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Defensive Technical Surveillance Countermeasures Doctrine

Volume 115

Openings, Junctions, and Flanking Control

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Contents

PART VI. OPENINGS, JUNCTIONS, AND WEAKEST PATHS

Openings are not exceptions to the acoustic boundary. They are engineered subsystems whose operation, movement, fire protection, accessibility, security and maintenance determine the room result. Chapter 20 begins Part VI with the most frequently operated opening, the door assembly. It treats the leaf, frame, seals, threshold, hardware and sound lock as one maintained system and preserves the distinction among laboratory ratings, installed field evidence, room performance and formal acceptance.

Chapter 20. Acoustic Doors, Frames, Seals, Thresholds, and Sound Locks

20.1 An acoustic door is an operable boundary, not a heavy leaf

A door assembly must open, close, latch, seal, survive use, satisfy egress and accessibility obligations, and often maintain fire or smoke protection. These functions make the opening intrinsically more fragile than a uniform wall; the leaf, frame, hinges, latch, seals, threshold, automatic bottom, vision panel, hardware preparations, anchors and perimeter are one system; a laboratory rating for one tested configuration cannot be transferred to a visually similar leaf with different hardware or field clearances.[1][2]

The evidence hierarchy is explicit. Laboratory testing under ASTM E90-23 measures a defined operable assembly installed in a test partition; ASTM E413-22 derives STC from the band data. ASTM E2964-26 provides field measurements of normalised door insertion loss and a door transmission class for suitable installed doors;[3][4][5] whole-room field measurements under ASTM E336-25a or ISO 16283-1:2025 include the door and all other paths;[6][7] none of these results, by itself, establishes occupied speech security or formal approval.

1 MB-0335. ASTM International, ASTM E90-23.
2 MB-1164. Steel Door Institute, SDI 128-24, Guidelines for Acoustical Performance of Standard Steel Doors and Frames.
3 MB-0335. ASTM International, ASTM E90-23.
4 MB-0284. ASTM International, ASTM E413-22.
5 MB-0245. ASTM International, ASTM E2964-26.
6 MB-0272. ASTM International, ASTM E336-25a.
7 MB-0875. International Organization for Standardization, ISO 16283-1:2025.

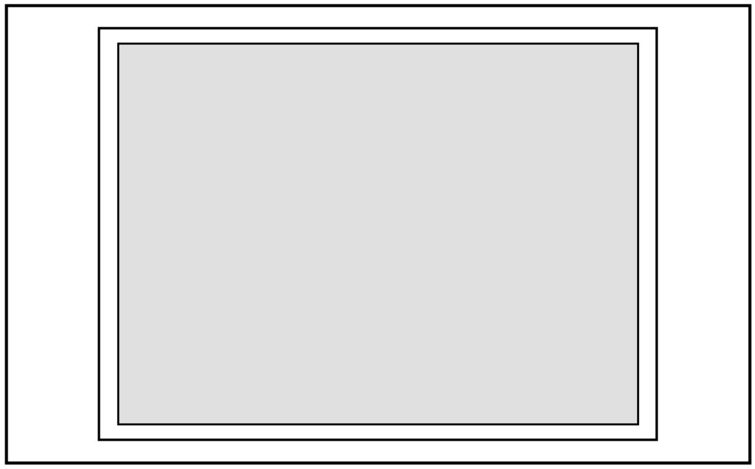

Figure 20-1. Complete acoustic door assembly comprising leaf, frame, hinges, latch, compression seals, automatic bottom, threshold, perimeter closure and wall interface. Author's original schematic.

Worked example 20.1. Door area controls a strong wall

A 24 m^2 partition contains a 2.1 m^2 door. The wall field has 60 dB transmission loss in a band and the door 35 dB. Composite coefficient is

$\tau = (21.9(10^{-6})+2.1(10^{(-3.5)}))/(24) = 2.86 \times 10^{-5}$,

so

$R = -10 \log_{10}(2.86 \times 10^{-5}) = 45.4$ dB.

The door reduces system performance by nearly 15 dB. Increasing the wall further is immaterial until the opening is addressed.

20.2 Laboratory specimen identity

A valid acoustic-door submittal includes the complete laboratory report; it identifies leaf dimensions and thickness, core, skins, frame, anchors, hinges, lock or latch, seal locations, threshold, automatic bottom, vision panel, installation, operability and test partition; SDI 128-24 emphasises testing fully operable steel-door assemblies and preserving the test configuration.[8]

A certificate or catalogue table without the report is insufficient for a high-consequence room; ratings can vary with door size, swing direction, frame profile, seal package and hardware; cutting a new vision panel, adding electric power transfer or changing lock preparations can alter the tested assembly. A substitution review compares details rather than brand labels.

Worked example 20.2. Scaling the leaf mass

A tested leaf is 0.91 m by 2.13 m and weighs 120 kg, giving areal mass

$m' = (120)/(0.91(2.13)) = 61.9\ \mathrm{kg/m^2}$.

A larger leaf of identical construction, 1.07 m by 2.44 m, would weigh about 162 kg if areal mass remained constant; hinges, frame and closer loads increase materially; acoustic similarity cannot be assumed because modes and seals also change.

20.3 Leaf construction, stiffness and coincidence

Acoustic leaves use mass, stiffness, damping and internal discontinuity. Steel skins can enclose mineral, fibrous, wood, honeycomb, cementitious or proprietary cores; wood leaves can use particleboard, stave, mineral or composite cores; multi-layer leaves may include damping sheets and internal frames; the design is often proprietary, and performance should be specified rather than inferred from a preferred core.[9]

A very stiff leaf can shift resonances and coincidence; a heavier leaf reduces ideal transmission but increases hardware loads and closing energy;

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8 MB-1164. Steel Door Institute, SDI 128-24, Guidelines for Acoustical Performance of Standard Steel Doors and Frames.
9 MB-0875. International Organization for Standardization, ISO 16283-1:2025.

internal hardware cut-outs create weak regions; edge channels and lock boxes can transmit vibration. The leaf must remain dimensionally stable under temperature, humidity and use.

Worked example 20.3. Ideal mass-law difference

Two leaves have surface masses 45 and 70 kg/m². Ideal difference is

$\Delta R = 20 \log_{10}(70/45) = 3.84$ dB.

Actual difference may be smaller or larger because seals, stiffness, core and modes govern. The calculation cannot select a door by weight alone.

20.4 Frames and the wall interface

The frame transfers leaf load and operating force to the wall; hollow metal frames can be grout-filled, insulated, reinforced or left hollow according to the tested system and fire requirements; grout may add mass and stiffness but can leave voids or deform frames. Timber frames have different section and attachment; the acoustic seal at the frame-to-wall perimeter is distinct from the leaf-to-frame seal.

Rough openings need dimensional tolerance compatible with the frame and sealant; shims, anchors and fasteners create local bridges; a cosmetic bead over a deep unfilled gap is not a reliable primary seal; the detail defines backing, sealant depth, substrate preparation and inspection. Frame plumb, square and twist directly affect seal compression.

Worked example 20.4. Frame twist and seal compression

A door frame is twisted so the upper latch corner is 3.0 mm out of plane relative to the lower corner; a compression seal designed for 4 mm working compression may receive only 1 mm at that corner after adjustment. If the seal requires at least 2.5 mm for continuous contact, the frame geometry cannot be corrected by latch force alone without excessive load elsewhere.

20.5 Hinges, pivots and alignment

Hinges support substantial mass and maintain the gap geometry; bearing wear, fastener loosening, frame deformation and hinge sag change clearances; continuous hinges can distribute load but alter the tested configuration; pivots carry loads differently and require floor coordination. Electrified hinges and power transfers introduce conductors and preparations.

An acoustic door should be adjusted by trained personnel; raising the leaf at one hinge affects head, jamb and bottom seals; over-tightening can bind the door or increase closing force; alignment records include gap measurements at several points and hinge condition.

Worked example 20.5. Sag angle

A 1.0 m wide leaf drops 2.0 mm at the latch edge. Small rotation is

$\theta \approx (0.002)/(1.0) = 0.002$ rad = 0.115^°.

The angle looks trivial, yet it can remove compression from the head seal and overload the automatic bottom at one end.

20.6 Latches, locks and compression

Compression seals need the leaf to be drawn against the stop; a positive latch supplies repeatable closure; deadbolts can provide security but may not compress the leaf uniformly; multi-point latches improve distribution but increase complexity, egress concerns and maintenance. Electromagnetic locks hold differently and must be reviewed within life-safety requirements.

