it occurred.

Recording of test speech should comply with authority and privacy requirements; synthetic content avoids creating sensitive records; timestamps should be synchronised with source and building-state logs.

9.28 Directivity, seating, and the incident field on the boundary

A room-average speech level does not specify the incident field at a particular boundary; a talker seated 0.5 m from a door and facing it can

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produce much higher local high-frequency levels than a talker 4 m away facing inward.

Simple geometric spreading can estimate direct-field changes where reflections do not dominate:

Equation 9.7

$$\Delta L = 20 \log_{10}\left(r_2 / r_1\right).$$

Moving from 4 m to 0.5 m increases ideal direct level by $20 \log_{10}\left(4/0.5\right) = 18.1$ dB. Real rooms reduce the difference through reverberation, but the example shows why seating matters.

Conference tables, lecterns, displays, and reflective walls alter directivity and early reflections; a table can couple loudspeaker vibration; a glazing wall can reflect high-frequency energy towards a door.

Threat-informed design may place high-risk seats away from weak boundaries; this is an operational supplement, not a substitute for construction; the room should still control foreseeable movement.

Source positions used in testing should include the closest credible talker and the room-average condition. A single central loudspeaker can miss a local path.

9.29 Doors as local speech-recovery zones

Doors combine lower mass, seals, hardware, and user access; the corridor side is usually an obvious listener position; a high room-average field metric can coexist with intelligible fragments at the jamb or threshold.

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Close-range mapping should include hinge jamb, latch jamb, head, threshold, astragal, vision panel, hardware penetrations, and frame-wall junction. The source should be placed at several credible talker positions.

Door state must be recorded. Closed is not the same as latched; a drop seal may engage only at full closure; pressure differential can alter compression; the closer may not overcome seals.

A vestibule reduces direct transfer only when its doors are not simultaneously open and its interior absorbs rather than reinforces. Interlocks, occupancy, and egress affect operation.

Speech-security commissioning should include ordinary users opening and closing the door. A laboratory-trained closure is not representative if daily use produces variable seating.

9.30 Ducts, plenums, and speech-shaped transfer functions

Duct paths can transmit speech through direct line-of-sight, reflections, modes, breakout, and regenerated grille radiation; the path transfer function may contain strong frequency structure; a broadband field class can hide a narrow speech-relevant band.

Cross-talk silencers, lined ducts, bends, offsets, and separated return systems reduce transfer; their performance depends upon dimensions, length, lining, airflow, pressure drop, and installation; a short unlined sleeve can bypass a high-rated wall.

Plenums are particularly variable. Ceiling tiles, open returns, cable trays, and partitions stopping below the deck create multiple paths. Masking above the ceiling may alter detection without repairing the path.

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Diagnostic measurement can place sources and microphones within accessible duct sections, subject to safety and authority. Transfer functions, coherence, and grille scans help distinguish duct-borne from wall transmission.

Operational states matter because damper position and fan flow change attenuation and background. Testing should include credible low-flow or fan-off states.

9.31 Windows, façades, and exterior listener conditions

Glazing may permit speech radiation to exterior or adjacent interior spaces; the listener condition outside differs from a reverberant receiving room; free-field spreading, façade reflection, wind, traffic, and access distance matter.

A close exterior listener near glass can receive a strong local field; a distant listener may exploit line of sight and quiet night conditions; the threat model should identify credible positions.

Interior blinds and curtains change room absorption but provide little guaranteed transmission loss. Laminated glass can improve coincidence behaviour, while frame and perimeter leakage may govern.

Exterior tests should record wind speed and microphone wind protection; wind-screen self-noise and façade reflection corrections affect results; night testing may reduce background but create a worst case.

Optical vibration methods are outside ordinary airborne speech metrics. The report should not imply that good exterior airborne privacy addresses laser vibrometry.

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9.32 Hearing acuity, binaural advantage, and listener capability

Listeners differ. Hearing threshold, age, language, attention, training, and binaural cues influence recovery. A room designed only for average office listeners may be vulnerable to a favourable listener.

Binaural listening can improve detection and separation through spatial cues; a monaural sound-level meter does not model this advantage; binaural recording and headphone trials can explore it, but calibration and head-related transfer functions introduce complexity.

Hearing impairment can reduce intelligibility but should not be used as a security assumption. The relevant listener may have excellent hearing or use lawful hearing assistance in an adjoining public space.

Electronic post-processing can improve some recordings; if the threat model excludes enhancement, state the exclusion; if recording access is credible, repeated listening and filtering may increase recovery.

A conservative assessment can use listeners with normal or better hearing, language fluency, and no prior script knowledge. Exceptional results should be reported.

9.33 Statistical treatment of word and token scores

A percentage score without denominator and confidence interval is incomplete. Forty per cent from five words is different from forty per cent from five hundred.

For binary token recovery, binomial intervals provide a starting point; listener and item effects violate simple independence; mixed-effects models

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can separate talker, listener, item, and room contributions in research-scale studies.

False positives matter. A listener may guess a word incorrectly but confidently; scoring should distinguish exact, partial, and category-level recovery; for digits, one wrong digit can change consequence.

Inter-rater agreement is relevant when transcripts are judged. Blinded adjudication reduces bias. The source script should be preserved securely.

A criterion might specify no more than a certain upper confidence bound for high-consequence token recovery. The authority must choose the risk level.

9.34 Masking failure modes and diagnostic signatures

Masking systems can fail through amplifier loss, loudspeaker failure, cable fault, control error, zoning mistake, equalisation drift, occupancy scheduling, power interruption, or deliberate tampering. Partial failures are harder to detect than complete silence.

A failed loudspeaker creates a quiet pocket; a reversed or miswired channel can create interference patterns; a ceiling change alters distribution; a control update can reset levels.

Monitoring should verify output or electrical health, but an electrical status does not prove the acoustic field. Periodic spatial measurements remain necessary.

Diagnostic spectra can distinguish masking from HVAC; masking is usually shaped and stable; HVAC contains tones and state changes; the commissioning record should preserve reference spectra.

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Alarm thresholds should consider normal variation without allowing dangerous drift. The response procedure should be tested.

9.35 Speech privacy in legal, medical, and commercial rooms

The same physical mechanisms apply outside classified facilities, but the decision authority and consequence differ. Attorney-client rooms protect privilege. Medical rooms protect patient information. Boardrooms protect commercial strategy. Each requires a stated risk model rather than borrowed classified terminology.

Legal rooms may have public corridors, glass, and electronic conferencing; medical rooms may have high ventilation and frequent door operation; commercial rooms may rely on demountable partitions; the appropriate field and speech criteria differ.

A public standard or professional guideline may support design, while organisational policy sets acceptance. Accreditation language should not be borrowed from government security programmes.

The monograph’s four-proposition doctrine remains useful. Laboratory evidence, field evidence, occupied consequence, and institutional acceptance should be separated in every sector.

9.36 Long-duration monitoring and privacy assurance

One commissioning test is a snapshot; long-duration monitoring can reveal background drift, masking failures, door-open events, and operational changes; it must be designed to avoid recording protected speech.

Privacy-preserving monitors can record band levels, system status, or test signals without content. Scheduled injected tests can verify path stability during unoccupied periods.

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Trend data should have thresholds and response ownership. Collecting data without action does not improve security.

Sensors and networks create cyber and privacy risks; access, retention, and integrity controls are needed; the monitor itself must not become a microphone vulnerability.

Long-duration evidence supports lifecycle assurance but does not replace periodic full testing and inspection.

9.37 Design example. Quiet executive suite

A private executive suite contains a conference room adjoining a quiet assistant office; the partition has strong laboratory evidence, but the receiving background is only 22 dBA at night; a door and shared return create local paths.

A room-average field test passes the nominal level-reduction target; close-range speech testing recovers digits at the return grille during fan-off periods; raising masking in the office is unacceptable because of work requirements.

The design response separates returns, adds a cross-talk silencer, improves the door seals, and relocates the assistant desk; post-remediation tests include fan-on and fan-off states; the speech result improves without relying on continuous masking.

The case demonstrates that low background can make an otherwise respectable boundary unsuitable for the actual consequence. The field metric, local path, and occupied use must be considered together.

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9.38 Design example. Diplomatic meeting room with exterior glazing

A hypothetical diplomatic meeting room has masonry interior walls and a large exterior window. Interior room-to-room isolation is strong. Night-time exterior background is low, and a service roof provides occasional access near the glazing.

The source protocol includes maximum credible voice near the window; exterior measurements identify a glazing-frame path; interior curtains improve reverberation but do not materially change exterior transfer.

A secondary interior glazing layer with independent frame and controlled cavity is installed; the post-remediation curve improves, but the authority also restricts roof access during meetings; the result package distinguishes architectural improvement from access control.

No public acoustic measurement is represented as formal accreditation. The competent authority retains that decision.

9.39 Minimum evidence set for an occupied privacy claim

A defensible occupied privacy claim requires room and boundary identity; source definition; source positions; receiving positions and access basis; background and masking spectra; field attenuation or path data; speech metric; listener model; operating states; uncertainty; decision rule; and limitations.

Photographs, plans, raw files, calibration records, and processing settings support reproducibility. The report should identify controlled or unavailable criteria without guessing.

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If one of these elements is missing, the conclusion should narrow; for example, a field attenuation test without listeners can support isolation, not direct observed intelligibility; a listening trial without calibrated source can support an observation under that trial, not a portable room rating.

9.40 The difference between average privacy and worst-position privacy

An office-acoustics programme may reasonably describe average privacy across a circulation area; a secure-room programme commonly cares about the most favourable credible listener position; these objectives require different sampling and statistics.

Averaging reduces the influence of local peaks; this is appropriate when occupants are distributed randomly and the consequence is general disturbance; it can be unsafe when a listener can choose a door jamb or grille; the test plan should therefore distinguish representative room averages from threat-informed maxima.

The maximum observed value is sample-dependent; a denser grid is more likely to find a peak; the report should state grid spacing and search method; physical inspection can guide adaptive refinement near suspected paths.

A percentile may provide a compromise for large public areas, but the chosen percentile is a policy decision. It should not be introduced after seeing the data.

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9.41 Speech privacy across multiple receiving spaces

A protected room may adjoin corridors, offices, roofs, floors, façades, and service spaces; each receiving space has a different background and access condition; one room-to-room test cannot represent the whole envelope.

The boundary inventory should list every adjoining or coupled space. Screening can rank paths. Formal measurements focus on high-consequence or weak paths. Exterior and structural paths may require different methods.

A whole-room claim should be based on the weakest credible receiving condition, or explicitly limited to tested boundaries. The report should not extrapolate from one passing wall to the room.

Changes in adjacent tenancy can alter background and access. Lifecycle review should revisit the receiving-space inventory.

9.42 Privacy under remote conferencing and distributed audio

Modern meeting rooms contain microphones, echo cancellers, loudspeakers, displays, cameras, USB devices, network codecs, and software. These systems alter acoustic source and create non-acoustic exfiltration channels.

Acoustically, loudspeakers can exceed human voice levels and radiate towards weak boundaries; automatic gain can raise quiet remote speech; echo cancellation can change signal dynamics. Table microphones can be reconfigured as loudspeakers in some devices.

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The source protocol should test maximum configured loudspeaker output and ordinary operation. The operating policy may limit output or disable local reinforcement for sensitive meetings.

Acoustic results do not establish cyber or electronic security. Equipment introduction, network control, and TSCM review remain separate.

9.43 Privacy in rooms with hearing-assistance systems

Hearing-assistance loops, infrared systems, and radio aids are designed to improve intelligibility. In a sensitive room, they can extend the speech field beyond the architectural boundary if not properly controlled.

An induction loop can create magnetic-field leakage; infrared can escape through glazing; radio systems can transmit beyond the room; these are not addressed by STC or airborne privacy metrics.

The room design should coordinate accessibility with secure communications; approved systems, zoning, encryption where applicable, and operational control may be required; the public monograph should not infer controlled criteria.

The acoustic measurement remains relevant to ordinary airborne paths, but the report must disclose the separate assistive channel.

9.44 Language, accent, and corpus effects

Intelligibility scores depend on language and familiarity; a listener fluent in the meeting language may recover fragments that another cannot; accents, speech rate, and vocabulary change difficulty.

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A standard corpus supports repeatability but may not represent technical or diplomatic speech. Supplemental corpora can include names, digits, and acronyms without using real sensitive content.

The report should state language, talker characteristics, listener fluency, and corpus. It should avoid generalising one language result to all use.

9.45 Privacy and machine-assisted transcription

A microphone recording that is unintelligible to a casual listener may yield partial machine transcription after enhancement; performance depends on signal quality, model, language, and repeated context; ordinary architectural privacy standards generally do not validate against every future algorithm.

If recording access is within the threat model, the assessment should preserve test audio and evaluate authorised enhancement methods under controlled conditions. The result is technology-specific and time-dependent.

The existence of machine assistance strengthens the need for margin and prevention of recording access. It does not justify claims unsupported by testing.

The final report should distinguish unaided human listening, aided human listening, and machine-assisted recovery.

9.46 Acoustic privacy and room pressurisation

Pressure differentials can change door-seal contact and airflow through gaps; a positively pressurised room may drive speech-bearing air through openings; a negatively pressurised room can pull corridor noise inward while changing seal force.

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Field tests should record pressure when mechanical balance is material. Door opening force and closer performance should be checked under design conditions.

A room that passes before balancing may change after HVAC commissioning. Acoustic retest should follow final balancing for critical boundaries.

9.47 Privacy during fire, emergency, and degraded modes

Life safety overrides acoustic security. Fire doors release, smoke-control systems change pressure, public address activates, and occupants evacuate. Sensitive discussion should stop.

The operating procedure should define degraded modes. The acoustic design must not obstruct alarms, egress, or emergency communication.

Post-event inspection may be needed if doors, seals, or systems operated unusually. Emergency testing itself should not use sensitive content.

9.48 Privacy in temporary and relocatable rooms

Temporary secure meeting rooms may use modular panels, portable sound locks, masking, and controlled location. Their performance is highly installation-dependent.

Floor, ceiling, façade, and service paths may dominate. A high-rated panel kit does not create a secure room in an uncontrolled host building.

Each deployment requires site survey, assembly inspection, field testing, operational controls, and authority acceptance. Previous deployment evidence is not sufficient.

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Relocation and repeated assembly introduce variability. Components should be inspected for damage and seals replaced as needed.

9.49 Influence of furnishing and interior treatment

Interior absorption changes reverberation, source field, and talker behaviour; absorptive finishes can reduce room-average incident level at boundaries and improve communication, which may reduce vocal effort; they do not provide the same isolation as a boundary.

Hard rooms encourage higher speech levels and strong reflections; strategic absorption near reflective boundaries can reduce excitation; diffusion can alter local peaks.

Furniture placement can create direct or shielded paths. A high-backed bench near a door may reduce direct high-frequency radiation but should not be treated as a permanent security element.

The as-tested furnishing state should be recorded. Later removal may change privacy.

9.50 Speech privacy and masking comfort trade-offs

Higher masking generally reduces intelligibility but can impair concentration, comfort, and communication within the receiving space. The design problem is multi-objective.

Spectrum shaping and spatial uniformity are more effective than indiscriminate level. A quiet office may require architectural improvement rather than high masking.

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Occupant complaints can lead facilities staff to lower masking without security review. Access controls and change management are therefore part of the design.

Post-occupancy evaluation should collect comfort and privacy evidence without recording protected speech.

9.51 A structured diagnostic decision tree

If speech is audible, first confirm source and background; if the residual is localised at a door or opening, inspect seals and penetrations; if it is distributed through the boundary, compare with wall predictions; if low-frequency vibration appears in remote structural elements, investigate flanking; if the result changes with fan state, test ducts and pressure.

Each branch predicts a state change; the examiner should perform the least intrusive discriminating test first; a remedy is selected only after the path is supported.

The decision tree should be project-specific. Generic troubleshooting lists are useful prompts but cannot replace observation.

9.52 Privacy acceptance and compensating controls

A marginal architectural result may be managed through masking, access restriction, seating, operating hours, or procedural controls. These are compensating controls, not evidence that the architecture met its requirement.

The authority should document the control, owner, monitoring, failure response, and expiry. Temporary controls should not become permanent by default.

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Contractual responsibility may remain with the builder even when operational use is authorised. The acceptance dossier should separate these decisions.

9.53 Chapter integration

Field isolation quantifies the completed path. Speech metrics estimate consequence. Background and masking modify consequence without changing the passive path; listener access and duration determine opportunity; the authority decides acceptable risk.

The integrity of the analysis lies in keeping these layers connected but distinct. Every later construction chapter should return to this chain when evaluating materials, doors, services, and remediation.

9.54 Privacy metrics and the problem of one-word compromise

Communication metrics are often calibrated against sentence or word understanding; security consequence can attach to one item; a project name, account number, identity, location, or decision may be compromising even when the surrounding sentence is unintelligible.

An average intelligibility score can therefore understate risk; the test corpus should include high-consequence token classes and report the maximum or upper confidence bound for recovery; the authority may require zero observed recovery in a defined sample, but the statistical limitation of zero events must still be stated.

Context changes consequence. A listener who knows the meeting agenda needs fewer acoustic cues; repeated names and numbers are easier to

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reconstruct; the threat model should not assume a naive listener unless that assumption is justified.

9.55 Privacy metrics and partial phonetic recovery

A listener may recover first consonant, syllable count, stress, or number of digits without the complete word. Partial cues can narrow possibilities. Scoring only exact words discards this evidence.

A graded protocol can record exact recovery, phonetic similarity, category recovery, and confidence; the analysis should prevent post hoc reinterpretation; blinded scorers can compare transcripts with the script.

Objective metrics can be correlated with partial recovery during validation. The relationship is corpus-specific and should not be generalised without evidence.

9.56 Effect of source-room absorption on boundary excitation

Adding absorption to the source room reduces reverberant build-up and can lower average incident level at boundaries; it also improves communication and may reduce vocal effort; these effects can support privacy without changing partition transmission loss.

The benefit is frequency-dependent and geometry-dependent; absorption near the talker or reflecting boundary can affect early energy; a simple Sabine calculation provides a first estimate but not local directivity.

The source-room treatment should be documented as part of the occupied condition. Removal or replacement can change performance.

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9.57 Effect of receiving-room absorption on audibility

Receiving absorption lowers reverberant build-up but can make a local direct leak more distinct by reducing diffuse background. The net privacy effect is not universally positive.

For room-average metrics, normalisation accounts for absorption. For a listener near a leak, direct sound may dominate and the correction may not describe consequence.

A quiet, absorptive office adjoining a secure room can be a worse listener environment than a lively corridor. The receiving-space inventory should reflect this.

9.58 Privacy under open-door transition events

Doors are opened during entry and exit; interlocks and vestibules reduce simultaneous openings, but transition events can expose speech; a room may meet all closed-state metrics and still be vulnerable operationally.

Procedures can pause sensitive discussion during door operation; door-position indicators, vestibule occupancy, and access control support discipline; acoustic testing can characterise transition duration but life safety and usability govern.

A single-door room should not claim continuous privacy during opening. The limitation belongs in training and accreditation records.

9.59 Privacy in shared structures and multi-storey buildings

Speech-related vibration can travel through slabs, columns, and beams to non-adjacent rooms; the receiving space may be above, below, or diagonally separated; airborne room-to-room tests across the nominal wall do not capture every path.

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Low-frequency residuals, coherent structural vibration, and repeated patterns can indicate a structural path. Mobility and transfer-function measurements from Chapter 6 support diagnosis.

A whole-envelope assessment should include vertical paths where access and consequence justify it. Massive construction is not automatically immune.

9.60 Privacy and façade reflections in courtyards

Courtyards and narrow urban gaps can reflect sound between façades; a window radiating speech may be heard at another elevation or returned to a nearby accessible location; free-field distance calculations can understate this.

Exterior testing should consider reflective geometry and open windows in adjacent spaces. Wind and traffic vary. Night-time may create the worst condition.

Architectural screens, secondary glazing, and access control can reduce risk. The field report should limit its conclusions to tested positions and weather.

9.61 Privacy in vehicles, ships, and relocatable platforms

Mobile platforms have lightweight structures, machinery noise, vibration, and changing external backgrounds; a high background can mask speech during operation but disappear when stationary; doors and hatches differ from building systems.

The same evidence hierarchy applies, but methods may require adaptation; public building standards should not be applied mechanically to shipboard or vehicle compartments; platform authority and applicable standards govern.

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Testing should include operational and quiet states, machinery paths, and hull or body radiation. Accreditation remains separate.

9.62 Privacy effects of active noise control

Active noise control can reduce low-frequency background at selected locations; this may improve comfort while reducing incidental masking and making transmitted speech more audible; it can also alter duct and room fields.

A privacy assessment should test active control on and off; the control system should not be assumed beneficial; failure and update states matter.

Active control is not a substitute for passive isolation. Its sensors and networks also require security review.

9.63 Privacy and sound reinforcement equalisation

Equalisation can boost bands that are weak inside the room, increasing boundary excitation; a room tuned for clarity may inadvertently transmit more speech; limiters and presets should be reviewed.

Commissioning should capture maximum allowed equalisation and output. User-accessible controls can undermine assumptions. A “speech” preset may emphasise consonant bands.

Operational policy can lock settings for sensitive use. The acoustic report should state the tested preset.

9.64 Privacy metrics for adjacent corridors

Corridors have moving listeners and time-varying background; a point test should include likely waiting, queuing, and doorway positions; averages along the corridor may hide the quiet alcove.

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The corridor background distribution can be measured over occupied and quiet periods. A minimum credible background is more relevant to security than a daytime average.

Masking zoning should extend to all accessible positions without spilling excessively into protected rooms.

9.65 Privacy metrics for ceiling voids and service spaces

Ceiling voids may be unoccupied normally but accessible to maintenance; their background can be low when plant is off; sound can travel long distances above partitions.

Testing requires safe access and appropriate source-receiver geometry; a microphone in the plenum may identify paths but does not represent ordinary unaided corridor listening; the threat model should define access.

Service-space evidence can guide repairs and TSCM inspection. Conclusions should be bounded to the method.

9.66 Post-remediation speech verification

After a repair, repeat the original source and listener protocol; match room state, background, positions, and processing; if the background differs, report both raw and normalised comparisons.

A successful local repair may expose another path; the whole-envelope result should be rechecked; do not stop after the first favourable scan.

The final report should show before and after spectra, speech scores, uncertainty, and residual limitations.

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9.67 Privacy programme governance

An institutional programme assigns ownership for design criteria, testing, masking, maintenance, room use, source control, access, incident response, and records. Acoustic performance deteriorates when responsibilities are fragmented.

Room users need concise instructions. Facilities staff need penetration and seal controls. Security staff need test and incident protocols. Procurement needs evidence requirements.

The programme should maintain a room register with baseline metrics, operating dependencies, retest dates, and change history. This converts privacy from a one-time project into lifecycle assurance.

9.68 Chapter evidence summary

The field result is a measured property of a configured room pair; speech consequence is a probabilistic outcome involving source, path, background, listener, and opportunity. Masking and operations modify consequence. Accreditation is a separate authority decision.

The chapter’s methods are designed to keep those propositions visible; they prevent a passing room-average class from concealing a local speech leak and prevent a favourable masking state from being mistaken for permanent passive isolation.

9.69 Privacy assessment under multiple talkers

Meetings contain overlapping voices. Simultaneous speech raises total level and changes spectral masking inside the source room; one talker can mask another within the room while increasing boundary excitation; a single recorded voice does not reproduce this state.

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A conservative protocol can test one maximum-effort talker near a weak boundary and a multi-talker condition for total excitation; the two tests answer different questions; overlap may reduce sentence intelligibility but preserve names or numbers spoken above the group.

The report should identify source count, positions, vocal effort, and whether speech was correlated or independent.

9.70 Privacy assessment for presentation systems

Presentation audio, video clips, and remote feeds can contain speech at sustained levels higher than conversation; the system may reproduce wide bandwidth and low-frequency energy; maximum configured output should be included in the source-state matrix.

The operating policy can restrict programme audio during sensitive use; if the control is relied upon, it should be locked, monitored, and tested; a field insulation result obtained with broadband noise remains relevant, but occupied consequence must use the actual audio state.

9.71 Privacy assessment for interpreters and simultaneous translation

Interpretation rooms and headsets introduce additional talkers, microphones, loudspeakers, and transmission systems; interpreters may speak continuously and at elevated level; booth glazing and ventilation can create paths.

The acoustic design should separate source control, booth isolation, electronic distribution, and listener access; standard office metrics are insufficient without system analysis; language and corpus effects are particularly relevant.

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9.72 Privacy assessment for video walls and large displays

Large displays can conceal cavities, loudspeakers, cooling fans, cable routes, and wall penetrations; their mounting can bridge resilient linings; a display may also reflect speech towards a boundary.

Testing before and after installation can identify changes; the as-built record should show penetrations and backing; electronic security remains a separate review.

9.73 Privacy assessment for underfloor air systems

Underfloor supply or return creates a connected volume beneath rooms. Floor diffusers, cable openings, and partitions may provide cross-talk. Background varies with airflow.

A room-level field test should include underfloor paths; diagnostic source placement in the cavity can identify transfer, subject to safety; fire and smoke compartmentation must be coordinated.

9.74 Privacy assessment for open return plenums

Open returns rely on ceiling plenums and transfer paths; they are difficult to reconcile with high speech isolation; ceiling tiles, grilles, and partition termination determine transfer.

A high wall rating below the ceiling does not control the plenum; cross-talk silencers, ducted returns, full-height barriers, and controlled penetrations may be required; fan noise can temporarily mask the weakness.

9.75 Privacy assessment near lifts and shafts

Lift shafts, stairs, and service risers can transmit sound vertically and create changing background; a quiet shaft during idle periods may become an effective path; doors and vents connect floors.

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Screening should include shaft-adjacent boundaries and quiet states; structural and airborne diagnostics may both be needed; access restrictions and fire requirements govern testing.

9.76 Privacy assessment in high-background industrial areas

Industrial background can provide strong incidental masking; the room may appear private while machinery operates and vulnerable during shutdown; the source room may also be exposed to vibration.

Testing should include shutdown or lowest credible operation; if continuous plant operation is guaranteed, the dependency should be documented and monitored; passive boundary evidence remains necessary for degraded states.

9.77 Privacy assessment in libraries and other very quiet spaces

A receiving space with exceptionally low background can make small transmitted fragments audible. Libraries, executive offices, bedrooms, and recording spaces are demanding neighbours.

Design criteria should reflect the quiet condition rather than a generic office background. Masking may conflict with use. Architectural isolation and access distance become more important.

9.78 Privacy assessment under rain and weather noise

Rain on roofs or façades can provide temporary masking and excite structure; wind changes exterior microphone noise and pressure; a passing test during adverse weather may overstate ordinary privacy.

Exterior and roof tests should record weather and, where possible, use quiet conditions. Weather-dependent results should be qualified.

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9.79 Privacy assessment after furniture reconfiguration

Moving tables, screens, cabinets, and absorptive panels changes source positions and room response. A new seating plan can place a speaker near a weak boundary.

Configuration control should include significant interior changes for critical rooms. Screening after reconfiguration may be sufficient unless paths or use change materially.

9.80 Privacy assessment during maintenance access

Ceiling tiles, access panels, and doors may be open during maintenance. Sensitive discussion should be prohibited. The maintenance permit should identify the room and restore the boundary.

Post-maintenance inspection verifies seals and closures; work that penetrates the boundary triggers targeted testing; the baseline record supports comparison.

9.81 Privacy incident triage

When a suspected speech leak is reported, preserve the state before repair; record who observed what, where, when, and under which room conditions; do not use the report as proof of interception.

Reproduce the source safely, measure background, inspect paths, and compare with baseline; electronic and TSCM review may be required; the technical conclusion should distinguish observed audibility, intelligibility, susceptibility, and proven compromise.

9.82 Closing professional rules

Never infer occupied privacy from a laboratory class alone; never infer accreditation from a speech test; map accessible positions, preserve source

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and background spectra, test credible states, and report probability and uncertainty honestly.

These rules keep the field measurement connected to real information risk without claiming more than the evidence supports.

9.83 Integrated privacy case study. Medical consultation room

A hypothetical medical consultation room adjoins a quiet waiting alcove; the wall and door satisfy the project’s field class, and daytime waiting-area noise usually masks speech; complaints arise during early-morning appointments when the alcove is empty and ventilation operates at reduced flow.

A time-resolved survey shows that receiving background falls by 9 dB in the reduced-flow state; room-average isolation does not change; close-range listening near the door recovers names and appointment times; the result is an occupied-condition failure caused by changed background and a local door path, not by a change in the wall.

Remediation combines improved door seals, relocation of waiting chairs, and a low-level controlled masking zone in the alcove; post-remediation testing uses normal and reduced-flow states, high-consequence token lists, multiple listeners, and uncertainty intervals; the field class rises modestly, while recovery probability falls substantially.

The report avoids government-security terminology. It states the healthcare confidentiality criterion, test conditions, and institutional acceptance; the four-proposition model still applies: laboratory component evidence, field room performance, occupied speech consequence, and organisational approval remain distinct.

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9.84 Integrated privacy case study. Commercial merger room

A temporary merger room is assembled inside a leased office using modular walls, an acoustic door, ceiling barriers, and masking; the host building has a shared raised floor and open returns; the panel system has strong laboratory evidence, but the site survey identifies uncontrolled underfloor and plenum paths.

The first screening test finds intelligible digits in an adjoining vacant office when masking is off; the boundary class is governed by the underfloor path; the project adds barriers around the floor cavity, ducts the returns through silencers, and extends masking into the accessible adjoining zone. The room is retested after every service penetration.

The operational plan prohibits sensitive meetings during ceiling access, masking fault, or adjacent construction; a status indicator and room log support compliance; the lease change process requires acoustic review before adjoining tenancy changes.

The case demonstrates the limits of product ratings in temporary construction; the modular panels performed as intended, yet the host building determined privacy; it also shows that masking can be a valid controlled dependency when its failure state is explicit and monitored.

9.85 Comparative measurement exercise. Room average, local maximum, and listener trial

A completed meeting room is tested with three evidence layers; the standard field test uses two source positions and multiple receiving positions to calculate a standardised weighted difference; a diagnostic survey maps local levels along the door, glazing, ceiling, and return grille; a

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blinded listener trial uses names, digits, and ordinary sentences at normal and raised source effort.