The latch should engage without occupants slamming the door; excessive force encourages propping and accelerates wear; strike adjustment is part of commissioning; access-control devices must not prevent full closure or introduce cables that interfere with seals.

Worked example 20.6. Latch moment

A latch applies 250 N at 0.95 m from the hinge axis, producing closing moment

M = 250(0.95) = 238 N m.

If seal resistance is concentrated near the hinge and latch unevenly, local compression differs. The moment calculation does not predict seal contact but helps compare hardware loads.

20.7 Perimeter compression seals

Compression gasketing must contact continuously along head and jambs; material properties, profile, compression range, corners, fasteners and durability govern; ANSI/BHMA A156.22-2021 establishes performance and installation requirements for gasketing and includes durability and acoustic-related properties.[10]

Corners are frequent leak points. Mitred, notched or moulded corners must remain continuous; paint, debris and field modifications can prevent contact; seals should be replaceable without dismantling the frame; a visual contact line, paper-strip test or controlled light test can aid inspection, but acoustic field testing remains the performance evidence.

10 MB-0049. ANSI/BHMA A156.22-2021.

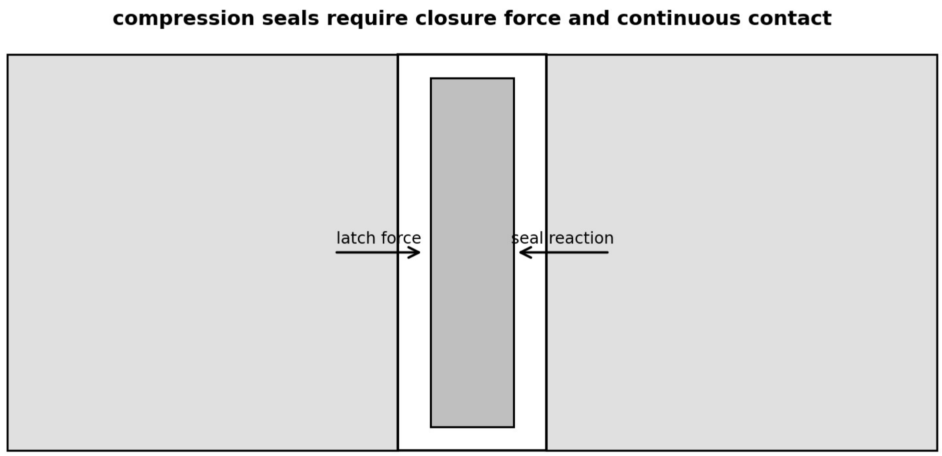

Figure 20-2. Compression-seal geometry showing correct contact, under-compression, over-compression and corner discontinuity. Author's original schematic.

Worked example 20.7. Seal compression ratio

A hollow seal projects 8 mm and is compressed to 5.2 mm when latched. Compression is

$\varepsilon\_c = (8-5.2)/(8) = 0.35$,

or 35 per cent. Acceptability depends on the profile's designed range. More compression is not automatically better because permanent set and closing force increase.

20.8 Automatic door bottoms and threshold contact

The bottom edge is difficult because the door must swing over the floor yet seal when closed; automatic bottoms deploy a seal as the door approaches the frame; adjustment must produce continuous contact without dragging or lifting the leaf. Floor flatness and threshold geometry are critical.

ANSI/BHMA A156.22-2021 includes durability requirements for automatic bottoms; public BHMA guidance notes Grade 1 cycling and retained contact-area criteria;[11] a product that passes component durability still requires correct field installation; a bottom cut too short leaves corner gaps; a warped threshold creates discontinuous contact.

Worked example 20.8. Threshold flatness tolerance

Across a 1.0 m opening, threshold high-to-low variation is 2.8 mm; an automatic bottom has 3.5 mm available compliant travel after initial contact; only 0.7 mm remains for wear, adjustment and leaf movement. The geometry is marginal even before operational tolerance is considered.

20.9 Thresholds, accessibility and trip risk

Thresholds provide a stable sealing surface, but height, bevel, slip resistance, drainage, fire listing and accessibility constrain design; ANSI/BHMA A156.21-2025 establishes threshold requirements and includes compressive-load, gasketing and slip-resistant tests;[12] applicable building and accessibility codes govern permitted geometry.[13][14]

A high raised threshold can improve acoustic contact but create an unacceptable barrier; recessed or low-profile systems may be required; floor transitions should be coordinated early; retrofitting a threshold after finishes often creates gaps and anchor conflicts.

Worked example 20.9. Ramp length for a bevelled transition

If a 12 mm rise is limited to a 1:2 bevel, horizontal run is 24 mm; accessibility rules may impose additional constraints depending on threshold type and jurisdiction; the geometric result does not establish code compliance.

11 MB-0049. ANSI/BHMA A156.22-2021.
12 MB-0048. ANSI/BHMA A156.21-2025.
13 MB-0794. International Code Council, 2024 International Building Code, subject to local adoption and amendment.
14 MB-0785. ICC A117.1, Accessible and Usable Buildings and Facilities.

20.10 Door undercuts and small clearances

An apparently small undercut has substantial area; a 6 mm gap across a 900 mm leaf is 0.0054 m^2, or 54 cm^2; airflow and high-frequency sound pass readily; brush sweeps can reduce leakage but may not match a tested acoustic assembly. Automatic bottoms and thresholds provide more controlled closure.

Worked example 20.10. Undercut effect

A 2.0 m^2 door field is 42 dB at a band. A 0.0054 m^2 open undercut gives

τ = ((1.9946)10^(-4.2)+0.0054)/(2.0) = 0.00276,

so R = 25.6 dB. The small undercut destroys most of the leaf performance.

20.11 Vision panels and glazing stops

Vision panels add glazing, stops, gaskets and corners; pane mass, laminate, area and frame determine transmission; fire-rated glazing and stops must remain within listings; security glazing may be heavy and require reinforced leaves. Field replacement must preserve exact configuration.

A small panel can control a high-performing leaf if its rating is lower. Stops can loosen or rattle. Gaskets age. The submittal should include the tested vision-panel size and location.

Worked example 20.11. Vision-panel composite

A 2.1 m^2 leaf at 45 dB contains 0.25 m^2 vision panel at 32 dB. Composite result is

R = -10 log_10((1.85(10^(-4.5))+0.25(10^(-3.2)))/(2.1)) = 39.4 dB.

The panel costs about 5.6 dB in this band.

20.12 Hardware preparations and electrification

Mortises for locks, closers, power transfers, monitoring contacts and access-control hardware remove core material and introduce cavities; surface-mounted hardware can preserve the leaf but create other constraints; concealed closers and floor pivots require large preparations. The tested assembly must match.

Wiring should not interfere with seals or create uncontrolled pathways; door-position switches, request-to-exit devices and card readers are part of the security system but do not establish acoustic closure; maintenance access should avoid damaging the leaf.

Worked example 20.12. Lock-pocket area

A lock pocket 180 mm by 90 mm has projected area 0.0162 m^2, less than one per cent of a typical leaf; its local transmission can nevertheless be important because it interrupts mass near the latch and may connect to hardware openings.

20.13 Closers, closing force and occupant behaviour

The door must close and latch reliably from expected opening positions; a closer set too weak leaves the leaf unlatched; too strong a closer impedes accessibility, increases impact and encourages propping; gasket compression, latch geometry, air-pressure differences and stack effect contribute to required force.

Commissioning measures opening and closing behaviour under operational HVAC conditions; a room pressurised relative to a corridor can resist closure; two doors in a sound lock can interact through trapped air; relief paths must not compromise acoustic security.

Worked example 20.13. Pressure force on a door

A 2.0 m^2 door experiences 15 Pa pressure difference. Net force is

$F = \Delta p A = 15(2.0) = 30$ N.

At a handle 0.9 m from hinges, pressure moment is about 27 N·m. This can materially affect closer and latch settings.

20.14 Fire doors and smoke doors

Fire-door assemblies are governed by listings, labels, installation, inspection and maintenance; NFPA 80-2025 provides current requirements for fire doors and other opening protectives, including inspection and maintenance;[15] smoke-door obligations are addressed by NFPA 105 and applicable codes;[16] acoustic seals, thresholds and hardware must not invalidate the listing.

Field drilling, trimming, gasketing and hardware changes are therefore controlled; intumescent seals and smoke gasketing may coexist with acoustic compression seals if the listed assembly permits; a non-listed modification that improves sound can reduce life safety; the door schedule should identify every performance obligation and the controlling evidence.

Worked example 20.14. Competing seal forces

Head and jamb gasketing produces average 18 N/m resistance over 5 m perimeter, or 90 N; bottom seal adds 35 N, pressure difference adds 30 N and latch friction 20 N; total closing resistance is approximately 175 N distributed through the closing cycle. The closer and hardware design must

15 MB-1037. National Fire Protection Association, NFPA 80, Standard for Fire Doors and Other Opening Protectives.
16 MB-1026. National Fire Protection Association, NFPA 105, Standard for Smoke Door Assemblies and Other Opening Protectives.

satisfy applicable opening-force and latching requirements, not merely overcome the sum at the handle.

20.15 Single doors, pairs and meeting stiles

Pairs of doors add a meeting stile, coordinators, flush bolts and overlapping seals; the inactive leaf may not close firmly; astragals improve overlap but affect egress sequence. Removable mullions create another perimeter. Laboratory evidence should match the pair configuration.

Where traffic permits, a single leaf is usually easier to seal than a pair; large equipment openings may use a secondary pair outside the primary meeting room or a removable wall section; operational convenience should not silently determine the weakest boundary.

Worked example 20.15. Meeting-stile gap

A 2.1 m high pair has a 2 mm open meeting gap; area is 0.0042 m^2, 42 cm^2; even before bottom and head gaps, this can dominate a high-rated pair.

20.16 Sound locks and vestibules

A sound lock places two door assemblies in series with an intervening vestibule; its benefit depends on both doors, room absorption, separation, operational sequence and flanking; if both doors are open simultaneously, the benefit disappears; if the vestibule is hard and small, energy can build up. Absorptive treatment reduces reverberation but must satisfy fire, durability and security requirements.

The two doors need not have identical ratings; the system can be optimised around traffic, egress and path dominance. Door swings should not conflict. Access control can enforce sequencing where authorised, but emergency egress must remain.

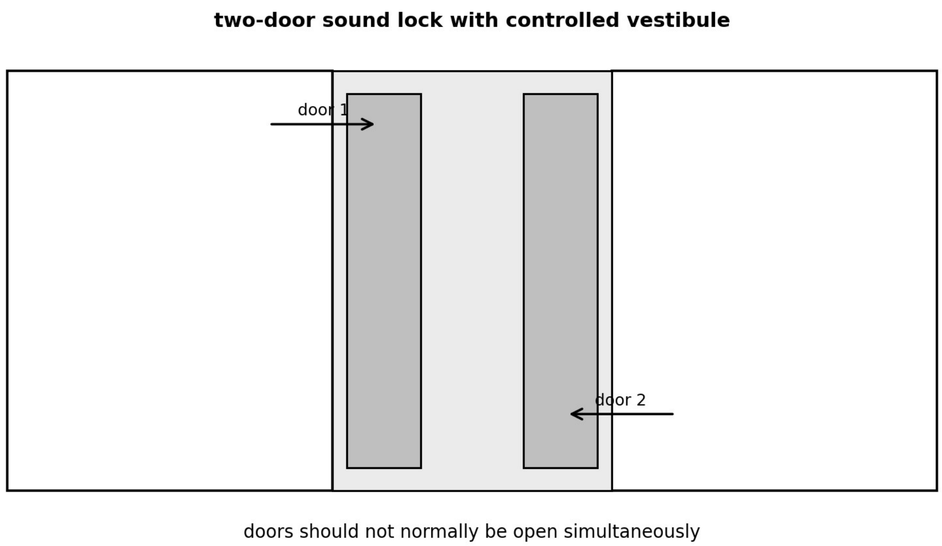

Figure 20-3. Two-door sound lock with absorbent vestibule, offset sight line, separate frames and controlled door sequence. Author's original plan.

Worked example 20.16. Ideal series-door screen

Two doors provide 38 and 42 dB insertion loss, and the vestibule contributes 8 dB through absorption and geometric separation in a selected band; an optimistic uncoupled screen gives 88 dB; real performance is much lower because of flanking, finite vestibule field, leakage and correlated paths. The example warns against adding ratings arithmetically without a validated model.

20.17 Field measurement under ASTM E2964

ASTM E2964-26 measures normalised door insertion loss and derives door transmission class for suitable field installations;[17] the method compares sound with the door open and closed and normalises source-side changes. It is valuable because E336 room measurements cannot ordinarily isolate one door without room modification; comparative research reported by the

17 MB-0245. ASTM International, ASTM E2964-26.

standard shows agreement with laboratory transmission loss where the door is between rooms and flanking is not significant, while corridor verification is more limited.

The report records source, microphone method, door direction, room geometry, background, open and closed states, seals and hardware; differences between measurement directions can occur; the result belongs to the installed door under test conditions.

Worked example 20.17. Normalised insertion loss concept

If receiving level falls from 67 dB with door open to 29 dB closed, raw insertion loss is 38 dB; if source-side level rises 1.2 dB when the door closes, normalised insertion loss is approximately 36.8 dB after correcting the source-side change. Exact processing follows the standard.

20.18 Commissioning protocol

Door commissioning proceeds from document review to geometry, operation, component inspection and acoustic testing; the team confirms labels, tested configuration, frame anchorage, perimeter seal, leaf clearances, hinge condition, latch engagement, closer action, gasket contact, bottom deployment, threshold, vision panel and electrification. Defects are corrected one mechanism at a time.

A light test can reveal gross gaps. Paper strips can compare compression. Feeler gauges quantify clearances. Acoustic scanning identifies local leakage. E2964 or whole-room tests provide performance evidence; the sequence preserves causation by documenting each adjustment before retest.

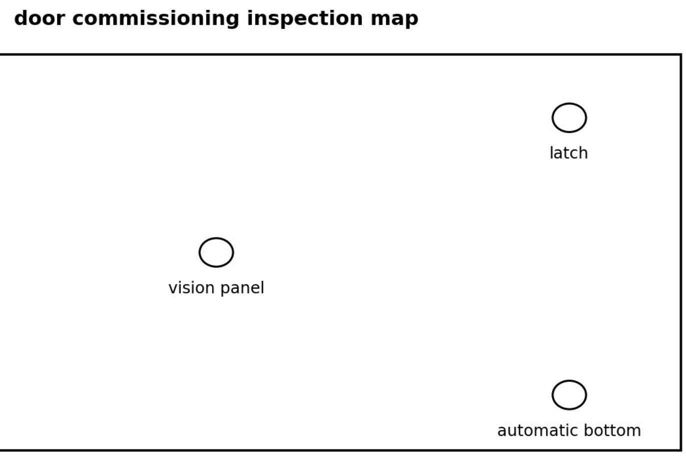

Figure 20-4. Door commissioning sequence from documents and geometry through operational adjustment, local leakage mapping, field measurement and lifecycle baseline. Author's original flow diagram.

Worked example 20.18. Clearance survey statistics

Twelve head-gap measurements have mean 3.1 mm and standard deviation 0.7 mm. Maximum is 4.6 mm. A mean alone conceals the local high gap; commissioning records the full spatial pattern and relates it to seal projection.

20.19 Lifecycle, maintenance and change control

Doors deteriorate through cycles, impact, wear, dirt, paint, seal compression set, closer drift and hardware changes; acoustic performance can decline without obvious leaf damage; fire-door and smoke-door inspection requirements coexist with acoustic inspection; a single coordinated programme avoids conflicting adjustments.

The baseline includes photographs, gap measurements, hardware settings, seal product, field data and spare parts; replacement gasketing must match profile and tested configuration; locksmith or access-control work triggers closure inspection; door leaves should not be undercut for carpet or airflow without formal review.

Worked example 20.19. Cycle accumulation

A conference-room door operates 180 cycles per working day for 240 days per year, or 43,200 cycles annually; over five years it accumulates 216,000 cycles; component durability ratings, maintenance intervals and observed wear should be compared with actual use rather than calendar age alone.

20.20 Forensic case study. High-rated leaf, low-performing room

A new meeting room has a laboratory-rated acoustic steel door; whole-room testing is 12 dB below the design basis in upper speech bands; the leaf and frame match the report; local scanning shows leakage at the threshold corners and upper latch jamb.

Inspection finds the threshold installed over an uneven stone floor with a 2 mm low area; the automatic bottom is cut 8 mm short, and the frame is twisted 2.5 mm; the closer slams the leaf, but latch compression remains uneven. Temporary corner seals improve the spectrum immediately.