The standardised result is 52 dB, comfortably above the project’s nominal 50 dB threshold; the local survey finds a narrow high-frequency peak at the latch jamb, 9 dB above the receiving-room spatial mean; under normal vocal effort, listeners recover no complete words; under raised effort from the seat nearest the door, two of sixty digits are recovered at the jamb position; no digits are recovered at the room-average positions.

These results are not contradictory. The field metric estimates a room-pair quantity; the diagnostic map identifies a local path; the listener trial estimates consequence under a favourable position and source; the decision authority must determine whether the rare recovery rate and state are acceptable; the acoustic team should not erase the local result because the room average passed, nor should it declare the room universally insecure because two digits were recovered in a contrived but credible adverse state.

The team adjusts the latch and seal, then repeats only the affected diagnostics and listener condition before performing a final abbreviated room test; the local peak falls by 7 dB, and no digits are recovered in the repeated trial; the standardised result changes by less than one decibel because the local path occupied a small part of the room-average field.

The exercise shows why a high-consequence programme needs layered evidence; room averages provide reproducible comparison; local diagnostics locate repairable defects. Listener trials test consequence. Uncertainty and sample size bound each conclusion; a single layer would have produced either false confidence or disproportionate alarm.

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9.86 Consequence-weighted speech fragments, multilingual listeners, and repeated access

Speech privacy is sometimes discussed as though every word carried equal value and every listener possessed the same linguistic competence; secure-room assessment requires a more discriminating view. A meeting may contain abundant low-consequence language and only a few consequential fragments, such as a surname, account number, date, code word, medical diagnosis, legal instruction, or operational location; a listener who recovers one such fragment may obtain useful information even when most sentences remain unintelligible. The assessment should therefore distinguish average intelligibility from the probability of recovering protected tokens under repeated exposure.[450]

Language and accent alter that probability; a listener fluent in the language, familiar with the speakers, and aware of the meeting subject can exploit partial phonetic cues more effectively than an unfamiliar listener; conversely, a listener without the relevant language may hear speech activity without recovering semantic content. No single adjustment factor can represent these differences across languages, dialects, accents, and specialist vocabularies; the report should state the assumed listener population and should avoid transforming an ordinary metric into a universal claim about comprehension.

Repeated access compounds the problem. One short observation may yield only uncertain fragments; a cleaner may occupy the adjoining room daily; a corridor may be accessible during every board meeting; a maintenance space may be entered intermittently but for long periods; repetition permits

450 MB-0747. ASTM International, ASTM E2638-24, ANSI/ASA S3.5-1997.

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the listener to compare phrases, learn speaker habits, recognise recurring names, and combine partial observations with external knowledge. The relevant exposure variable is therefore not only level or intelligibility at one instant; it includes duration, recurrence, listener opportunity, and the ability to aggregate observations.

A consequence-weighted protocol can begin by defining protected token classes before testing; the classes may include personal identifiers, financial values, dates, project names, locations, or decision verbs; test material should contain representative tokens embedded in natural sentences rather than isolated word lists alone. The listener trial should record false positives as well as correct recoveries because an apparent success rate can be misleading when participants guess from a restricted vocabulary; the result should report the listener group, language competence, source effort, talker orientation, background condition, number of presentations, and scoring rule.

An illustrative calculation shows why repeated opportunity matters; suppose the probability of correctly recovering at least one consequential token from a single observation is 0.03 under the stated source, path, background, and listener model; if ten observations are treated as independent, the probability of at least one recovery becomes

$$P_{any} = 1 - \left(1 - 0.03\right)^{10} = 0.263.$$

The independence assumption is often optimistic because observations may share the same words, listeners, paths, and contextual clues; positive dependence can reduce the gain predicted by the equation, while learning and contextual accumulation can increase practical recovery; the calculation

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is therefore a screening illustration, not a universal rule; it nonetheless demonstrates that a small per-event probability can become material when access is repeated.

Multilingual meetings introduce another complication. Participants may switch languages, use abbreviations, or pronounce proper names consistently across languages; a test conducted in only one language may miss the most recoverable fragments; where the room serves a diplomatic, legal, medical, or international commercial function, the test plan should identify the language states most relevant to the mission. This does not require an exhaustive trial for every possible language; it requires an explicit statement of what was and was not tested.

Electronic conferencing can increase consequential exposure even when room speech levels remain unchanged; remote participants may be reproduced through loudspeakers with equalisation, compression, and automatic gain control; a quiet distant participant can be amplified to a stable local level, while local speech may be reinforced through sidetone or room loudspeakers. The source protocol should therefore include representative conferencing states, not merely unaided conversation; any local recording, transcription, or network-security issue remains outside the acoustic conclusion and must be controlled separately.[451]

The bounded conclusion should state the exact claim; it may establish that, for the tested source material and listener group, the probability of recovering defined protected tokens at accessible positions remained below a project threshold; it may establish only that speech was audible but not

451 MB-0748. ASTM International, ASTM E2638-24, IEC 60268-16:2020.

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reliably intelligible. It may reveal a local position at which names or numbers were recovered despite a favourable room-average metric; none of these findings alone constitutes accreditation; they provide evidence for the competent authority’s decision.

9.87 Chapter conclusions

Field isolation metrics describe completed room pairs under measured conditions; speech metrics describe consequences for defined source, background, room, and listener models. Neither category is self-executing. The specification and security authority must define the proposition and decision rule.

The durable method is to preserve the chain from source through room, boundary, flanking, receiving condition, and listener; each transformation requires its own evidence; a single number may summarise one link; it cannot prove the whole chain.

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Chapter 9 Glossary

Apparent sound reduction. A field quantity that includes the combined direct and flanking transmission observed between rooms under the applicable method.

Audibility. Detection that a sound is present, distinct from recognition or understanding of its content.

Equivalent absorption area. The area of a perfectly absorbing surface that would provide the same absorption as the receiving room under the applicable model.

Level difference, D. The difference between spatially averaged source-room and receiving-room levels in a defined frequency band.

Normalised level difference, D_n. A field level difference adjusted to a reference equivalent absorption area.

Receiving condition. The combination of background sound, room response, listener location, access, and operating state on the receiving side.

Speech Intelligibility Index (SII). An ANSI/ASA metric estimating intelligibility-related audibility through band importance and disturbance.

Speech Transmission Index (STI). An IEC metric based upon preservation of speech-envelope modulation through a channel.

Standardised level difference, D_{nT}. A field level difference adjusted to a reference reverberation time.

Word score. The proportion of test words correctly recovered under a defined corpus, talker, listener, and condition.

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Chapter 10. Measurement Uncertainty, Decision Rules, Guard Bands, and Acceptance Risk

10.1 A measurement result is an estimate, not the measurand itself

Building-acoustics reports often place one number beside one requirement and invite a binary conclusion; the apparent simplicity conceals the measurement model; source and receiving levels are estimated from finite samples. Background is corrected. Decay time is fitted. Geometry is measured. Calibrations have uncertainty. The result may then be weighted and rounded; the reported number is therefore an estimate of a defined measurand under stated conditions, accompanied by uncertainty and model limitations.[452]

The measurand must be specified before uncertainty can be evaluated; “STC of the room” is not an adequate measurand because a room does not have a universal STC; “apparent Sound Transmission Class between Room 201 and Corridor 2 under ASTM E336-25a and E413-22, with the doors latched, HVAC in occupied mode, and masking off” is closer. A speech-security measurand must also identify source vocal effort, receiving positions, background, listener model, and scoring.

Uncertainty is not evidence that the measurement is poor; it is evidence that the laboratory or field team understands the limits of the estimate; a result without uncertainty can appear more precise while being less defensible; the purpose of uncertainty analysis is to support comparison, diagnosis, and decision, not to make every conclusion inconclusive.

452 MB-0672. JCGM 100:2008, NIST Technical Note 1297.

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Building acoustics contains both repeatable and variable components; instrument calibration may be small; spatial sampling can be large; background correction can dominate a high-isolation band; construction state can change between tests; some components belong to measurement uncertainty; others belong to the variability of the object under different states; the report should distinguish them.

ISO 12999-1 addresses determination and application of measurement uncertainties in building acoustics; the GUM, NIST TN 1297, ILAC guidance, and ISO/IEC 17025 provide broader metrological and laboratory frameworks; these sources should be used coherently, not as ceremonial citations.[453]

10.2 The measurement model and sensitivity coefficients

A useful uncertainty analysis begins with an explicit model

Equation 10.1

$$y = f\left(x_1, x_2, \ldots, x_n\right),$$

where y is the output estimate and x_i are input quantities. For a standardised level difference,

Equation 10.2

$$D_{nT} = L_1 - L_2 + 10\log_{10}\left(T/T_0\right).$$

The first-order combined standard uncertainty is

Equation 10.3

$$u_c^2(y) = \sum_i c_i^2 u^2\left(x_i\right) + 2\sum_{i<j} c_i c_j u\left(x_i, x_j\right),$$

453 MB-0671. International Organization for Standardization, ISO 12999-1:2020, ISO/IEC 17025:2017.

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where $c_i = \partial f / \partial x_i$ are sensitivity coefficients and $u(x_i, x_j)$ are covariances. The expression shows why input uncertainty cannot be combined by simple arithmetic. Each term is scaled by the model's response.[454]

For Equation 10.2, the sensitivities to L_1 and L_2 are +1 and -1. The sensitivity to T is

Equation 10.4

$$c_T = \frac{10}{\ln 10} \frac{1}{T}.$$

At $T = 0.50$ s, $c_T = 8.686$ dB/s. A decay uncertainty of 0.05 s contributes 0.43 dB. At $T = 1.5$ s, the same absolute uncertainty contributes 0.14 dB. The model reveals where control matters.

Covariance matters when the same calibration or environmental effect influences multiple terms; if one analyser range shifts both source and receiving levels in the same direction, some error may cancel in the difference; treating the inputs as independent can overstate uncertainty; if the same background estimate enters several bands, correlation can affect a classification; the covariance assumptions should be stated.

The model also defines scope. A change in door state is not a small uncertainty component if it creates a different measurand; it is a different configuration requiring a separate result; uncertainty should not be used to blur distinct physical states.

454 MB-0682. JCGM 100:2008, NIST Technical Note 1297.

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Worked example 10.1. Combined uncertainty in a standardised difference

Suppose $u(L_1)=0.40$ dB, $u(L_2)=0.55$ dB, $T=0.60$ s, and $u(T)=0.05$ s. Assume independence. The decay contribution is

$$u_T=\frac{10}{\ln 10}\frac{0.05}{0.60}=0.362\,dB.$$

Then

$$u_c=\sqrt{0.40^2+0.55^2+0.362^2}=0.77\,dB.$$

With coverage factor $k=2$, expanded uncertainty is approximately 1.54 dB. The calculation is dimensionally consistent because the decay sensitivity converts seconds into decibels. The result applies to the stated band and model, not automatically to the weighted classification.

10.3 Type A and Type B evaluations

Type A evaluation uses statistical analysis of repeated observations; examples include the spread among microphone positions, repeated source positions, repeated door closures, and repeated decay measurements; type B evaluation uses other information, such as calibration certificates, instrument specifications, resolution, environmental corrections, and prior data; the labels describe evaluation method, not importance.[455]

Repeated observations should represent the variability relevant to the measurand; taking ten consecutive readings at one fixed position may estimate short-term instrument noise but not spatial variation; repeating a door test without opening and closing it does not estimate closure

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variability; the sampling design determines what the standard deviation means.

A Type B component requires a distribution; a calibration certificate may provide expanded uncertainty with a coverage factor; a specification may state a limit with no distribution; the analyst should assign a defensible distribution and standard uncertainty, document the choice, and avoid counting the same effect twice.

Finite sample size affects uncertainty of the mean. The standard deviation of a small set is itself uncertain. Effective degrees of freedom and coverage factors may matter when one component dominates. Automated software should not substitute a universal $k=2$ without checking the intended confidence and distribution.

Construction variability is often assessed through repeated specimens or locations rather than measurement repeats; it can be reported separately as population variability; combining it with measurement uncertainty may be useful for design reliability, but the categories should remain visible.

10.4 Expanded uncertainty and coverage

Combined standard uncertainty is analogous to a standard-deviation scale under the model. Expanded uncertainty is

Equation 10.5

$$U = k\,u_c,$$

where k is a coverage factor selected for the desired coverage under stated assumptions. The common use of $k \approx 2$ often corresponds to about 95 per

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cent coverage for an approximately normal distribution with sufficient degrees of freedom. It is not a universal law.[456]

The report should state u_c, k, U, and the intended coverage. Writing "±2 dB" without these details leaves the reader unable to distinguish a tolerance, repeatability, expanded uncertainty, or engineering allowance.

Uncertainty intervals should not be interpreted as probabilities about a fixed true value without specifying the framework; the GUM provides a well-established expression of knowledge about the measurand; conformity decisions require an additional rule linking the result and uncertainty to a specification limit.

Weighted single-number ratings complicate interval reporting because the mapping from band values to class is discrete and nonlinear; a band-level uncertainty budget cannot always be converted by one root-sum-square equation; perturbation or Monte Carlo methods may be more informative.

10.5 Decision rules and the separation of measurement from acceptance

A decision rule describes how measurement uncertainty is taken into account when stating conformity with a requirement; ISO/IEC 17025 requires laboratories to document the decision rule where conformity is reported and the rule is not inherent in the specification; ILAC G8 and JCGM 106 provide guidance on decision risk.[457]

The simplest rule may be shared risk: pass if the measured value meets the limit, without guard band; this creates non-zero probability of false acceptance and false rejection near the boundary; a guarded rule requires

456 MB-0694. JCGM 100:2008, NIST Technical Note 1297.
457 MB-0695. ISO/IEC 17025:2017, JCGM 106:2012.

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the result to exceed a higher acceptance limit; the guard band reduces consumer risk at the cost of increasing producer risk.

For a minimum-performance requirement L, a simple guard-band acceptance rule can be written

Equation 10.6

$$\text{accept if } y \geq L + g,$$

where g is the guard band. The value of g may be linked to expanded uncertainty, a target risk, or a contractual policy. It should be agreed before testing.

The decision diagram in Figure 10-2 illustrates the guard-band concept. The shaded regions are explanatory, not a universal rule. A result in the guard-band region may be reported as indeterminate, conditional or nonconforming depending upon the agreed rule.

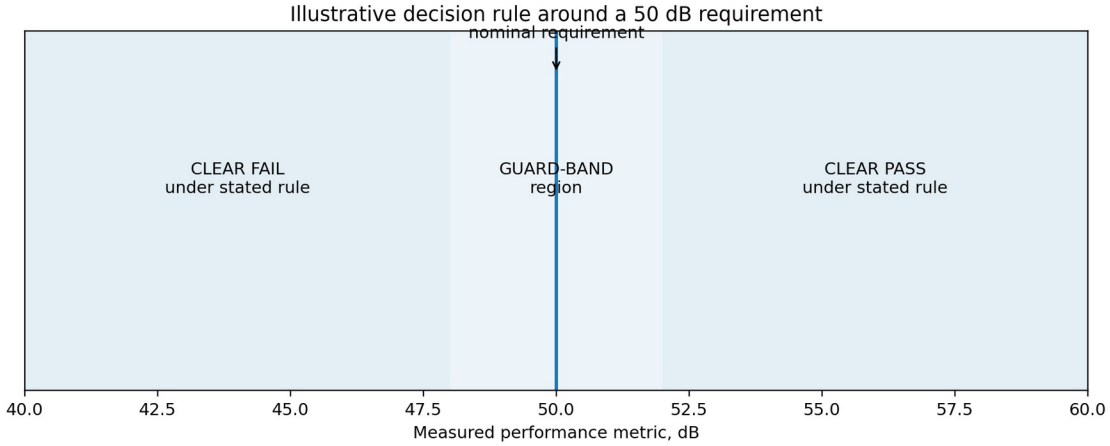

Figure 10-2. Illustrative guard-band decision. Author's original diagram. The acceptance threshold can be separated from the nominal requirement to control decision risk.

The decision rule must match the metric; a 2 dB guard band on a field level difference does not automatically correspond to a two-point guard band on

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STC; classification discreteness and band interactions matter; the rule should also address lower-bound results and censored bands.

10.6 Consumer risk, producer risk, and institutional consequence

Consumer risk is the risk of accepting an item that does not truly conform; producer risk is the risk of rejecting an item that does conform; in secure-room work, the “consumer” may be the institution relying upon privacy; the “producer” may be the contractor or design team. Both risks have cost, but the consequences are asymmetrical.[458]

A false acceptance can leave a vulnerable room in service; a false rejection can trigger expensive reconstruction, delay, and dispute; the decision rule should be selected through consequence analysis rather than habit; high-consequence classified use may justify a conservative rule; a low-risk private office may use shared risk.

Risk also depends upon prevalence and prior information; an experienced contractor with strong quality records and a robust margin presents a different prior condition from an unverified retrofit; formal Bayesian treatment may be possible, but even a qualitative prior should not silently alter the test rule after results are known.

The authority should distinguish measurement decision from accreditation decision; a laboratory can state conformity under a rule; the competent authority decides whether that evidence is sufficient for use; additional controls, waivers, or compensating measures may apply.

458 MB-0697. JCGM 100:2008, IEC 60268-16:2020.

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The probability plot in Figure 10-4 shows how the probability that a true value exceeds a 50 dB limit depends upon both the best estimate and uncertainty. A measured 51 dB result with 0.5 dB standard uncertainty is not equivalent to the same estimate with 2 dB uncertainty.

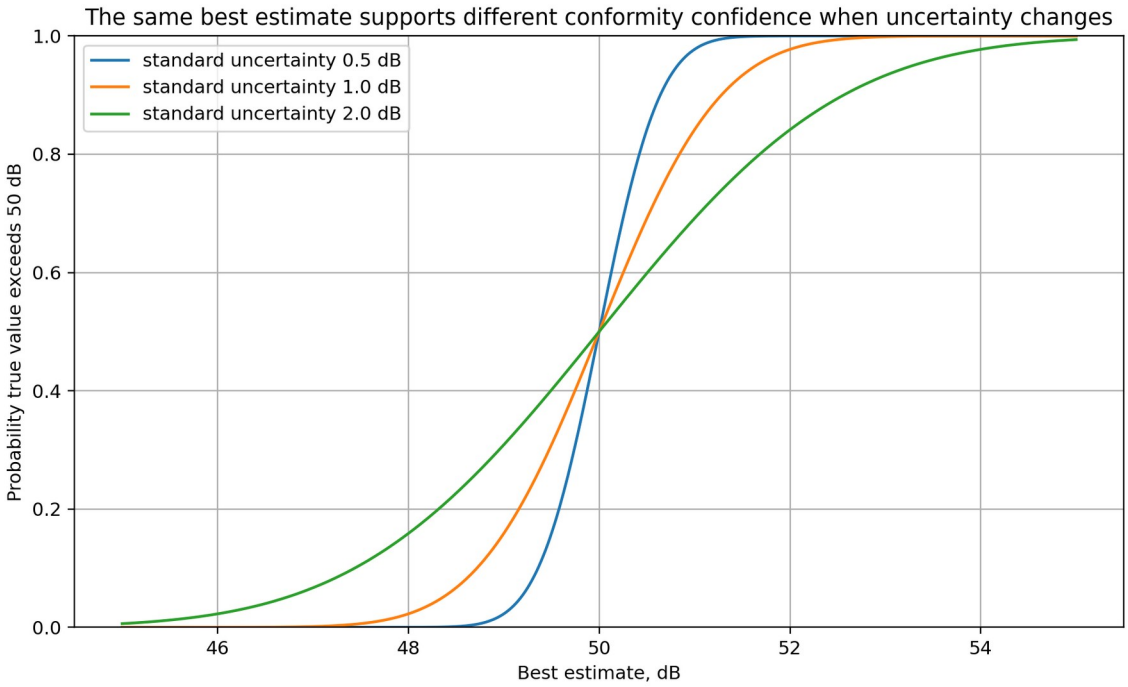

Figure 10-4. Conformity probability and uncertainty. Author's original plot using normal-distribution illustrations. The same best estimate supports different confidence when uncertainty changes.

10.7 Building-acoustics uncertainty contributors

Spatial sampling commonly dominates room measurements. The source and receiving fields vary. Microphone and source positions are finite. Reverberation measurements vary. Background correction becomes unstable near the floor. Source output drifts. Doors and services change state. Geometry and area measurements affect apparent quantities. Figure 10-1 shows an illustrative budget.[459]

459 MB-0698. International Organization for Standardization, ISO 12999-1:2020, ASTM E336-25a.

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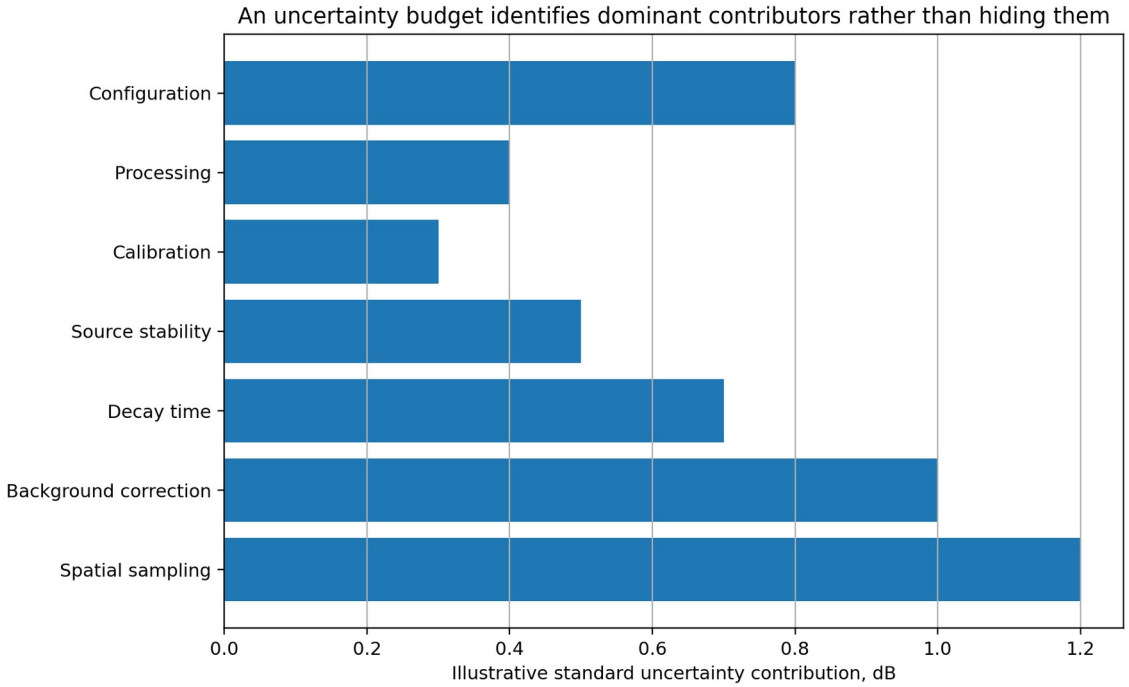

Figure 10-1. Illustrative uncertainty budget. Author's original plot. The bars are explanatory rather than universal values and show why dominant contributors should be identified.

Instrument calibration is necessary but often not dominant; an immaculate calibrator cannot correct poor spatial sampling; conversely, extensive position averaging cannot repair a clipped source channel; the budget should include both.

Configuration uncertainty deserves special treatment. A door closure, operable partition, or damper may have a distribution of states; if the measurand is "performance under ordinary operation," repeated cycles can estimate variability; if the measurand is "performance in the verified latched state," closure variability belongs to operational robustness rather than the measurement uncertainty of that state.

Analyst choices can contribute uncertainty or bias; band averaging, background limits, decay fit, contour calculation, and data exclusion should

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be controlled by validated procedures; manual selection after viewing the result creates decision bias.

10.8 Uncertainty in STC and Rw classification

A classification is a nonlinear function of band values; small changes may leave the class unchanged, while a change in one influential band may shift it by an integer; the output distribution can therefore be discrete and asymmetric; reporting “STC 52 ± 1” may be convenient but can obscure the underlying probability distribution.[460]

One approach is sensitivity perturbation. Apply plausible positive and negative band deviations, preserving correlations where known, and recompute; another is Monte Carlo simulation; draw input curves from their distributions, apply the complete classification algorithm, and tabulate the probability of each class.

The result might be 65 per cent probability of STC 52, 25 per cent of STC 51, and 10 per cent of STC 53; this is more informative than a symmetric interval; the decision rule can then require a chosen probability of meeting the specified class.

Specimen variability remains separate. A laboratory classification distribution does not predict every field installation; design reliability may require combining laboratory uncertainty with manufacturing and construction variability through a project model.

10.9 Monte Carlo propagation for nonlinear models

The GUM linearisation works well when the model is smooth and input uncertainties are small; monte Carlo propagation is useful when the model

460 MB-0699. ASTM International, ASTM E413-22, ISO 717-1:2020.

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is nonlinear, distributions are non-normal, limits are present, or classification is discrete; JCGM 101 provides an established framework.[461]

The procedure specifies input distributions and correlations, draws many trials, evaluates the measurement model, and summarises the output distribution; the simulation should use enough trials for stable tails; random seeds, software version, code, and validation should be retained.

The distribution in Figure 10-3 represents an illustrative standardised level difference derived from uncertain source level, receiving level, decay and volume-related effects. The example includes nonlinear logarithmic terms. The distribution is approximately smooth here. Classification outputs would be discrete.

461 MB-0700. JCGM 101:2008, JCGM 100:2008.

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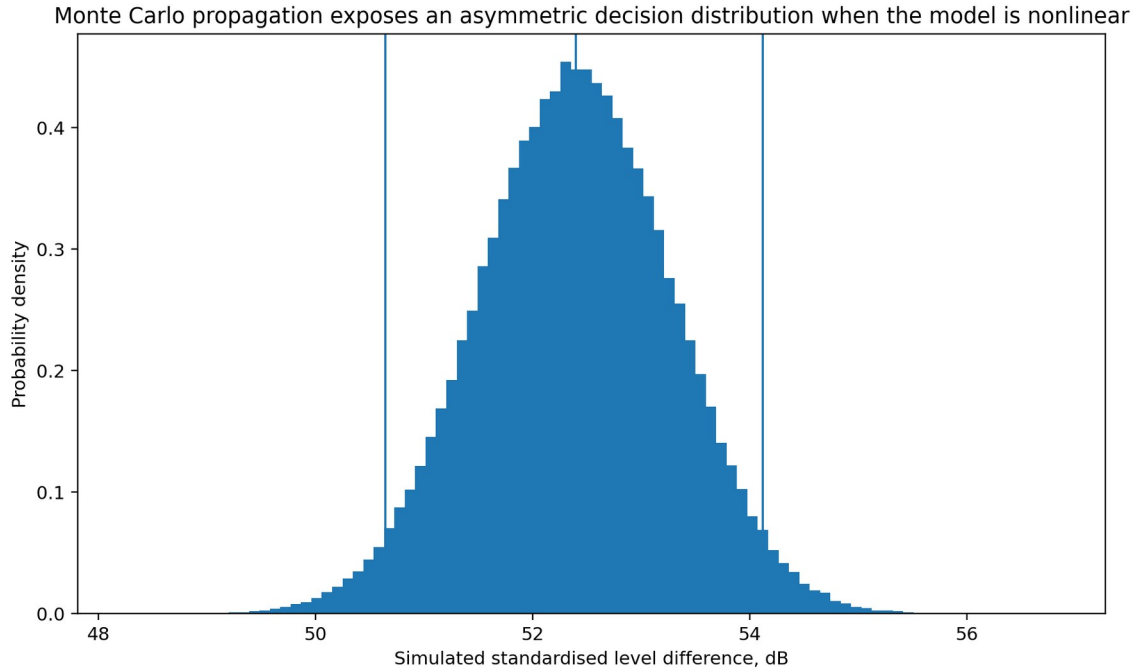

Figure 10-3. Monte Carlo output distribution. Author's original simulation. Vertical lines indicate the illustrative 2.5th percentile, median, and 97.5th percentile.

Monte Carlo does not rescue a poor model; if a flanking path is omitted, the simulation produces a precise distribution for the wrong measurand; input distributions must reflect evidence rather than convenience.

Worked example 10.2. Nonlinear background subtraction

Source-on level is normally distributed with mean 30.0 dB and standard uncertainty 0.5 dB; background has mean 27.0 dB and standard uncertainty 0.6 dB; because logarithmic subtraction is nonlinear and undefined when background exceeds source-on, Monte Carlo is appropriate; simulated valid trials may yield a skewed corrected-level distribution; the report should state the invalid-trial treatment and may conclude that the band is too close to background for a reliable correction.

10.10 Traceability, calibration, and laboratory competence

Metrological traceability is the property of a result whereby it can be related to a reference through a documented unbroken chain of calibrations, each

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contributing uncertainty; traceability belongs to the result, not merely to an instrument sticker.[462]

A field chain includes microphone, preamplifier, analyser, acoustic calibrator, time base, software, and environmental instruments as relevant; pre- and post-test checks demonstrate short-term stability. Periodic calibration establishes traceability. Neither substitutes for the other.

Laboratory competence includes method validation, staff competence, equipment control, environmental control, data integrity, and reporting; accreditation to ISO/IEC 17025 can provide confidence in these systems for the laboratory's scope; it does not prove that every project decision is correct or that a method outside the accredited scope is valid.

Software requires validation. Classification spreadsheets should be checked against known examples; monte Carlo code should be tested with analytic cases; firmware and settings should be recorded; an unnoticed software update can alter processing.

Traceability also applies to drawings and configuration; the measurement result should be related to the tested room state through photographs, plans, identifiers, and timestamps; a perfectly calibrated analyser measuring the wrong door state produces a traceable but irrelevant result.

10.11 Guard bands in procurement and commissioning

A specification should declare the nominal requirement, measurement method, uncertainty treatment, acceptance threshold, retest policy, and

462 MB-0673. JCGM 200:2012, ISO/IEC 17025:2017.

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remediation procedure; if the acceptance rule is introduced after testing, it can be manipulated to favour the desired outcome.[463]

A project may use a design target higher than the acceptance minimum; the design margin addresses construction variability and unknown flanking; the acceptance guard band addresses measurement decision risk. These are distinct. Combining them into one unexplained “five-point safety factor” obscures responsibility.

Retesting can reduce uncertainty if it adds independent information; repeating until a passing result appears is not a valid rule; the retest policy should define triggers, number of repeats, state control, and combination of results.