The repair resets the threshold on a continuous bed, replaces the bottom at correct length, adjusts the frame and hinges, and balances closer and latch; e2964 measurement documents the installed improvement; the lesson is that a rated leaf is not a rated field assembly, and a field assembly is not the whole room.

20.21 Airflow, pressure relief and acoustic compromise

Ventilation designers sometimes use door undercuts or transfer paths to balance air; such practices conflict directly with high acoustic isolation;

pressure-relief strategies should use designed ducts, silencers or controlled return paths rather than uncontrolled gaps; the door should be tested under the operating pressure differential because seal contact and closing behaviour change.

A sound lock can trap or compress air when one door closes; slow equalisation can resist the second door or whistle through small gaps; a silenced relief path may be necessary; its location and insertion loss become part of the boundary design.

Worked example 20.20. Relief-air velocity

A room requires 0.10 m^3/s relief flow. A silenced path has free area 0.040 m^2, giving mean velocity

$v = 0.10/0.040 = 2.5$ m/s.

Velocity, pressure drop and regenerated noise require mechanical design. Enlarging an undercut is not an acceptable substitute.

20.22 Blast, ballistic and forced-entry requirements

Some secure doors also resist forced entry, ballistic attack or blast; added mass, stiff frames, multi-point latches and specialised glazing can assist security but increase operating force and structural load; blast deformation allowances can conflict with tight acoustic seals. Ballistic cores can have different resonances from acoustic cores.

Performance claims must remain separate. A ballistic rating does not imply STC, and an STC rating does not imply forced-entry resistance; the tested multi-hazard configuration is preferred; where separate tests are used, the designer confirms that specimen details remain equivalent.

Worked example 20.21. Leaf kinetic energy during closing

A 180 kg leaf has effective edge speed 0.35 m/s before latch. Translational screen gives

E = (12)/(mv^2 = 11.0\) J.

Actual rotational energy differs, but the value illustrates why a heavy security leaf can damage seals and frames if the closer is poorly adjusted.

20.23 Power-assisted and automatic operators

Automatic operators can overcome heavy leaves and accessibility constraints, but their arms, pivots, wiring and control sequence alter the assembly; the operator must permit full latch engagement and seal compression without holding the leaf off the stop. Power failure behaviour, emergency release and manual opening are reviewed.

Operator noise can mask speech during movement but is irrelevant when the door is closed; maintenance personnel must not adjust latch or closer settings independently of acoustic commissioning; the tested door configuration should include or permit the operator.

Worked example 20.22. Operator closing margin

Measured resistance near latch is 145 N, and operator available closing force at that position is 175 N; margin is 30 N, or 17 per cent of available force; dirt, pressure change or seal ageing can consume this margin, indicating need for monitoring rather than one-time acceptance.

20.24 Seal ageing, compression set and replacement

Elastomeric seals lose resilience through compression set, contamination and wear; automatic bottoms accumulate cycles and can lose parallel contact; replacement profiles that appear similar can have different hardness and geometry; maintenance should use controlled parts and document adjustment.

A useful inspection combines visual condition, contact tests, gap measurements and acoustic spot checks; replacing one seal at a time and retesting preserves causal information; wholesale replacement can improve performance but obscures which component failed.

Worked example 20.23. Compression-set loss

An original bulb seal projects 9.0 mm; after service it recovers to only 7.2 mm unloaded; projection loss is 20 per cent; if frame geometry required 3.0 mm compression originally, available compression falls from 3.0 to 1.2 mm, likely creating incomplete contact.

20.25 Double-egress pairs and coordinators

Double-egress pairs swing in opposite directions and use specialised meeting seals; coordinators, overlapping astragals and sequence-dependent latching may be restricted; the acoustic design must follow egress geometry rather than adapting a conventional pair blindly.

Meeting-stile seals experience shear and impact; the inactive-leaf concept may not apply; field measurement should include both normal operating directions and hardware states.

Worked example 20.24. Pair-perimeter growth

A single 1 m by 2.1 m leaf has about 6.2 m of sealing perimeter including bottom; a pair of two such leaves has outer perimeter plus a 2.1 m meeting stile, about 10.3 m total. The pair has substantially more potential discontinuity even before hardware complexity.

20.26 Threshold anchorage and substrate movement

Thresholds fixed into concrete, stone, timber or raised floors behave differently; anchors can loosen, sealant can debond and substrates can move; a threshold spanning an isolation joint becomes a rigid bridge; a saddle installed over resilient flooring can rock.

The detail defines structural support, fasteners, bedding, sealant and movement; threshold replacement should not cut post-tensioned tendons or heritage stone without review; drainage and cleaning access remain.

Worked example 20.25. Threshold rocking

A 1.0 m threshold bears at its ends with a 1.5 mm central void; a 900 N wheel load at centre creates bending and repeated impact; even if the section remains strong, seal contact can vary by the void magnitude. Continuous bedding is an acoustic as well as durability requirement.

20.27 Door-leaf modal testing

Impact or shaker testing can identify leaf modes and rattles; the source level must remain safe for glazing and hardware; accelerometers, laser vibrometry or acoustic holography can map response; a resonance does not automatically cause room leakage; it matters when excited by the source and coupled to the receiving field.

Comparing a suspect door with a known-good identical door can be useful if mounting and seals are equivalent; differences can indicate loose skins, core debonding or hardware; destructive opening is a last resort.

Worked example 20.26. Modal damping

A leaf resonance at 315 Hz has half-power bandwidth 18 Hz; approximate loss factor is 18/315 = 0.057; after repair, bandwidth is 27 Hz, giving 0.086;

greater damping may reduce resonant transmission, but the field spectrum must confirm benefit.

20.28 Acoustic leakage localisation around the perimeter

A small probe microphone or intensity system can scan the door perimeter under broadband source excitation; results are mapped by coordinate and frequency; local peaks at corners, latch, hinges and bottom guide adjustment; near-field reflections and probe orientation require controls.

Temporary tape or putty can isolate one segment; changes should be measured, not judged only by ear; the scan complements E2964 and whole-room testing; it does not replace them.

Worked example 20.27. Perimeter contribution ranking

Four segments contribute estimated receiving powers proportional to 1.0, 0.5, 0.2 and 0.1. Total is 1.8. The first segment contributes 56 per cent. Eliminating it reduces level by

$10 \log_{10}(1.8/0.8) = 3.5$ dB.

Several segments may need treatment for a large system gain.

20.29 Sound-lock reverberation and absorption

The vestibule between doors should not be treated as empty space; its volume, absorption and geometry affect the pressure presented to the second door; hard stone, glass and metal can produce long decay; absorptive wall or ceiling treatment reduces build-up, subject to fire and security constraints.

Doors should be offset where circulation permits, reducing direct line of sight and changing source incidence; a larger separation can improve performance but consumes valuable area; the benefit is verified through system testing.

Worked example 20.28. Vestibule reverberation

A 12 m^3 sound lock has equivalent absorption area 3.0 m^2. Sabine estimate is

T_{60} = 0.161(12)/(3.0) = 0.64 s.

Adding 4 m^2 equivalent absorption reduces it to 0.28 s. The shorter decay can reduce energy incident on the second door between transient events.

20.30 Acceptance matrix and responsibility

Door performance crosses architectural, hardware, fire, security, electrical and acoustical trades. A responsibility matrix identifies who supplies the tested report, verifies rough opening, installs frame, grouts or seals perimeter, hangs leaf, installs hardware, adjusts closer and latch, commissions access control, performs fire inspection and conducts acoustic testing.

Acceptance is staged. Product compliance precedes installation acceptance. Operational acceptance precedes acoustic measurement. Fire and accessibility findings are closed before use. The competent authority then considers the room as a whole.

Worked example 20.29. Decision guard band

A field DTC requirement is 40. Measurement result is 40.8 with expanded uncertainty 1.6 dB; a conservative acceptance rule requiring result minus uncertainty to meet 40 gives 39.2 and therefore does not pass; the rule must be specified before testing; it is not invented after seeing the result.

20.31 Leaf modal behaviour and composite door construction

A door leaf is a finite plate with edges, hardware cut-outs, internal cores and surface skins; its sound transmission cannot be inferred from weight alone. A solid timber leaf, a mineral-core fire door, a steel-stiffened leaf, a constrained-layer composite and a double-leaf acoustic door can have similar mass but different bending stiffness, damping and coincidence behaviour; the tested leaf identity must therefore include construction, thickness, facing, core, glazing, hardware preparations and dimensions. [18]

Finite dimensions matter. Large leaves have lower panel modes and greater susceptibility to twist; door closers and latches apply concentrated loads; vision panels interrupt the plate and add glazing stops. Lock pockets remove core material. Internal stiffeners may improve serviceability while creating radiation patterns; a catalogue STC belongs to the tested configuration, not to an abstract door type.