Conditional acceptance may be appropriate when the acoustic metric is marginal but an occupied speech test and compensating control are satisfactory; the authority should document the condition and lifecycle monitoring; the contractor’s contractual obligation remains a separate issue.

10.12 Forensic and litigation reporting

An expert report should disclose the measurement model, uncertainty, decision rule, and alternative explanations; a conclusion that a wall “failed by 1 dB” is incomplete if expanded uncertainty is 2 dB and the contract lacks a rule; the expert should explain what the data support without rewriting the contract.[464]

463 MB-0674. JCGM 100:2008, IEC 60268-16:2020.
464 MB-0675. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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Uncertainty is not a defence for every defect; a result 8 dB below the requirement with 1 dB uncertainty is clearly different from a result 0.2 dB below; the magnitude and mechanism matter.

Raw data should be preserved. Screenshots are insufficient. The record includes audio or time histories where lawful, spectra, decay curves, positions, photographs, calibrations, software, calculations, and hashes; changes after inspection should be documented.

The report should separate measurement uncertainty from uncertainty of cause; the metric may be measured precisely while the path remains ambiguous; conversely, the path may be obvious while the exact classification is background-limited.

10.13 Worked acceptance examples

Worked example 10.3. Shared-risk rule

A minimum field requirement is 50 dB; the measured estimate is 50.3 dB with expanded uncertainty 1.6 dB; under a shared-risk rule that accepts when the estimate meets the limit, the result passes; the report must state that the interval overlaps the limit.[465]

Worked example 10.4. Guarded rule

The same requirement uses a guard band equal to expanded uncertainty; acceptance limit is 51.6 dB; the 50.3 dB result does not pass; this reduces false acceptance risk and increases false rejection risk.

465 MB-0759. JCGM 100:2008, IEC 60268-16:2020.

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Worked example 10.5. Clear failure

Measured estimate is 45.5 dB with expanded uncertainty 1.2 dB; even the upper interval remains below 50 dB; the result is a clear failure under either rule, subject to method validity.

Worked example 10.6. Lower-bound result

Receiving bands are background-limited and support only $D_{nT,w} \geq 52$ dB. The requirement is 50 dB. Whether this can support conformity depends upon the method and rule. If the lower bound itself exceeds the guard-band threshold, acceptance may be supportable. If classification stability depends on censored bands, further testing may be required.

10.14 Classification uncertainty as an integer-valued output

A one-third-octave curve consists of continuous estimates; a classification is commonly an integer; the mapping resembles a staircase. For most small perturbations, the output does not move; near a contour boundary, a fraction of a decibel in one or several bands can move the result by a whole point; this behaviour invalidates the casual assumption that the class has a symmetric normal uncertainty.[466]

A practical stability study begins with the covariance matrix of the band estimates; independent random perturbation of each band is rarely defensible because the same source calibration, microphone calibration, room state, and decay estimate influence several bands; spatial variance can also be correlated across neighbouring bands; the analyst should preserve the correlation structure as far as evidence permits.

466 MB-0676. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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Each simulated curve is passed through the complete rating algorithm; the output is a probability mass function over integer classes; the report can state the most probable class, median class, lower percentile, and probability of meeting the requirement; this is especially useful where a contractual threshold sits on a fragile class.

The analysis must use the actual rating algorithm, including deficiency limits, reference curve, rounding, and any treatment of censored bands; simplified teaching contours are insufficient for conformity; software should be cross-checked against a known standard example.

The class distribution is not the distribution of field performance over future rooms; it represents uncertainty in the tested curve and calculation; construction variability requires another model; a design team may use both to estimate the chance that a future installation meets the field requirement, but the layers should remain separable.

10.15 Uncertainty of spatial averages

Spatial averaging attempts to estimate a room quantity from finite positions. The standard deviation among positions reflects real field variation as well as measurement noise; the uncertainty of the energetic mean is not always obtained by dividing the decibel standard deviation by the square root of the number of positions, because decibel values are logarithmic and positions may be correlated.[467]

A robust method can transform levels to linear mean-square quantities, analyse the sample, and transform back; bootstrap resampling offers

467 MB-0677. International Organization for Standardization, ISO 12999-1:2020, ASTM E336-25a.

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another approach when the distribution is irregular; the method should respect source-position grouping and repeated measurements.

Low-frequency positions are often highly correlated over parts of a room because wavelengths are long and modes dominate; adding many closely spaced microphones does not create independent information; position selection should span the field.

For security diagnostics, the maximum accessible position may be more relevant than the mean; the uncertainty question then concerns extreme-value sampling; a coarse grid can miss the true maximum; adaptive scanning and physical path information improve confidence.

The report should state whether the result represents an average, maximum, minimum, percentile, or specific point; the same data can support different statistics, but the decision rule must identify one in advance.

10.16 Source stability and spectral drift

A field source must remain stable over the measurement cycle; loudspeaker heating, amplifier limiting, battery voltage, automatic protection, room temperature, and signal processing can change output; a broadband source that drifts by one decibel during a multi-position test biases source and receiving averages differently if measurement order is fixed.[468]

Source monitoring can use a fixed reference microphone, repeated source-room checks, or interleaved positions; the monitoring channel must not disturb the field; its own stability and calibration enter the budget.

468 MB-0678. International Organization for Standardization, ISO 12999-1:2020, ASTM E336-25a.

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Spectral drift is more important than overall drift; a loudspeaker may compress low bands at high level while high bands remain stable; a one-number source monitor can miss this. Band monitoring is preferable.

Measurement sequencing can reduce bias. Randomising or alternating source and receiving positions prevents monotonic drift from aligning with one room; automated systems should record timestamps and source status.

A source that is intentionally varied, such as a live talker, requires a different model; repeated utterances, level monitoring, and statistical source descriptors quantify variability; the result should not be compared with a fixed-source acceptance limit without adjustment.

10.17 Geometry, area, and volume uncertainty

Apparent sound-reduction quantities depend upon separating area and receiving absorption; room volume enters absorption calculations and some prediction methods; geometry may appear exact on drawings while as-built surfaces, columns, soffits, alcoves, sloped ceilings, and open connections make the effective quantities uncertain.[469]

The separating area should correspond to the common boundary under the method; including a flanking façade or excluding a recessed door can bias the result; the report should show the area calculation.

Laser measurement, tape measurement, and drawing extraction have different uncertainties; for ordinary rooms, geometric uncertainty may be small relative to acoustical sampling; for small specimens or irregular rooms it can matter.

469 MB-0679. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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Volume uncertainty affects equivalent absorption area through the Sabine relation. If volume and decay are correlated because the same room model is used, covariance should be considered.

Geometry errors are systematic if the wrong boundary is selected; uncertainty analysis cannot legitimise a misdefined measurand; the drawing and calculation require technical review.

10.18 Environmental and operational state uncertainty

Temperature and humidity influence sound speed, atmospheric absorption, microphone response, and building operation; over short indoor distances, these effects may be modest, but they can matter in phase-sensitive, ultrasonic, or long-duration measurements; environmental records also provide evidence of HVAC state.[470]

Pressure differential across a door or partition can alter seal compression and leakage; a room tested under one ventilation balance may perform differently after balancing; the test should record pressure where relevant.

Operational noise is stochastic. HVAC cycles, lifts, traffic, and occupancy create time-varying background; short samples may not represent the protected period; percentile or time-history analysis can characterise the distribution.

The uncertainty budget may include temporal sampling; alternatively, different operating states can be reported separately; the choice depends on whether variability is random within one measurand or defines different conditions.

470 MB-0680. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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10.19 Correlation among one-third-octave bands

Many uncertainty budgets treat bands independently because it simplifies calculation; calibration gain, source drift, microphone sensitivity, and room state often create correlation; classification algorithms combine bands, so correlation affects the class distribution.[471]

A common gain error shifts all bands and can move the reference contour coherently; a background correction affects only limited bands; spatial modes create local correlation; the covariance matrix should be constructed from repeated data and known common components.

Ignoring positive correlation can understate uncertainty in a weighted sum; in other cases, differencing common errors cancels; the effect depends on the model.

Monte Carlo simulation can draw correlated multivariate inputs using a covariance matrix; the matrix must be positive semi-definite and supported by evidence; shrinkage or structured correlation models can be used when sample size is limited, but assumptions should be disclosed.

10.20 Decision rules for two-sided and asymmetric requirements

Not every requirement is a minimum; masking systems may have a permitted range; background noise can have an upper comfort limit and a lower privacy limit; reverberation may have both minimum and maximum bounds; a two-sided decision rule must control risk at both limits.[472]

For a permitted interval $[L, U)$, a guarded acceptance region can be $[L+g_L, U-g_U)$. The guard bands may differ because consequences differ. A

471 MB-0681. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.
472 MB-0683. JCGM 100:2008, IEC 60268-16:2020.

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low masking level can create privacy risk, while a high level creates comfort and communication risk.

Asymmetric distributions also require care. Background-corrected levels and logarithmic quantities can be skewed; symmetric intervals may misrepresent tail risk; monte Carlo or quantile-based rules can be more appropriate.

The contract should identify whether uncertainty is considered at both limits and how indeterminate results are handled. Retesting should not be used selectively at one side.

10.21 Multiple comparisons and room portfolios

A facility may contain dozens of secure rooms and hundreds of tested boundaries; if each is accepted at a nominal five-per-cent false-acceptance risk, the probability that at least one false acceptance occurs across the portfolio can be much larger; decisions made room by room should therefore consider institutional scale.[473]

This does not mean applying a simple Bonferroni correction to every acoustic test; it means recognising that repeated marginal acceptance creates cumulative risk; the quality plan can require stronger design margins, representative destructive verification, or portfolio-level sampling.

Sampling of repetitive room types should be risk-based; testing only the best accessible room is not representative; random selection, first-of-type testing, worst-case selection, and change-triggered testing each have roles.

473 MB-0684. International Organization for Standardization, ISO 12999-1:2020, ASTM E336-25a.

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The report should identify the population to which the tested rooms are intended to generalise. A result for one mock-up does not automatically certify all production rooms.

10.22 Uncertainty in remediation claims

Before-and-after differences have uncertainty from both measurements and any correlation between them; if the same instruments, positions, and calibration are used, common components may cancel; if room state changes, the difference may include confounding.[474]

For independent estimates y_1 and y_2, standard uncertainty of the difference is

Equation 10.7

$$u^2(y_2 - y_1) = u^2(y_2) + u^2(y_1) - 2\,u(y_1, y_2).$$

A claimed 1 dB improvement is not meaningful if uncertainty of the difference is 1.5 dB; a 10 dB local improvement near a sealed gap may be clear even when room-average classification changes little.

Remediation should target the mechanism and repeat the diagnostic measurement that identified it. The final acceptance test then addresses the room-level requirement. These are separate comparisons.

10.23 Numerical example. Uncertainty of a before-and-after change

A field band result before repair is 42.0 dB with standard uncertainty 0.8 dB. After repair it is 45.0 dB with standard uncertainty 0.7 dB. Common

474 MB-0685. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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calibration contributes 0.3 dB to each and is fully correlated. The covariance is $0.3^2 = 0.09$ dB².[475]

Equation 10.7 gives

$$u_\Delta = \sqrt{0.8^2 + 0.7^2 - 2(0.09)} = 0.97\,dB.$$

The improvement is 3.0 ± 1.9 dB for $k = 2$. The interval is approximately 1.1 to 4.9 dB, supporting a positive improvement under the assumptions. If the common calibration were incorrectly treated as independent, the interval would be slightly wider.

The calculation does not prove that the repair alone caused the change unless other state variables were controlled.

10.24 Measurement system validation and software assurance

A laboratory or commissioning team should validate its complete data path; the process includes microphone response, calibrator, analyser, time synchronisation, file format, averaging, background correction, decay fitting, classification, uncertainty calculation, and report generation.[476]

Reference files with known expected results can test software; synthetic signals can test logarithmic arithmetic and FFT processing; hand calculations can verify classification and uncertainty; regression tests detect changes after updates.

Spreadsheets deserve the same control as compiled software. Cells should be protected, formulas reviewed, versions archived, and inputs separated from calculations. Copy-paste errors are common.

475 MB-0686. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.
476 MB-0687. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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Automation can improve reproducibility but can also conceal assumptions; the final report should retain sufficient information for an independent calculation; proprietary software output without raw data is inadequate.

10.25 Internal quality control and proficiency evidence

Routine quality control can include duplicate measurements, reference rooms, travelling instruments, interlaboratory comparisons, and trend charts. These reveal drift that annual calibration may miss.[477]

A reference partition or room pair measured periodically can show system stability; changes may indicate instrumentation, software, room condition, or operator effects; the reference need not be a standard artefact if its history is controlled.

Proficiency testing and interlaboratory comparisons assess reproducibility; differences should be investigated rather than averaged away; the results inform uncertainty and laboratory competence.

Field teams can use check standards, such as a known attenuator or calibration signal, but acoustic path validation remains necessary; electronic injection does not test microphones, loudspeakers, rooms, or positioning.

10.26 Decision documentation and governance

The decision record should state who owns the risk; the test laboratory supplies measurements and, if authorised, conformity statements under the agreed rule. The designer interprets construction. The contractor responds to contractual defects; the security authority determines use; these roles should not be collapsed.

477 MB-0688. ISO/IEC 17025:2017, JCGM 200:2012.

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Waivers and compensating controls should identify the unmet requirement, evidence, consequence, duration, owner, monitoring, and expiry. A temporary acceptance should not become permanent through silence.

Change control should specify when the decision must be revisited; door replacement, new cabling, HVAC modification, masking changes, wall penetration, tenant change, or altered listener access can invalidate the original measurand.

The final acceptance dossier should preserve result, uncertainty, rule, raw evidence, and authority decision; without that chain, a future reviewer sees only a number and cannot know why the room was accepted.

10.27 Uncertainty in decay-rate estimation

Decay time is obtained from a fitted slope over a specified range; the uncertainty depends upon signal-to-noise ratio, excitation method, room non-diffuseness, fit range, number of decays, microphone positions, and temporal stationarity; a software display of three decimal places does not imply corresponding accuracy.[478]

The decay curve should be retained; curvature can indicate coupled volumes, changing background, non-exponential decay, or insufficient dynamic range; fitting a straight line through a visibly curved trace produces a number whose model error is not represented by regression uncertainty alone.

Repeated decays at one position estimate short-term variability. Multiple positions estimate spatial variability. The uncertainty budget should not combine them without considering their sampling design.

478 MB-0689. ASTM International, ASTM E2235-04, ISO 3382-2:2008.

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At low frequency, modal decay can vary substantially by position; a room-average standardised difference should use the method's prescribed averaging; a local speech-security assessment may need the actual receiving response at the listener position rather than a room-average correction.

10.28 Uncertainty in background correction near the detection floor

Logarithmic background subtraction is ill-conditioned when source-on and background levels are close; the sensitivity to each input increases rapidly as their difference decreases; this creates skewed output distributions and a significant probability of invalid draws in Monte Carlo analysis.

A laboratory or field procedure should define correction limits; values beyond the limit are lower bounds or censored results; reporting software should preserve the inequality symbol.

The uncertainty analysis should not assign a finite symmetric interval to an undefined subtraction. A one-sided bound or decision based on the detectable minimum is more defensible.

Background may contain the same source through another path or through leakage during the nominal background measurement; in that case it is not independent background; the measurement sequence should ensure that the test source is off and residual decay has ended.

10.29 Calibration uncertainty and common-mode cancellation

Sound-level differences can cancel common calibration errors when the same instrument channel is used sequentially and remains stable; separate source and receiving instruments introduce independent or partially correlated calibration components.

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Field checks before and after the test provide evidence of drift; if the change exceeds the procedure’s limit, results may be invalid; interpolating a correction assumes linear drift and should be justified.

Microphone frequency response uncertainty is band-dependent; an overall calibrator check at 1 kHz does not establish low- and high-band response; phase mismatch matters for intensity and arrays.

The uncertainty budget should separate absolute sensitivity, frequency response, linearity, range switching, and time-base effects as relevant; common components should be represented by covariance rather than counted twice.

10.30 Model discrepancy and omitted paths

A measurement uncertainty budget assumes that the measurement model represents the measurand; model discrepancy arises when important mechanisms are omitted or simplified; in a field isolation test, an omitted flanking path may not bias the measurement because the receiving level includes it; in a predictive model, omission can be decisive.

Model discrepancy should not be hidden as a small random uncertainty if it can create systematic error; it may require an explicit allowance, alternative model, validation data, or limitation statement.

A composite wall calculation that assumes independent area transmission omits frame leakage and interaction; its result is a screening estimate; a secure-room decision should not attach a narrow uncertainty interval to such a simplified model.

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Validation compares predictions with independent observations; residuals can inform model discrepancy, but only within the validated domain; extrapolation to different constructions or frequencies requires caution.

10.31 Effective degrees of freedom and coverage factors

When input components have limited degrees of freedom, the coverage factor for a desired confidence may exceed two; the Welch-Satterthwaite approximation can estimate effective degrees of freedom for a linear uncertainty budget; modern Monte Carlo methods can avoid some approximations by working directly with distributions.[479]

A report should not burden ordinary readers with unnecessary mathematics, but it should not claim 95 per cent coverage from $k=2$ when one dominant component is based on three repeats. The technical appendix can document the calculation.

Large position datasets do not automatically provide large degrees of freedom if observations are correlated. Independence assumptions should be examined.

10.32 Uncertainty and logarithmic averaging

The energetic mean is nonlinear. If levels have large spread or different uncertainties, uncertainty of the mean should be propagated in linear energy space or by Monte Carlo; averaging standard uncertainties in decibels is generally not rigorous.

Position weighting may be equal under a standard method; threat-informed local analysis may use a maximum or percentile; each statistic has a different uncertainty.

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479 MB-0693. JCGM 100:2008, NIST Technical Note 1297.

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For repeated source positions, hierarchical models can separate source-position and microphone-position variance; this helps determine whether more source positions or more microphone positions would reduce uncertainty most effectively.

10.33 Detection limits and qualified measurement range

Every test system has a qualified range; at the lower end, self-noise and background limit detection; at the upper end, source or receiver overload and facility flanking limit the result; high reported attenuation can be a lower bound imposed by the facility.

The qualified range should be established by validation, not inferred from nominal analyser dynamic range. Loudspeaker capability, room background, chamber flanking, and microphone noise all contribute.

A laboratory report may state a maximum reliably measurable loss by band; a field report should identify bands limited by available source level; procurement should not require a result beyond the qualified range without an alternative method.

10.34 Uncertainty in dimensions and material properties for prediction

Prediction of gypsum, masonry, concrete, or glazing performance uses surface density, stiffness, damping, cavity depth, stud spacing, junction properties, and loss factors; these inputs vary by product and workmanship.

A sensitivity study can identify which properties require measurement; surface density may be available from batch data. Damping may be uncertain. Junction stiffness can dominate flanking. Assigning narrow generic distributions creates false confidence.

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Bayesian updating can combine prior material data with project measurements. The method should be transparent and not used to force agreement with desired performance.

Prediction uncertainty should include model discrepancy and construction variability. It is usually broader than instrument uncertainty in a completed test.

10.35 Risk-based selection of test locations

Testing every possible boundary may be impractical. Risk-based selection should consider consequence, construction novelty, weakest paths, access, contractor variability, and prior failures.

Worst-case selection provides assurance for known risks but can miss random workmanship defects; random sampling provides population inference but may miss unique high-consequence rooms; a mixed strategy is often appropriate.

The sampling plan should be written before results. Replacing a failed sampled room with an unplanned better room biases the conclusion.

If the tested sample is used to accept a population, statistical and institutional assumptions should be stated; a field test of one room does not certify all rooms by implication.

10.36 Sequential testing and stopping rules

Sequential testing can reduce cost by stopping when evidence is clear; it can also inflate error if the team repeats until a desired result appears; a stopping rule should be predeclared.

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For example, one test may suffice if the result exceeds the guarded threshold by more than expanded uncertainty; a marginal result may trigger two independent repeats; the combined decision uses all results, not the best.

Repairs between tests create new configurations and should begin a new sequence. The report should preserve every result.

10.37 Metrological treatment of maximum and minimum states

Secure-room acceptance may depend on the minimum performance across operational states; estimating a minimum is harder than estimating a mean; limited testing can overestimate the true minimum.

Repeated door closures, fan states, and masking zones can reveal distribution; extreme-value or tolerance-limit methods may be appropriate for production-scale studies; in ordinary projects, a conservative observed minimum with explicit sampling limitations may be more honest.

The decision rule should state whether every tested state must pass, whether the worst result governs, or whether a statistical tolerance applies; an average should not silently replace a minimum requirement.

10.38 Uncertainty and speech-recovery probabilities

Speech-recovery models contain uncertainty in source distribution, path attenuation, background, listener capability, and model calibration; the output is a probability or score, often with greater epistemic uncertainty than a sound-level result.

A privacy claim should report sensitivity; which assumption changes the conclusion most? If listener capability dominates, additional listening trials

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may help; if path attenuation dominates, improved field measurement is useful.

Probabilities should not be quoted to excessive precision; “estimated probability 0.0037” is rarely credible when source and listener distributions are uncertain; ranges and scenario bounds may be more defensible.

Decision rules can apply to an upper confidence bound on recovery probability; the authority selects the acceptable risk; the acoustic team supplies the evidence and uncertainty.

10.39 Uncertainty budgets for masking systems

Masking verification includes level, spectrum, spatial uniformity, temporal stability, instrument calibration, and operating state; a point measurement may have small instrument uncertainty while the room-wide minimum has larger sampling uncertainty.

The acceptance measurand should state whether it concerns mean, minimum, maximum, or deviation from target spectrum. Comfort and privacy may impose two-sided limits.

A system can meet average level while one failed loudspeaker creates a quiet zone. Sampling design and fault monitoring are therefore central.

Drift over months is lifecycle variability rather than commissioning measurement uncertainty. Periodic verification controls it.

10.40 Contract drafting for uncertainty and decision rules

A model clause should identify the metric, method edition, room states, test authority, uncertainty framework, decision rule, guard band, retest rule, and

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consequence; it should avoid saying merely “allow for measurement tolerance.”

The clause should specify whether uncertainty is reported by the laboratory or calculated by the consultant. Competing calculations after a failure are avoidable.

If a standard embeds a decision rule, the contract should reference it; if not, the project rule should be explicit; the laboratory must be informed before work.

The clause should address lower bounds; a result reported as “at least 55” can satisfy a 50 requirement under some rules without forcing the laboratory beyond its detection floor.

10.41 Example decision-rule schedule

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Table 10-1. Illustrative decision schedule for minimum field performance

Result relative to requirement	Uncertainty condition	Illustrative disposition	Required record
Estimate exceeds guarded acceptance limit	Qualified uncertainty budget	Pass under stated rule	Result, expanded uncertainty, coverage factor, rule and state
Estimate meets nominal limit but not guarded limit	Interval overlaps decision boundary	Indeterminate or fail under guarded rule	Retest or authority disposition
Estimate below nominal limit but interval overlaps	Marginal nonconformity	No automatic pass	Diagnostic review and contractual decision
Upper interval remains below limit	Clear nonconformity	Fail	Path diagnosis and remediation
Only a lower bound is available and bound exceeds acceptance limit	Detection-limited high performance	Potential pass if the rule permits	Lower-bound method and stability review

The table is an example, not a universal rule. The governing contract and authority decide the actual disposition.

10.42 Uncertainty in index and rating conversion claims

Projects sometimes attempt to convert STC, R_w, NIC, ASTC, and $D_{nT,w}$ using fixed offsets. Any such conversion has uncertainty arising from curve shape, room geometry, and method differences. The error can be larger than the claimed distinction.

A regression derived from a database may support screening within the construction families represented; it should report prediction interval, sample size, and domain; it should not be used for formal conformity unless the specification permits.

Where band data are available, calculate the required metric directly. Where they are not, obtain new evidence or state the limitation.

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10.43 Structured expert review of a marginal result

A marginal result should trigger a structured review; confirm the method and edition; verify calibration and source stability. Inspect background correction. Recalculate the metric. Review positions and room state. Evaluate uncertainty. Check the decision rule. Examine physical diagnostics. Separate contract and accreditation consequences.

The review should be documented by a person independent of the original calculation where practical. A second pair of eyes often finds transcription, area, or classification errors.

If the result remains marginal, the authority may choose remediation, retest, compensating controls, or acceptance. The technical report should not make a policy decision outside its mandate.

10.44 Lifecycle uncertainty and change

The accepted room is not static; seals wear, walls are penetrated, masking drifts, HVAC is rebalanced, and adjacent occupancy changes; the original uncertainty interval does not cover all future changes.

Lifecycle assurance uses inspections, configuration control, alarms, periodic tests, and change-triggered recommissioning. It addresses temporal variability rather than stretching the commissioning budget indefinitely.

A baseline record enables comparison. Trend changes can be detected before a formal failure. The baseline should include raw spectra and state information, not only classes.

10.45 Final metrological rules

Define the measurand. Write the model. Identify inputs and correlations. Evaluate uncertainty with a method appropriate to linearity and

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distributions. State coverage. Declare the decision rule before testing; separate measurement, construction variability, operational variability, and accreditation.

These rules convert a decibel result into evidence. Without them, the apparent precision of the number is greater than the knowledge it represents.

10.46 Uncertainty of maximum credible speech source

The source term in a privacy calculation is often more uncertain than the acoustic instrumentation; maximum credible vocal effort is not a fixed physical constant; it depends upon talker population, posture, distance, orientation, room feedback, emotional state, and whether amplification is available.

A conservative source distribution can be built from published speech data and project observations; the tails deserve attention because the protected event may be rare; a percentile should be selected by the authority and documented.

When the source is a loudspeaker, maximum output can be measured more directly, but software gain, compression, limiters, and content spectrum create state uncertainty; the commissioned configuration should be locked and monitored.

Source uncertainty should not be hidden inside a generic “security margin.” Its spectral and behavioural basis affects the privacy model and operational controls.

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10.47 Listener-model uncertainty

Listener capability is another model input; hearing threshold, binaural advantage, language, attention, training, context, and post-processing affect recovery; a single “average listener” may be inappropriate for high consequence.

Scenario analysis can use ordinary, favourable, and enhanced listener models; the conclusion may be robust across all three or sensitive to the favourable case; the authority can then select controls.

Human trials estimate the combined effect but have sampling uncertainty; listener and item effects should be reported; a small trial cannot establish a universal probability.

10.48 Uncertainty in sound masking performance

The nominal masking set point is not the listener’s actual background. Loudspeaker tolerances, room response, ceiling changes, zoning, and time variation produce a spatial distribution.

Commissioning should estimate mean, spread, and minimum in accessible zones. If minimum masking governs privacy, the grid must be dense enough to find quiet pockets.

Instrument uncertainty is usually smaller than spatial variability; maintenance drift is a lifecycle concern; a control system status does not replace acoustic verification.

10.49 Uncertainty in door-state performance

A rated door set may show a distribution over closures. Hinge wear, closer speed, latch engagement, seal compression, debris, and pressure difference affect result.

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Repeated opening and closing provides Type A evidence for ordinary operation; the minimum or a lower tolerance bound may govern; testing only one carefully assisted closure overstates robustness.

The report should distinguish the verified latched state from user-operated distribution. Operational controls such as door-position switches can reduce state uncertainty but require testing.

10.50 Uncertainty in flanking-path prediction

Flanking prediction uses structural junction properties, element dimensions, radiation efficiency, and path combinations; junction vibration-reduction indices may come from standard data rather than project measurement; the resulting uncertainty can dominate once direct wall transmission is high.[480]

A path table should list input provenance and confidence; sensitivity analysis can identify which junction requires measurement or redesign; a single overall “field deduction” does not reveal this.

Field calibration against one room can reduce uncertainty locally; extrapolation to another geometry remains uncertain; the model should be validated against independent data.

10.51 Uncertainty in composite-element calculations

Area-weighted transmission assumes independent elements and known areas; door and glazing areas are well defined, but cracks, frames, joints, and penetrations are not; interaction and edge paths are omitted.

480 MB-0696. International Organization for Standardization, ISO 10848-1:2017, ISO 12354-1:2017.

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A composite calculation should therefore report a screening interval or sensitivity range. If the conclusion changes with plausible crack area, field diagnostic evidence is required.

The calculation is most reliable when known panels dominate. It is least reliable when leakage dominates.

10.52 Uncertainty in acoustic material data

Surface density, elastic modulus, loss factor, flow resistivity, absorption coefficient, and dynamic stiffness vary by product, batch, frequency, humidity, and mounting. Catalogue values may be nominal.

Prediction should use measured project data where sensitivity is high; otherwise, ranges from authoritative sources can support uncertainty; the source register should identify data provenance.

A precise model using uncertain material values is not precise evidence. Sensitivity plots are often more honest than one deterministic curve.

10.53 Measurement uncertainty versus tolerance

A construction tolerance is an allowed physical deviation. Measurement uncertainty describes knowledge of the measurand. They are not interchangeable.

A specification may allow a 3 mm joint gap before sealing and require a field metric; the tolerance controls workmanship; the metric verifies performance; adding “±2 dB tolerance” to the metric without a decision rule confuses categories.

The report should avoid calling uncertainty a tolerance. Contract documents should use each term deliberately.

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10.54 Bias, blinding, and analyst expectations

Knowledge of the desired outcome can influence source positions, microphone placement, data exclusion, decay fit, and retest decisions. Procedures and blinding reduce bias.

Position plans and processing rules should be fixed before results. Automated scripts should log changes. Marginal cases should receive independent review.

Bias is not captured fully by repeated-measurement standard deviation. Quality systems address it through method validation and review.

10.55 Data integrity and computational provenance

Raw files should be immutable or hashed. Processing should occur on copies. The calculation script, software version, settings, and output should be linked to the raw evidence.

Manual transcriptions invite error. Automated import reduces error but needs validation. Every table in the report should be reproducible from source data.

A checksum proves file identity, not measurement validity. It is one link in the evidence chain.

10.56 Rounding and significant digits

Input and output precision should match uncertainty; reporting decay as 0.573846 s and a band result as 52.137 dB is misleading when uncertainty is tenths or whole decibels.

Rounding should occur at the end of calculation, not at every intermediate step. Classification follows the governing standard’s rules.

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The report may preserve higher precision in machine-readable appendices while presenting appropriate significant digits in the narrative.

10.57 Negative and physically constrained quantities

Monte Carlo draws can produce impossible values if normal distributions are used for positive quantities such as decay time, area, or transmission coefficient; truncated, lognormal, or other distributions may be appropriate.