Composite leaves can be designed to separate resonant features; unequal skins and damping layers reduce symmetry; internal air spaces can introduce mass-air-mass behaviour; structural rails and stiles provide load paths around softer cores. The engineer should review full transmission curves and not merely the single-number rating.

Field diagnosis can use tapping, laser vibrometry or accelerometers to identify local modes, but the excitation and boundary state differ from airborne testing; a strong modal response does not automatically mean the leaf controls room transmission. Perimeter leakage often dominates. Modal testing is most useful after seal paths have been bounded.

18 MB-0329. ASTM International, ASTM E90-23, ASTM E413-22.

Integrated worked example 20.30. Leaf-mode shift after adding a surface plate

A 1.0 m by 2.1 m leaf has a measured first bending mode at 78 Hz; a steel protection plate adds 12 kg and increases bending stiffness locally; if total moving mass increases from 72 to 84 kg while effective stiffness rises by 30 per cent, a simple frequency ratio is

$f_2/f_1 = \mathrm{sqrt}[(1.30)/(84/72)] = 1.055.$

The mode shifts to about 82 Hz; added mass alone would lower the mode, but stiffness increase reverses the direction; the calculation is a bounded single-degree screen; real mode shapes, attachments and damping require measurement.

20.32 Frame cavities, anchors, grout and perimeter closure

The frame is part of the door system; hollow metal frames contain profiles, anchor pockets and cavities; grout filling can add mass and support, but it can also create rigid coupling and concealed voids; timber frames have joints, stops and movement; precast or masonry openings may be irregular. The perimeter seal must close the actual gap, not only the visible trim line.

Frame installation begins with plumb, square and twist control; a small diagonal error changes seal compression and latch engagement; anchors should hold the frame without distorting it; shims, grout and fasteners create discrete stiffness paths; the wall opening must provide adequate backing; a high-rated leaf in a twisted frame will not perform as tested.

Grout should not be assumed continuous. Dense grout around hinge reinforcements may leave pockets elsewhere; the primary acoustic air seal may belong at the frame-to-wall perimeter rather than within the frame cavity; fire-rated systems may require specific grout or sealant conditions; the detail should distinguish structural anchorage, cavity fill, firestop and acoustic closure.

Perimeter closure is inspected before casing or wall finishes conceal it; photographs show gap depth, backing and sealant; a local pressure or smoke test can reveal open corners; acoustic scanning around the frame after installation identifies remaining hot spots. The result is recorded by jamb, head and threshold segment.

20.33 Seal mechanics, compression set, temperature and wear

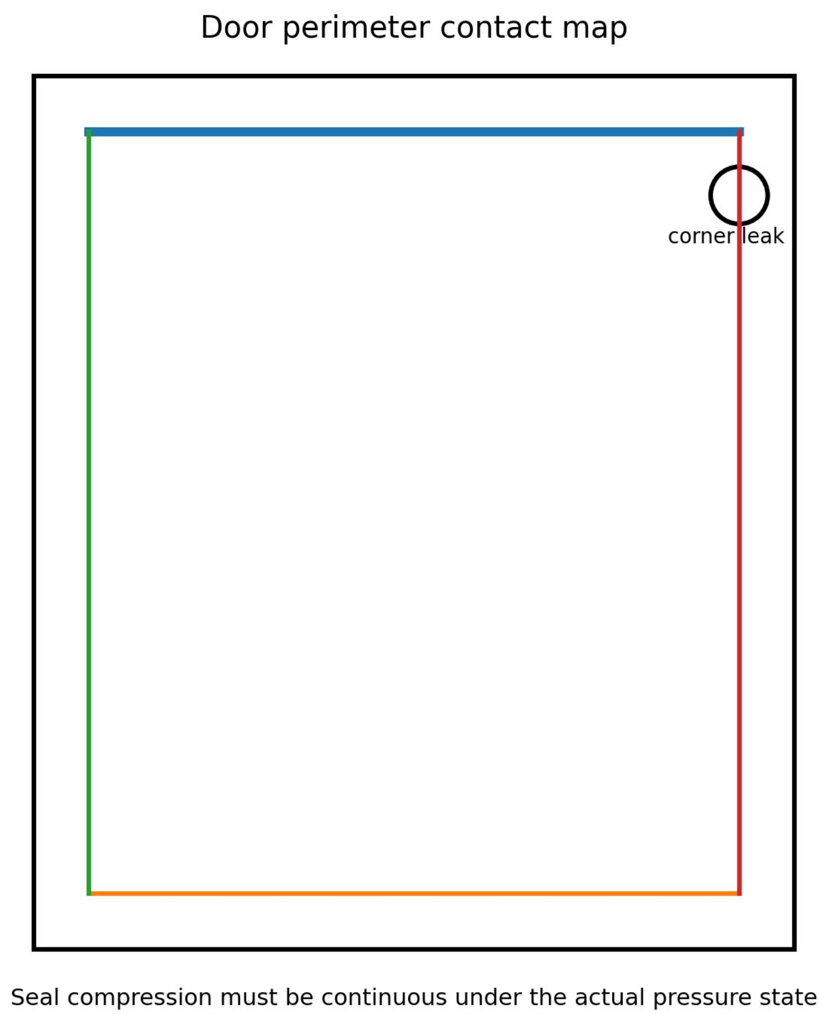

Figure 20-R1. Door perimeter contact map with a weak bottom and corner leak. Author's original schematic.

Compression seals work through contact pressure over a continuous line; performance depends upon profile geometry, material hardness, compression, surface finish, temperature and ageing; too little compression leaves gaps; excessive compression raises operating force, prevents latching and accelerates permanent set. [19]

19 MB-0372. Builders Hardware Manufacturers Association, ANSI/BHMA A156.22-2026.

Corners are difficult because profiles must meet without open mitres or excessive overlap; hinges and pivots create local changes in gap; the latch side may compress more than the hinge side; a magnetic or bulb seal has different force-displacement behaviour from a blade seal. The tested door set includes the profile and installation.

Compression set reduces recovery after long closure. Temperature can stiffen elastomers. Cleaning agents and ultraviolet exposure can degrade surfaces; a door used heavily may polish or tear the seal; maintenance should measure closure and contact, not only age.

Contact can be mapped with pressure-sensitive film, feeler gauges, light testing or local acoustic scans. Each method has limits. Film can alter the gap. Light does not detect every acoustic leak. A paper-pull test is qualitative. A high-consequence door may require a documented grid and repeatable force method.

Integrated worked example 20.31. Seal-force balance

A perimeter seal has compressed length 5.8 m and average required line force 18 N/m, giving 104 N total closing resistance before latch and hinge friction; the closer supplies 135 N at the relevant door angle. A pressure differential across the 2.0 m2 leaf adds 40 Pa times 2.0 m2 = 80 N opposing closure; total demand is now 184 N, exceeding closer capacity.

The door may stop short of latch despite correct seals; increasing closer force can create accessibility and wear problems; pressure relief, vestibule control or seal selection may be preferable; the calculation illustrates system interaction and does not replace code-compliant force measurement.

20.34 Automatic bottoms, thresholds and floor topology

An automatic door bottom deploys a seal during the final closing movement; plunger adjustment, leaf sag, floor flatness and threshold profile determine contact; a seal that deploys too early drags and wears; a seal that deploys too late leaves a gap. The bottom must retract fully when the door opens.

The floor is rarely perfectly flat. Carpet transitions, stone joints, raised-floor panels and floating-floor boundaries create local height changes; a continuous threshold can provide a controlled surface but must satisfy accessibility, fire and egress requirements; threshold anchors can bridge an isolated floor or damage waterproofing.

Drop-seal contact should be checked along the full width; a single centre measurement can miss corner gaps; the inspection record includes plunger setting, deployment depth, threshold straightness and compression; repeated cycles are observed because the mechanism may stick intermittently.

Water, debris and cleaning can affect the bottom seal; a vestibule exterior door has different exposure from an interior secure-room door; replacement parts must match the tested assembly where rating evidence is relied upon.