The distribution choice should reflect evidence. Arbitrary truncation can bias results. Model inputs should remain physically meaningful.

Background subtraction can produce undefined trials. The simulation must report their treatment rather than silently discard them.

10.58 Robustness and sensitivity reporting

A conclusion is robust when plausible changes in assumptions do not alter it. Sensitivity analysis varies source level, background, decay, listener model, path attenuation, and decision rule.

The report should identify the decision-driving variables; this guides remediation and future data collection; a tornado chart or scenario table can communicate the result.

Sensitivity is not probability unless distributions are assigned. The distinction should be preserved.

10.59 Uncertainty and cross-jurisdiction comparison

American, ISO, British, and Canadian sources may use different metrics and decision frameworks. Comparing results introduces method uncertainty and semantic uncertainty.

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The safest practice is to report each quantity under its own method. A crosswalk should explain differences and avoid fixed conversion where unsupported.

Accreditation criteria may be controlled. Public metrics can support engineering evidence but cannot be assigned an uncertainty that magically bridges to unavailable requirements.

10.60 Uncertainty in historic records

Historic reports may lack raw data, calibration, standard edition, room state, or uncertainty. Their evidentiary weight is limited.

A modern reanalysis can use surviving curves and drawings, but assumptions should be explicit; reclassifying a historic curve under a current standard creates a new calculation, not a correction of the original.

Where source information is absent, the result may remain qualitative.

10.61 Uncertainty in qualitative inspection findings

Inspection observations such as an open joint, missing seal, or rigid bridge can be clear without a decibel uncertainty. Their consequence remains uncertain until measured or modelled.

The report should distinguish certainty of condition from certainty of performance effect; photographs and measurements support the former; controlled perturbation supports the latter.

10.62 Acceptance under incomplete information

Projects sometimes face occupancy deadlines before all data are available; the authority may issue conditional acceptance with compensating controls;

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the record should identify missing evidence, conservative assumptions, expiry, and required follow-up.

Absence of evidence should not be converted into a pass; a lower-bound result may support acceptance if the bound exceeds the guarded threshold; an untested path does not.

10.63 Uncertainty review checklist

Before release, verify measurand definition; model; inputs; distributions; correlation; type A and Type B components; coverage; nonlinear propagation; classification stability; decision rule; risk ownership; censored bands; configuration; and lifecycle limits.

The checklist should be signed or otherwise attributable to a reviewer. It provides a compact audit trail for a complex calculation.

10.64 Integrated case study. Marginal field acceptance

A hypothetical secure conference room requires a standardised weighted difference of at least 50 dB; the measured estimate is 51 dB; band uncertainty is driven by receiving background at low frequency and spatial variance near a door; monte Carlo classification yields 55 per cent probability of 51, 35 per cent of 50, and 10 per cent of 49.

Under a shared-risk point-estimate rule, the room passes; under a rule requiring 95 per cent confidence of at least 50, it does not; a diagnostic scan identifies the door threshold; adjustment improves two bands and shifts the class distribution so that 97 per cent of simulations meet 50.

The case shows why uncertainty and diagnosis should work together; the guard band did not merely reject the room; it directed attention to a fragile path and produced a more robust boundary.

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10.65 Integrated case study. High result limited by background

A concrete room pair produces no measurable receiving signal in several bands; the report can establish only lower bounds; the specification requires a class below those bounds; the laboratory’s decision rule permits conformity if every plausible class consistent with the bounds exceeds the acceptance threshold.

The room can therefore pass without inventing exact high values. The report states the detection limit and does not advertise an unsupported rating.

This is metrologically stronger than forcing a number beyond the system’s qualified range.

10.66 Uncertainty in source-room and receiving-room identification

Field records sometimes use informal room names that change during construction; a microphone may be logged in “Conference 2” while drawings identify “2.143”; misidentification is not a small numerical uncertainty; it is a provenance failure.

Room identifiers should be tied to current drawings, door numbers, photographs, and coordinates; if a room is subdivided or renumbered, the change should be recorded; test files and reports should use stable identifiers.

The same requirement applies to boundaries; a wall type on a plan may differ from the actual tested path; the report should mark the boundary and source-receiver direction.

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10.67 Timestamp uncertainty and state correlation

Building systems change with time. A result should be linked to HVAC, masking, access-control, and door states through synchronised timestamps; clock offsets can misalign acoustic data and building logs.

Ordinary NTP synchronisation may be sufficient for slow state changes; transient diagnosis may require common hardware timing; the required accuracy should follow the event.

Clock uncertainty is an input when correlating signals or states. It should not be ignored merely because level metrics are time-averaged.

10.68 Uncertainty from microphone mounting and orientation

Microphone response can be affected by orientation, supports, windscreens, operator proximity, and nearby surfaces. Close scans near doors and grilles are particularly sensitive.

The measurement protocol should specify free-field or random-incidence orientation as appropriate, maintain clearances, and document close-field exceptions. A microphone placed in a narrow gap changes the field.

Mounting variability can be evaluated through repeats or controlled fixtures. Photographs support reproducibility.

10.69 Uncertainty in intensity and path-localisation measurements

Sound-intensity measurements depend on phase match, probe spacing, field indicators, scan speed, surface definition, and reactive fields. Their uncertainty differs from ordinary pressure measurements.

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A path-localisation scan can rank regions even when absolute sound power uncertainty is large. The report should distinguish qualitative mapping from quantitative power estimation.

Probe orientation and sign convention must be recorded; negative intensity can reflect reverse flow, reactive energy, or error; it should not be discarded without analysis.

10.70 Uncertainty in structural-vibration diagnostics

Accelerometer mass loading, mounting, orientation, cable motion, magnetic bases, adhesive layers, and sensor noise affect vibration results. Structural fields vary spatially and by mode.

A high coherence between source audio and structural response supports a path, but coherence itself has statistical uncertainty and can be inflated by common noise; transfer functions should include averaging and confidence.

Vibration diagnostics often support mechanism rather than an acceptance metric. The report should state the evidentiary role.

10.71 Uncertainty under non-stationary operating conditions

Fans ramp, dampers modulate, lifts pass, traffic changes, and occupants move; a stationary analysis may not represent the process; time histories and state segmentation can separate conditions.

A result can be reported for each stable state or as a distribution over operation. Mixing states into one average can conceal a vulnerable quiet interval.

The sampling duration should capture relevant cycles. A ten-minute test cannot establish annual variability without supporting data.

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10.72 Uncertainty in rare-event security states

Rare states can dominate risk: masking failure, simultaneous vestibule-door opening, emergency ventilation, maintenance access, or maximum vocal effort. They may not occur during routine commissioning.

Scenario testing and fault injection can provide evidence. The authority should decide which rare states require physical test and which are governed operationally.

Probability of state occurrence and consequence are separate. A low-probability event with severe consequence may justify control.

10.73 Decision rules for qualitative plus quantitative evidence

Some acceptance decisions combine a numerical metric with inspection findings; a room may meet the field class but contain an unsealed penetration that has not yet affected the tested path; the authority may reject because configuration is noncompliant.

A decision framework should state whether all prescriptive conditions and the performance criterion are required, or whether performance can compensate; fire, security, and lifecycle concerns often make some conditions non-substitutable.

Qualitative evidence should be documented with photographs, dimensions, and applicable requirements. It should not be reduced to an arbitrary decibel penalty.

10.74 Decision rules for repeated room types

A production programme may accept a room type after mock-up testing and sample field tests; the decision rule should define construction controls, sampling, failure response, and whether one failure expands testing.

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Statistical acceptance sampling can be used where the population and defect consequences are understood. High-consequence rooms may require 100 per cent testing.

The rule should avoid accepting untested rooms solely because their drawings match. Workmanship and penetrations vary.

10.75 Handling uncertainty in value engineering

Value-engineering proposals often compare nominal ratings without uncertainty or field reliability. A cheaper assembly with the same catalogue class may have greater variability and less robust details.

The comparison should include curve, source evidence, construction sensitivity, field margin, inspection burden, remediation risk, and lifecycle cost. Expected value can include probability and consequence of failure.

A small material saving can be irrational if it increases late-stage test risk. Uncertainty analysis supports commercial as well as technical judgement.

10.76 Uncertainty in manufacturer engineering judgements

An engineering judgement extends test evidence to an untested variant. Its uncertainty depends on the similarity of materials, dimensions, mechanisms, and supporting data.

The judgement should identify the tested baseline, differences, analysis, and limits; it should not be labelled a test report; independent review may be warranted for critical boundaries.

A chain of multiple extrapolations compounds uncertainty. At some point a new test is more defensible.

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10.77 Reporting correlations and dominant contributors

A full covariance matrix may be too detailed for the main report, but dominant correlations should be disclosed. A technical appendix can preserve the matrix and model.

A contribution chart helps readers see whether uncertainty is controlled by background, positions, decay, calibration, or configuration. Improvement efforts should address the dominant terms.

Uncertainty budgets should not include dozens of negligible components while ignoring one large state variable. Completeness is not the same as verbosity.

10.78 Peer review of uncertainty calculations

An independent reviewer should reproduce selected calculations from raw inputs. The review should check units, signs, logarithmic conversions, covariance, distributions, coverage, classification, and decision rule.

Automated tests can compare software output with hand cases. The review record belongs in the QA file.

Disagreements should be resolved before the conformity statement, not explained after a dispute.

10.79 Communicating uncertainty to non-specialists

Decision-makers need clear language. A useful statement gives the best estimate, expanded uncertainty, coverage, rule, and practical conclusion; it avoids technical jargon in the executive summary while preserving detail in appendices.

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For example: “The measured field result was 52 dB with expanded uncertainty 1.4 dB; under the agreed guarded rule requiring at least 51.4 dB, the boundary passes”; this is clearer than a page of equations without a decision.

Graphics can show the result, requirement, and interval. They should not imply probability where none was calculated.

10.80 Uncertainty and accreditation statements

The acoustic team may report conformity with a public measurement requirement. It should not state that the room is accredited unless the competent authority has issued that decision.

Uncertainty in the acoustic result does not translate directly into probability of accreditation. Accreditation may consider physical, technical, procedural, and classified criteria.

The report should provide evidence and preserve the boundary of authority.

10.81 Final integrated example. Two paths and one decision

A room has a strong wall path and a weaker door path; wall apparent attenuation is estimated at 58 dB with standard uncertainty 1.0 dB; door-region attenuation is 49 dB with standard uncertainty 0.8 dB; the room-average metric is 51 dB with expanded uncertainty 1.6 dB; the requirement is 50 dB under a guard band of 1.5 dB.

The room-average estimate does not reach the 51.5 dB acceptance limit; diagnostics show the door controls; adjusting seals improves the door region by 4 dB and the room average by 2 dB; the new estimate is 53 dB with expanded uncertainty 1.5 dB, exceeding the 51.5 dB limit.

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The wall was never the rational remediation target; the uncertainty rule prevented marginal acceptance, and path evidence directed an efficient repair; this is the intended relationship among metrology, diagnosis, and decision.

10.82 Uncertainty in microphone self-noise and preamplifier noise

High-isolation receiving levels can approach the measurement chain’s self-noise; microphone capsule noise, preamplifier noise, cable interference, and analyser input noise contribute; an acoustic calibrator does not characterise the noise floor.

The system noise spectrum should be measured with an appropriate acoustic termination or quiet condition and compared with room background; if instrument noise contributes materially, the result is a lower bound; switching to a lower-noise microphone may improve range, but overload in the source room must still be controlled.

10.83 Uncertainty from analyser range and automatic gain

Range changes can alter noise, calibration, and linearity; automatic gain control should normally be disabled for measurement because it changes transfer unpredictably; if separate ranges are used in source and receiving rooms, their calibration relationship enters the budget.

Overload indicators and raw waveforms should be reviewed. A clipped broadband source can appear stable in overall level while its spectrum is distorted.

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10.84 Uncertainty from FFT window and bandwidth choices

FFT window, record length, averaging, and band integration affect spectral estimates; one-third-octave results should be calculated under a validated procedure; narrow tones near band edges can move between bands with frequency drift.

The processing record should identify settings and retain raw data; software defaults are not a method; window and overlap choices should be validated with synthetic signals.

10.85 Uncertainty from source directivity

A dodecahedral source approximates broad radiation but is not perfectly omnidirectional, especially at high frequency; orientation and room position affect the field; a conventional loudspeaker is more directional.

Multiple orientations or positions reduce bias; source directivity data and operating range should be retained; a speech loudspeaker test should document its directional relation to the boundary.

10.86 Uncertainty from loudspeaker distortion

At high output, a source can generate harmonics; energy intended for low bands appears in higher bands and biases transmission estimates; amplifier clipping creates broadband components.

Distortion should be measured or controlled; increasing source level beyond linear capability does not improve dynamic range reliably; multiple sources or quieter receiving conditions may be preferable.

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10.87 Uncertainty from room non-diffuseness

Laboratory and field equations often rely on sufficiently diffuse fields; small rooms, low frequency, strong absorption, and irregular geometry violate the approximation; spatial variance is evidence of this limitation.

Methods provide position and room requirements, but residual non-diffuseness remains; additional positions, moving microphones, diffusers, or model-based analysis may help; the report should identify bands where assumptions are weak.

10.88 Uncertainty from coupling to adjacent rooms

Open doors, shared plenums, and flexible elements can create coupled-room decay; a single receiving volume and decay time may be an inadequate model; multi-slope decay is a warning.

The test should isolate or explicitly model coupled spaces. Otherwise, normalisation can be biased. The room state and open connections should be documented.

10.89 Uncertainty from temperature gradients and airflow

Temperature gradients change sound speed and refraction. Airflow across microphones creates noise. Strong flow through grilles can alter acoustic impedance.

Indoor effects are often modest, but close duct and exterior measurements require wind protection and state control. Environmental data support comparability.

10.90 Uncertainty from operator movement

An operator standing near a microphone or source reflects and absorbs sound. Cable handling produces noise. Manual scanning speed varies.

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Remote operation, fixed stands, marked positions, and training reduce effects; video or photographs can document configuration; repeated scans estimate operator variability.

10.91 Uncertainty from door and seal temperature

Gasket stiffness and compression can vary with temperature; exterior doors and unconditioned spaces may perform differently seasonally; seal ageing compounds the effect.

Critical doors can be tested in representative temperature states or assigned a lifecycle margin. Product data should identify environmental range.

10.92 Uncertainty from moisture and material condition

Moisture changes porous absorption, timber properties, gypsum integrity, and sealant condition; masonry cracks and corrosion can develop; a laboratory dry specimen may not represent field exposure.

The inspection record should note moisture and damage; prediction uncertainty increases when material condition is unknown; remediation may require building-envelope repair before acoustic work.

10.93 Uncertainty in acoustic camera and beamforming maps

Beamforming and acoustic-camera images depend on array geometry, frequency, distance, reflections, and algorithm. Spatial resolution varies with wavelength. Bright colour does not prove a unique leak.

Maps should be validated by state changes and conventional measurements. The report should disclose processing and avoid treating interpolated pixels as direct measurements.

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10.94 Uncertainty in infrared and visual inspection inference

Thermal or visual gaps can suggest acoustic leakage, but heat, air, and sound follow different transfer mechanisms. A visible crack is relevant; its decibel consequence requires acoustic evidence.