20.35 Hinges, pivots, closers, latches and access-control forces

Hardware determines leaf position and seal compression; hinges carry weight and resist moment. Pivots place loads differently. Continuous hinges distribute force and can improve alignment, but preparations and frame reinforcement must match; closers control speed and final force; latches draw the leaf into seals; access-control hardware adds strikes, cables and power transfer. [20]

Wear accumulates. Hinge bearings loosen. Screws move. Frames distort. Latch alignment changes with building movement; a door can remain operable while acoustic contact degrades; preventive maintenance should include gap and compression measurements.

Electrified locks complicate the edge. Wireways and transfer devices remove material; electric strikes require frame pockets; power failures may change latch state; the security, fire and acoustic modes should be tested under normal, emergency and degraded power states.

Automatic operators must provide enough closing force to overcome seals and pressure while meeting safety requirements; control timing should allow the latch to engage; a door that rebounds or remains slightly open is an acoustic failure even if the operator reports a completed cycle.

20.36 Door pairs, meeting stiles, coordinators and astragals

Pairs double the vertical meeting line and introduce sequencing; one leaf may be active and one inactive; flush bolts, coordinators, overlapping astragals and gasketing interact; a small misalignment at the head can continue down the stile. Pairs are generally more difficult to maintain than single leaves.

An overlapping astragal can improve closure but requires correct leaf order; a coordinator ensures the inactive leaf closes first; panic hardware, vertical rods and floor strikes create penetrations and wear points; removable

20 MB-0376. Builders Hardware Manufacturers Association, ANSI/BHMA A156.4-2024, ANSI/BHMA A156.17-2025.

mullions can improve performance but change egress and operational flexibility.

Inspection should test each state: active leaf alone, both leaves, emergency release and access-control operation; meeting-stile contact is mapped under pressure difference; a pair that passes when manually pulled shut may fail under automatic operation.

20.37 Sound locks, vestibule absorption and operational discipline

A sound lock places two doors in series with an intermediate volume; its benefit depends upon each door, the vestibule absorption, wall and ceiling paths, floor continuity and operating discipline; if both doors are open simultaneously, the series benefit disappears. A small highly reverberant vestibule can couple the doors more strongly than expected.

The vestibule should not become a service plenum or storage space; ceiling penetrations, return-air grilles and shared walls create bypasses; absorptive treatment reduces reverberant build-up but must satisfy fire and durability requirements; lighting, sprinklers and access control should be integrated without uncontrolled penetrations.

Interlocks can enforce one-door-at-a-time operation where life safety permits; they must be coordinated with egress and emergency release. Human behaviour remains important. Users may prop doors open or follow closely; training and monitoring are operational controls, not substitutes for construction.

Integrated worked example 20.32. Vestibule absorption and inter-door level

A 12 m3 vestibule has equivalent absorption area 6 m2 sabin in a speech band; adding wall treatment increases absorption to 14 m2; under a simplified diffuse-field relation, reverberant level change is 10 log10(14/6) = 3.7 dB reduction. The second door therefore receives a lower reverberant field.

The calculation does not include direct line-of-sight transmission, door leakage, non-diffuse behaviour or simultaneous opening. It supports absorption design as one part of the sound-lock system.

20.38 Field measurement, leakage localisation and uncertainty

ASTM E2964-26 provides a field method for normalised door insertion loss and Door Transmission Class for primarily hinged personnel doors under its stated scope; it reduces, but does not eliminate, surrounding flanking; the result belongs to the installed door and test environment. [21]

The test record should identify door dimensions, leaf and frame construction, seals, hardware, operating state, room geometry, source and microphone positions, background, calibration and uncertainty; open and closed measurements must be stable; a door that changes position during the test invalidates comparison.

Leakage localisation follows the whole-door result; near-field scans around jambs, head, threshold, vision panels and hardware identify candidate paths; intensity methods can be valuable where field conditions permit;

21 MB-0273. ASTM International, ASTM E336-25a, ASTM E2964-26.

temporary sealing can test causation; the intervention must not be left in place as an unapproved permanent repair.

Uncertainty is both metrological and configurational. Repeatability may be good while the result changes after one hundred cycles or under pressure differential; acceptance should specify the door state and decision rule; a field DTC is not a speech-security classification by itself.

20.39 Lifecycle maintenance, cycle testing and change control

Doors are moving assets. The maintenance programme should record cycles, adjustments, seal replacements, hardware changes, frame movement and test results; high-use doors may require inspection by condition rather than annual calendar alone; door counters or access-control logs can estimate use.

Triggers include visible seal damage, latch difficulty, closer change, floor replacement, pressure rebalance, fire inspection findings and security-hardware modification; a replacement seal or automatic bottom must be compatible with the tested assembly; substituting a similar-looking profile can change compression and performance.

Maintenance staff should have a door schedule showing protected assemblies, approved components, adjustment ranges and test methods. Work is photographed and signed. Acoustic retesting is targeted after significant change or unexplained degradation.

20.40 Integrated secure-door design case

A secure meeting suite requires a personnel door in a concrete wall; the corridor is quiet after hours, so door leakage is consequential; the design selects a tested acoustic door set with mineral-core leaf, reinforced frame, compression seals and automatic bottom. Fire rating, egress, accessibility and electronic access control also apply.

The rough opening is surveyed before frame fabrication; the frame perimeter uses a structural anchor system, compatible grout where required and a separate continuous air seal; access-control wiring follows a documented route and does not create open frame cavities. The threshold is supported from the corridor slab while the room side has a floating floor; a purpose-designed transition preserves isolation without creating a trip hazard.

A full-scale mock-up is installed early. Closing force is measured under the design pressure differential. Seal contact is mapped. The automatic bottom is cycled. Field DTC testing establishes the installed result; a speech-shaped source and controlled listening test then evaluate the room consequence at accessible corridor positions; the two results are reported separately.

During commissioning, one upper corner shows weak contact; hinge adjustment improves alignment, but latch force rises; the team changes shim and closer settings within the approved hardware range rather than adding an untested seal. Retesting confirms improvement. The final dossier contains product reports, frame and seal details, fire and accessibility records, field measurement, uncertainty, operational state and maintenance schedule.

The door is not described as “soundproof” or “classified”. It is described as a tested and commissioned component within a complete room, with formal use subject to the competent authority.

20.41 Door pressure regimes, HVAC balance and emergency modes

A door is tested and adjusted within a pressure environment; supply and return imbalance, stack effect, wind and smoke-control operation can change the force on the leaf; the pressure state should therefore be included in commissioning and maintenance records.

Normal occupied mode, after-hours mode, emergency purge and fire-alarm mode may produce different pressures; a door that latches in one state may stall in another; a vestibule can buffer pressure, but interlocked doors can trap air and increase closing force. Relief paths must be acoustically controlled.

Pressure differential is measured on both sides of the opening during force and leakage tests. Building controls are logged. Acceptance criteria should identify the required operating modes; if an extreme emergency mode cannot preserve acoustic closure, operational policy should recognise the limitation rather than concealing it.

20.42 Thresholds at floating floors and seismic joints

Where a secure room uses a floating floor, the door threshold crosses between moving and fixed systems; a rigid threshold anchored to both sides can short-circuit the isolation; a threshold supported only from one side may experience relative movement and seal variation.

The detail should allocate support, movement and air closure explicitly; a flexible bridge plate may accommodate movement but radiate; a split threshold can preserve isolation but complicate accessibility and water control. Full-scale mock-up is often justified.

Seismic joints create larger movement demands. Door frames near such joints require structural coordination; a door should not straddle a building separation unless a purpose-designed system exists; post-event inspection should include frame geometry, seal contact and threshold condition.

20.43 Door schedules as controlled configuration records

A conventional hardware schedule lists leaf, frame and hardware; a secure-room door schedule should also record acoustic report, fire listing, seal profiles, threshold, frame perimeter system, access-control state, closer settings, pressure state, field test result, maintenance interval and approved replacement parts.

Each door receives a unique identifier. Photographs document seals and gaps. Changes are signed and dated. The schedule links to the room penetration and equipment registers; this prevents an apparently minor hardware substitution from becoming an undocumented acoustic change.

20.44 Failure investigation after a sudden performance loss

A sudden loss of privacy should trigger a state-controlled investigation; first confirm source, background and test geometry; then inspect door closure, latch, seals, threshold, frame and pressure; review recent maintenance and access-control work. Localise leakage before disassembly.

Common causes include torn seals, failed automatic bottoms, loose hinges, strike movement, debris on thresholds, frame distortion and changed pressure; a temporary reversible repair can test the hypothesis; permanent work should use approved components and be retested.

Evidence is preserved where dispute or security incident is possible; photographs, removed parts, adjustment measurements and test data are retained; the report distinguishes vulnerability, confirmed disclosure and causal attribution.

20.45 Fire, smoke, egress and acoustic coordination

A fire door assembly is governed by its listing, hardware, clearances, self-closing and self-latching functions, inspection and maintenance; acoustic modifications cannot invalidate those requirements; adding seals, changing a closer or altering a threshold requires review against the listed assembly and applicable code. [22]

Smoke gasketing and acoustic gasketing may share components, but their test objectives differ; a profile effective for air leakage may not provide the compression or durability needed for high acoustic isolation; conversely, a heavy acoustic seal can raise operating force. The schedule should identify which requirement each component satisfies.

Egress and accessibility measurements are made under the actual pressure and seal state; a door should not be accepted acoustically if users cannot operate it safely; where the conflict cannot be resolved with one assembly, a sound lock or alternative route may be preferable.

20.46 Blast, ballistic and forced-entry door systems

Blast, ballistic and forced-entry requirements add mass, stiffeners, multi-point latches, heavy frames and specialised anchors; these features can improve some transmission bands but increase operating force and structural coupling; the tested acoustic configuration must include the security hardware.

22 MB-1036. National Fire Protection Association, NFPA 80, Standard for Fire Doors and Other Opening Protectives.

A blast door can deflect under design load and may require large clearances or flexible seals; ballistic glazing in a vision panel has layered construction and substantial mass. Multi-point locks require precise alignment. The frame-to-wall connection becomes critical.

No acoustic change should reduce protective performance. The disciplines should coordinate through one opening schedule and full-scale mock-up where consequence justifies it.

20.47 Accessibility, human factors and reliable closure

A door that is difficult to operate will be propped open, manually pulled, or left unlatched; human factors are therefore part of acoustic reliability; opening force, closing speed, latch effort, clear width and threshold geometry should be measured and observed with representative users.

Automatic operators can resolve force problems but add control states and maintenance. Hold-open devices require release logic. Access readers should not encourage tailgating through both doors of a sound lock; operational design should make the secure state the easy state.

20.48 Procurement and submittal evidence for acoustic doors

The submittal should include the complete laboratory report, leaf and frame construction, dimensions, seals, threshold, hardware preparations, fire listing, installation instructions and approved substitutions. A one-page certificate is insufficient.

The specification should require field commissioning and identify the test method, source state, decision rule and responsibility for adjustment; the contractor should not be forced to guess whether the requirement applies to the leaf, door set, partition or room.

Approved equals should be compared mechanism by mechanism. Same nominal STC does not establish equivalent fire rating, operating force, seal durability or field performance.

20.49 Vision-panel systems and glazing retention

A vision panel is a composite opening within the leaf; glass type, thickness, laminate, pane area, air space, stops, gaskets and fasteners determine performance; fire and ballistic glazing add constraints; the panel often becomes the weakest field of an otherwise heavy leaf.

Stops must compress gaskets continuously. Screws can loosen. A large pane changes leaf stiffness and centre of gravity. Replacement glass should match the tested construction, not only thickness.

20.50 Door-leaf edges, lock blocks and hardware cut-outs

Leaf edges contain rails, stiles, lock blocks and channels; hardware preparations remove material and can connect internal cavities; mortised locks, exit devices and electric power transfers require exact reinforcement.

Acoustic test reports should identify hardware; field substitutions can change cut-outs; unused preparations should be closed with approved components; surface-applied hardware may preserve the core but add mass and stiffness.

20.51 Cam-lift hinges and specialised acoustic hardware

Some high-isolation doors use cam-lift hinges or mechanisms that lower the leaf onto seals as it closes; they can achieve strong bottom contact without continuous drag; alignment, lubrication and floor level are critical.

Specialised hardware requires trained maintenance. Replacing it with conventional hinges or adjusting outside the manufacturer’s range can destroy performance. Spare parts and service arrangements belong in procurement.

20.52 Door seals under contamination and cleaning regimes

Dust, fibres, paint, wax and cleaning residue reduce seal contact. Threshold grooves collect debris. Healthcare, laboratory and diplomatic facilities may use cleaning chemicals that attack elastomers.

Maintenance procedures should specify compatible products and inspection; a seal may be acoustically degraded before visibly torn; contact tests and local scans can verify condition.

20.53 Temporary doors and construction-phase security

During construction, permanent acoustic doors may not be installed; temporary doors, hoardings and access controls provide limited isolation; sensitive discussions should not rely on them without measured evidence and compensating controls.

Construction-phase testing can identify rough-opening and wall defects before the final door arrives. It should not be confused with final acceptance.

20.54 Door-system records for incident investigation

If suspected disclosure occurs, the door record provides cycle count, maintenance, access logs, pressure state and recent changes; the investigation preserves seal condition before adjustment; local tests are conducted under controlled authority.

The finding distinguishes a vulnerable condition from proof of information loss. Technical evidence, access and content exposure require separate analysis.

20.55 Laboratory door testing and specimen fidelity

Laboratory transmission-loss testing under ASTM E90 treats the door as part of a specimen installed in a test opening; the report should identify leaf size, frame, wall, seals, threshold, hardware, glazing and mounting; a door label or model name without the full report is weak evidence.

Specimen wall stiffness and flanking control affect the result; a door tested in a massive laboratory wall may perform differently in lightweight field construction; larger leaves have different modes and longer seal perimeters; hardware preparations can change the core.

A design comparison should use complete curves and tested configurations; the laboratory result is one proposition; field DTC, room isolation and occupied privacy remain separate.

20.56 Field DTC test planning under ASTM E2964

The field plan defines source room, receiving room, open and closed states, microphone method, source stability, background and door operation; the door must be fully latched in the closed state and held in a reproducible open state; pressure and HVAC mode are recorded. [23]

The method reduces surrounding flanking relative to a whole-partition test but does not remove it completely; results below laboratory STC are expected in the field; if the receiving room is very small, large or absorptive, the method's normalisation and scope should be reviewed carefully.

Repeat measurements after cycling can expose intermittent seals; a single close may be unrepresentative; the report includes band data, DTC, uncertainty and deviations.

23 MB-0273. ASTM International, ASTM E336-25a, ASTM E2964-26.

20.57 Acoustic leakage localisation methods for doors

Localisation can use near-field microphones, scanning intensity, pressure-gradient probes, light, smoke, pressure and reversible sealing. Each responds to different aspects. Light detects direct gaps but not porous paths. Smoke requires pressure. Intensity needs suitable field conditions. Temporary tape can test causation but changes the boundary.

The door perimeter is divided into segments; jambs, head, threshold, meeting stiles, vision panels and hardware are scanned; results are compared with gap and contact measurements; a local hot spot is not automatically the only controlling path.

20.58 Door adjustment as a controlled engineering intervention

Adjustment changes hinge position, closer force, latch, automatic bottom and seals. One improvement can worsen another. Raising the leaf may close the threshold but reduce head contact; increasing latch preload can raise operating force; the work should be staged and measured.

Baseline gaps, forces and acoustic scans are recorded; adjustments remain within manufacturer limits; after each significant change, closure and safety are checked; final settings are entered in the door schedule.

20.59 Door pairs and sound-lock operational logic

A pair in a sound lock introduces four leaves and multiple sequences. Interlocks, coordinators and access control should prevent uncontrolled simultaneous opening where permitted. Emergency egress remains available.

The vestibule pressure changes as leaves move; a rapidly closing outer door can pressurise the space and resist the inner door; relief paths require acoustic treatment; commissioning includes realistic user sequences.

20.60 Threshold and seal design at carpet, stone and resilient flooring

Floor finish affects seal contact. Carpet pile compresses and wears. Stone joints create local steps. Resilient flooring can curl. A threshold provides a controlled surface but adds height and anchors.

The finish schedule and door detail must be coordinated; replacing carpet with hard flooring changes gap; stone polishing can alter level; maintenance should trigger readjustment and retest where necessary.

20.61 Door hardware acoustical noise inside the protected room

Hardware can create impact and structure-borne noise during operation; latches, closers, strikes and operators may disturb meetings or reveal occupancy patterns; soft-close control and damping can improve the interior environment without compromising secure closure.

The concern is distinct from sound transmission; a quiet door can still leak, and a high-performing door can be noisy; both are considered in user acceptance.