Inspection methods are complementary. Their uncertainty is often qualitative and should not be converted into precise ratings.

10.95 Uncertainty from undocumented construction

Existing walls may contain unknown layers, voids, studs, ties, and repairs; prediction ranges should reflect alternative hypotheses; borescope, radar, ultrasound, or controlled opening can reduce uncertainty where justified.

The report should not choose the most favourable construction without evidence. Competing models can be compared with measured curve shape.

10.96 Uncertainty in security consequence

Acoustic metrics are only one input to consequence; the sensitivity of information, listener access, duration, recording ability, and organisational controls affect risk; these are policy and threat variables, not measurement noise.

A risk assessment can combine scenarios without pretending that every input is a precise probability. Qualitative uncertainty and sensitivity should be disclosed.

10.97 Uncertainty in cost estimates for remediation

Repair cost depends on path diagnosis, access, finishes, fire systems, operations, and retesting. A preliminary acoustic finding does not support a precise construction estimate.

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Options should include ranges and contingencies; early diagnostic certainty can reduce cost uncertainty; the report should separate technical recommendation from contractor pricing.

10.98 Uncertainty in programme schedules

High-isolation testing may require quiet periods, room completion, balancing, masking commissioning, and access; delays occur when prerequisites are not met; schedule risk should be planned.

Mock-ups and pretests reduce late uncertainty. The acceptance plan should include remediation and retest time rather than assume first-pass success.

10.99 Uncertainty in future changes of standards

Standards evolve. A current compliant measurement may be described differently under a future edition; the report should preserve the exact edition and raw data so later reanalysis is possible.

A change in standard does not retroactively change the physical room; it can change classification or reporting; contracts should avoid ambiguous “latest edition” language after award unless change control is defined.

10.100 Uncertainty in comparative product claims

Manufacturer claims may use different laboratories, standards, specimen sizes, and reporting conventions. Comparing integers without harmonising these factors adds uncertainty.

A fair comparison uses full reports and equivalent configurations. Where evidence remains unequal, the selection should disclose that uncertainty and rely on mock-up or field verification.

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10.101 Uncertainty in acoustic commissioning authority

The person directing tests may be designer, independent consultant, contractor, laboratory, or security authority. Independence and competence affect confidence.

Roles should be declared. The tester should not alter acceptance criteria; the authority should not edit raw results; conflicts of interest should be managed.

10.102 Uncertainty in speech-test scoring

Speech scores depend on transcription rules, spelling variants, partial credit, listener confidence, and adjudication. A scoring manual should be written before testing.

Automated scoring can reduce clerical error but needs validation. Blinded dual scoring and disagreement resolution improve reliability.

10.103 Uncertainty in failure localisation

A field failure may have multiple paths; temporary sealing one path can make another dominant; the measured improvement bounds the first path’s contribution but does not prove exclusivity.

Sequential perturbations and path models can estimate contributions. Conclusions should remain proportional to evidence.

10.104 Uncertainty in remediation durability

A temporary seal can produce an excellent retest and fail months later. Permanent repair must satisfy movement, fire, maintenance, and environmental conditions.

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The acceptance record should identify materials, installation, inspection, and warranty. Lifecycle checks confirm durability.

10.105 Uncertainty in waiver effectiveness

A compensating control may reduce risk but rely on human compliance. Its effectiveness has behavioural uncertainty. Monitoring and training reduce but do not eliminate it.

Waivers should be time-limited and reviewed. The acoustic defect remains documented.

10.106 Uncertainty in room-use assumptions

A room designed for conversation may later host amplified training, media playback, or larger groups. Source assumptions become invalid.

The room register should state authorised use and trigger review for changes. A rating is not a universal licence for all audio activity.

10.107 Uncertainty in adjacent-space future use

A storage room may become a quiet office; a controlled corridor may become public; receiving background and access change.

Lease, renovation, and space-planning processes should consult the secure-room register. Reassessment can occur before occupancy changes.

10.108 Uncertainty in record completeness

Missing drawings, raw data, or calibration certificates limit future interpretation. The acceptance package should be checked for completeness before project closeout.

Digital preservation requires formats, checksums, access control, and migration. A file that cannot be opened is not an enduring record.

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10.109 Final uncertainty doctrine

The purpose of uncertainty is disciplined knowledge. It identifies what the result means, how strongly it supports a decision, and what additional evidence would change the conclusion.

A secure-room programme should prefer an honest interval and clear rule to an impressive but unsupported integer; that preference is not caution for its own sake; it is the foundation of reproducible engineering and defensible governance.

10.110 Integrated uncertainty case study. Portfolio acceptance of twelve rooms

A hypothetical institution constructs twelve nominally identical secure conference rooms; a full field test of every room would be expensive, but the consequence of a hidden defect is high; the quality plan therefore uses one instrumented mock-up, first-of-type testing, random production sampling, and mandatory testing of rooms with unusual doors, façades, or service routes.

The mock-up achieves a field estimate 5 dB above the minimum with expanded uncertainty 1.4 dB; early production rooms show greater variability because of door adjustment and penetration workmanship; one sampled room fails the guarded rule by 2 dB; under the predeclared plan, the failure expands testing to all rooms built by the same crew and triggers inspection of comparable door thresholds.

The programme discovers three marginal rooms; remediation and retest bring every measured room above the guarded threshold; untested rooms are not accepted solely by drawing identity; they receive documented

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inspections, and the authority decides whether the combined evidence supports use.

This case separates four uncertainties: instrument and sampling uncertainty within each test; construction variability among rooms; sampling risk in generalising to untested rooms; and institutional consequence; a single expanded uncertainty on one room cannot represent the portfolio; the quality plan uses different controls for each layer.

10.111 Integrated uncertainty case study. Conflicting expert interpretations

In a hypothetical dispute, a contractor’s expert states that a measured ASTC 49 fails an ASTC 50 requirement; the owner’s expert states that expanded uncertainty is 2 dB and therefore the room should be treated as passing; both statements are incomplete because the contract contains no decision rule.

The measurement is reanalysed. Raw data and classification are correct; the interval overlaps the limit; a door-jamb diagnostic shows a correctable path; the legal question is not answered by metrology alone; the contract’s allocation of risk, ordinary industry practice, change orders, and prior communications must be considered by counsel or the tribunal.

The technical report states that the best estimate is below the nominal requirement, uncertainty overlaps it, and no predeclared guarded or shared-risk rule exists; it does not rewrite the contract; after repair, the estimate rises to 52 with lower uncertainty and the dispute becomes practically moot.

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The case demonstrates why decision rules should be agreed before testing; uncertainty does not automatically convert a failure into a pass, and a one-point shortfall is not automatically decisive when the measurement model and contract are silent.

10.112 Comparative decision exercise. The same result under three rules

A field measurement produces a best estimate of 50.8 dB. The combined standard uncertainty is 0.9 dB, and the project uses $k=2$, giving expanded uncertainty 1.8 dB. The nominal requirement is 50 dB. Three plausible decision rules produce different dispositions.

Under shared risk, the estimate is compared directly with the limit; the result passes because 50.8 exceeds 50; this rule is simple and transparent, but the interval extends below the requirement; the institution accepts some probability of false acceptance.

Under a guard band equal to one standard uncertainty, the acceptance limit is 50.9 dB; the result is 0.1 dB below and does not pass; under a guard band equal to expanded uncertainty, the acceptance limit is 51.8 dB, and the result clearly does not pass. Each rule can be rational under a different consequence and risk allocation; none should be selected after the result is known.

Suppose the diagnostic evidence shows no concentrated weak path, band results are stable, and occupied speech trials are favourable under the required source and background conditions; the competent authority may issue conditional use approval even if the guarded contractual field rule is not met; that authority decision does not rewrite the field measurement or

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eliminate the contractor's contractual obligation; conversely, a contractual pass under shared risk does not compel security accreditation.

The example demonstrates why one unexplained word, "pass," is inadequate; a complete statement names the metric, estimate, uncertainty, coverage, decision rule, result, configuration, and authority; it also separates measurement conformity from use approval.

A mature programme chooses the rule during design, prices the resulting margin, and writes remediation and retest procedures; the measurement team then applies the rule without knowing whether it will favour owner or contractor; this procedural independence is as important to credibility as the arithmetic itself.

10.113 Uncertainty statement template for secure-room reports

A concise uncertainty statement should identify the measurand, result, expanded uncertainty, coverage factor, intended coverage, dominant contributors, and decision rule; it should also state configuration and exclusions. A model paragraph is:

"The standardised weighted level difference between the identified source and receiving rooms was 52 dB. Expanded measurement uncertainty was 1.6 dB using coverage factor $k=2$ under the documented model. Dominant contributors were receiving-room spatial sampling and low-frequency background correction. Under the predeclared guarded rule requiring a best estimate of at least 51.5 dB, the result conforms. This statement applies only to the tested door, HVAC, masking, furnishing, and access states and does not constitute governmental accreditation."

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The statement is short because the technical appendix contains the model, budget, distributions, covariance, raw data, and calculations; it avoids both extremes: a bare integer that hides uncertainty and a dense metrological discussion that leaves the decision unclear.

When the result is a lower bound, the statement should preserve the inequality; when the class distribution is discrete, it should report probabilities or percentile classes rather than force a symmetric interval; when no decision rule was agreed, the report should state the measurement and uncertainty without inventing conformity.

This template should be adapted, not copied mechanically; each room has different contributors and authority; its purpose is to ensure that the final sentence retains the evidence needed for independent review.

10.114 Asymmetric loss, model discrepancy, and defensible acceptance near a boundary

A decision rule is incomplete until it states whose risk is being controlled and what loss follows an error; in a conventional procurement dispute, a false rejection may impose delay and cost, while a false acceptance may produce reduced acoustic performance; in a high-consequence discussion space, the losses can be strongly asymmetric because a small undetected weakness may expose protected information. The guard band should therefore be selected from the decision context rather than inherited as a habitual fraction of expanded uncertainty.[481]

The simplest guarded rule compares a measured estimate with a threshold after allowing for measurement uncertainty; that rule controls only the

481 MB-0690. ISO/IEC 17025:2017, JCGM 106:2012.

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uncertainty represented in the measurement model; it does not automatically include construction-model error, untested operational states, ageing, future penetrations, or an incorrect assumption about the dominant path. These effects are often called model discrepancy or scenario uncertainty; they should be handled explicitly through additional test states, conservative design allowances, separate diagnostic evidence, or a decision memorandum; concealing them inside an enlarged uncertainty number can make the calculation opaque and difficult to audit.

A useful decision structure separates three layers; the first is metrological uncertainty, which arises from calibration, spatial sampling, source stability, background correction, reverberation, geometry, and data processing; the second is configuration uncertainty, which concerns whether the measured state represents the intended operational state. Doors, masking, HVAC, movable partitions, access panels, and conferencing equipment may change; the third is mission uncertainty, which concerns listener access, source effort, consequence, and future use; the laboratory or field team can quantify the first layer and document portions of the second; the authority must decide how the third layer affects acceptance.

Suppose a project requires a minimum field result of 50 dB; a measured estimate is 51.2 dB with expanded uncertainty of 1.6 dB at the stated coverage probability; a simple rule requiring the lower expanded limit to meet the requirement gives 49.6 dB, so the result does not pass. Now suppose a second project has the same estimate and uncertainty but the requirement is advisory rather than contractual, the receiving space is continuously controlled, and an independent speech test shows a large privacy margin; the authority may reach a different operational decision, but

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it should not alter the measurement statement. The measured result, uncertainty, and rule remain distinct from the broader acceptance decision.

Asymmetric loss can be represented through a risk function. Let C_{FA} denote the consequence of false acceptance and C_{FR} the consequence of false rejection. Let $P_{FA}(g)$ and $P_{FR}(g)$ be the corresponding probabilities under guard band g. An illustrative expected decision loss is

$$R(g)=C_{FA}P_{FA}(g)+C_{FR}P_{FR}(g).$$

The guard band that minimises this expression depends upon the distributions, costs, and assumptions. The equation does not remove the need for judgement. It forces the project to disclose which error is considered more serious. In secure-room work, C_{FA} may be difficult to monetise and may include institutional, legal, diplomatic, or personal harm. A qualitative risk category may therefore be more defensible than a spurious currency value.

Decision analysis must also account for discrete classifications; an integer rating can change by one point when small correlated band changes move the reference contour. Near that transition, the probability distribution of the integer class may be non-symmetric even when the band uncertainties are approximately symmetric; directly propagating the band distributions through the classification procedure, by Monte Carlo simulation or another validated method, can estimate the probability assigned to each possible class. Reporting only a standard uncertainty on the integer may obscure that structure.[482]

482 MB-0691. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

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Model discrepancy should be tested rather than merely acknowledged; if the field result is dominated by a suspected door leak, repeat measurements after controlled seal adjustment and compare the band changes; if a ceiling plenum is suspected, alter the receiving position or use diagnostic excitation consistent with the method. If masking affects the speech criterion but not the isolation metric, test both masking states; each intervention should have a predicted signature; a change that does not produce the predicted response weakens the proposed mechanism and prevents premature remediation.

The acceptance record should preserve the complete chain: requirement, measurand, method, configuration, estimate, uncertainty budget, coverage statement, decision rule, result, diagnostic evidence, operational restrictions, and authority disposition; it should also identify any assumption whose failure would change the decision; this enables later reviewers to distinguish a measurement result from a design judgement, a contractual determination, and an accreditation decision.

Finally, the decision rule should survive ordinary project pressure; a marginal result may invite selective retesting, favourable averaging, exclusion of inconvenient bands, or a late change in the rule; the protocol should define retest conditions before measurement, preserve all valid trials, and explain any excluded data. Where an instrument fault or procedural departure invalidates a run, the reason should be documented; the objective is not bureaucratic rigidity; it is to prevent the acceptance boundary from moving after the evidence is known.

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10.115 Chapter conclusions

Uncertainty completes rather than weakens a measurement result; it identifies the range of values compatible with the model and evidence; a decision rule then allocates the risk of acting near a limit.

Secure-room acceptance should never be reduced to comparing an unexplained integer with an unexplained requirement; the result, uncertainty, configuration, metric, and rule form one proposition; accreditation remains a separate decision of the competent authority.

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Chapter 10 Glossary

Combined standard uncertainty, u_c. Standard uncertainty obtained by combining input components through the measurement model, including covariance where relevant.

Consumer risk. Risk of accepting an item or result that does not truly conform to the specified requirement.

Coverage factor, k. Multiplier applied to combined standard uncertainty to obtain expanded uncertainty for a stated coverage purpose.

Decision rule. Documented rule describing how measurement uncertainty is considered when stating conformity.

Expanded uncertainty, U. Quantity $k\,u_c$ defining an interval about a measurement result for a stated coverage purpose.

Guard band. Difference between the specification limit and the acceptance limit used to control decision risk.

Measurand. Quantity intended to be measured, defined with sufficient specificity to establish the model and conditions.

Metrological traceability. Property of a measurement result relating it to a reference through a documented chain of calibrations, each contributing uncertainty.

Producer risk. Risk of rejecting an item or result that truly conforms.

Sensitivity coefficient. Partial derivative describing how a change in an input quantity affects the output estimate.

Type A evaluation. Evaluation of an uncertainty component by statistical analysis of repeated observations.

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Type B evaluation. Evaluation of an uncertainty component using information other than the statistical analysis of repeated observations.

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