20.62 Door commissioning case. Pressure reversal after HVAC balancing

A door passes field testing before final HVAC balance; later, the room becomes positively pressurised by 45 Pa; the door no longer latches reliably and corridor leakage increases; the acoustic construction has not changed, but the operating state has.

Investigation measures pressure, closer force and seal contact; return-air balance is corrected and a controlled relief path added; the closer is adjusted within accessibility limits. Retesting confirms recovery.

The case demonstrates that commissioning must occur after systems reach final operation and that later balancing changes require review.

20.63 Maintenance acceptance and spare-parts control

Spare seals, automatic bottoms, hinges and closer components should be identified during procurement; a discontinued profile can force an unverified substitution; stock and service agreements support lifecycle assurance.

Maintenance acceptance verifies part identity, installation, operation and acoustic contact; removed parts are examined for wear; the door record is updated; significant changes trigger field testing.

20.64 Door-system final evidence package

The evidence package contains laboratory reports, field measurements, leaf and frame schedules, fire and accessibility records, pressure state, hardware settings, contact maps, photographs, maintenance requirements and residual limitations.

The conclusion is bounded. It identifies the installed door result and its role in the room. Formal approval remains with the competent authority.

20.65 Door-leaf construction families and their failure signatures

Acoustic door leaves can be solid timber, mineral-core, steel-stiffened, composite, laminated or specially fabricated multi-layer systems; equal mass does not imply equal behaviour. Core shear stiffness, face-sheet thickness, internal ribs, edge rails, lock blocks and adhesive continuity influence bending modes and damping; a steel leaf can be locally stiff yet radiate through large unsupported face areas; a timber composite can provide useful damping but change with moisture and hardware machining. Product evidence must identify the exact leaf, size, hardware preparation and tested frame. [24]

Field symptoms can guide diagnosis. A broad mid-frequency depression may reflect leaf resonance; a sharp local leak near a cut-out indicates an edge or hardware condition; rattle or level dependence can indicate loose internal components; the investigation should distinguish leaf transmission from perimeter leakage before recommending added mass or replacement.

20.66 Leaf size, aspect ratio and oversize doors

Tested performance is conditional upon specimen dimensions. Increasing width or height changes bending modes, seal length, hardware loading and frame deflection; an oversize leaf based on a standard-size test may require additional engineering and project-specific evidence; the door schedule should state maximum tested size, proposed size, leaf thickness, weight and hardware capacity. [25]

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24 MB-0328. ASTM International, ASTM E90-23, ASTM E413-22.
25 MB-0327. ASTM International, ASTM E90-23, ASTM E413-22.

A larger leaf also increases closing moment and pressure force; users may not pull it fully into latch; automatic operators can solve one problem while creating another if they do not achieve final compression; the operational test should include representative users and pressure states.

Integrated worked example 20.33. Pressure force on an oversize leaf

A door is 1.2 m wide by 2.4 m high and experiences 18 Pa pressure difference; the net force is F = delta-p A = 18(1.2)(2.4) = 51.8 N, acting near the leaf centroid for a uniform pressure screen. About the hinge line, the approximate moment is 51.8(0.6) = 31.1 N m before seal friction, closer resistance and latch geometry are considered; the calculation uses pascals and square metres, producing newtons; it demonstrates why pressure can affect final closure; it does not predict user force or acoustic performance without the complete hardware system.

20.67 Frame stiffness, anchorage and wall interaction

The frame transfers leaf weight, latch force and closer reaction into the wall; thin or poorly anchored frames can twist, opening the seal at one corner; grout filling may improve local stiffness and mass but can leave voids, crack at anchors or form a rigid structure-borne path. The tested door assembly and field wall interface should be considered together.

Frame anchors, shims and perimeter seal should be inspected before trim. A visible bead on the room side does not prove closure through the full depth; in masonry, the frame may intersect hollow cells or irregular grout; in gypsum walls, reinforcing and stud alignment affect movement; a frame survey records diagonal dimensions, jamb plumb, head level and stop geometry before the leaf is hung. [26]

20.68 Hinges, pivots and sag under service cycles

Leaf sag changes head, jamb and threshold gaps; hinge wear, fastener loosening and frame movement accumulate with cycles. Continuous hinges distribute load differently from butt hinges; pivots can carry heavy leaves but require accurate geometry and floor coordination; self-closing hinges and closers impose additional forces; BHMA standards describe hardware performance classes, but the selected grade must be coordinated with actual leaf mass, frequency of use and security function. [27]

Commissioning establishes a geometry baseline. Hinge knuckle position, fastener torque where specified, clearances and latch engagement are recorded; maintenance thresholds can be based on gap change or measured sag rather than waiting for audible leakage.

20.69 Latches, multipoint systems and seal compression

A latch does more than secure the opening; it draws the leaf into seals and holds compression against pressure and closer rebound. A single latch can permit bowing on tall leaves; multipoint systems distribute force but increase adjustment complexity; electrified locks and strikes must achieve the same mechanical engagement in every authorised mode; access-control release should not leave the leaf resting against the stop without latch preload. [28]

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26 MB-0302. ASTM International, ASTM E557-12, ANSI/SDI A250.8-2023.
27 MB-0375. Builders Hardware Manufacturers Association, ANSI/BHMA A156.4-2024, ANSI/BHMA A156.17-2025.
28 MB-0374. Builders Hardware Manufacturers Association, ANSI/BHMA A156.25-2023, ANSI/BHMA A156.31-2024.

The required compression should come from seal and hardware data, not from arbitrary over-tightening; excessive latch force can increase user effort, damage seals and prevent emergency operation; the commissioning record identifies final contact and operating forces.

20.70 Perimeter gasketing as a continuous contact system

Gasketing performance depends upon material, profile, compression, corner treatment and substrate straightness. Small discontinuities at mitres, strike plates or hinge reinforcements can dominate upper-band leakage; the contact map should be measured around the entire perimeter under the relevant latch and pressure state; ANSI/BHMA A156.22 provides the hardware framework, while the acoustic acceptance remains tied to the tested assembly and field method. [29]

Seal replacement should preserve profile and compression; a visually similar substitute can change stiffness or recovery; spare parts should be controlled by part number and material, with approved alternatives documented before an emergency replacement is needed.

20.71 Automatic door bottoms and drop timing

An automatic bottom typically deploys when a plunger contacts the frame; timing, drop, parallelism and floor flatness determine contact; if the seal drops too early, it drags and wears; if too late, the latch can close before full contact. Uneven floors produce corner leaks. The threshold and bottom should be treated as one subsystem.

Adjustment should be recorded by plunger setting, drop and contact survey; cleaning regimes should avoid damaging soft seals; replacement flooring or

29 MB-0373. Builders Hardware Manufacturers Association, ANSI/BHMA A156.22-2026.

carpet can change the required drop and friction; a door that passed before a floor renovation requires reinspection.

Integrated worked example 20.34. Bottom-seal contact tolerance

A 1,000 mm wide door bottom has a measured floor variation of 3.0 mm from one end to the other; the seal can accommodate 4.0 mm compression range before excessive force; allowing 1.5 mm installation and wear uncertainty leaves only 2.5 mm reliable accommodation, less than the measured variation. The detail therefore needs a level threshold, a more compliant profile or a different mechanism; the arithmetic is a geometric tolerance screen. It does not establish insertion loss.

20.72 Thresholds, accessibility and water management

Thresholds must coordinate acoustic closure with accessibility, egress, cleaning, water and flooring transitions. A high stop can improve contact but create a trip or wheelchair barrier; a flush threshold may require a precise drop seal and level substrate; exterior or wet conditions add drainage and corrosion requirements; ANSI/BHMA A156.21 and applicable accessibility provisions govern hardware and geometry, while the project must still demonstrate acoustic contact. [30]

A threshold should not bridge a floating floor or seismic joint unless the transfer is designed; isolated plates or flexible covers can preserve movement; the final detail must survive carts, chairs and maintenance without bending into a leak.

30 MB-0371. Builders Hardware Manufacturers Association, ANSI/BHMA A156.21-2025.

20.73 Door pairs, coordinators and meeting-stile logic

Pairs create a vertical meeting joint, two bottoms, two leaves and an interaction between active and inactive hardware; astragals may overlap, split or incorporate seals; coordinators control closing sequence where required; flush bolts and strikes introduce cut-outs. One leaf left unlatched can defeat the pair.

Commissioning should test both normal and abnormal sequences, including access-control modes and emergency release; the operational procedure should be simple enough for occupants to follow; where the threat does not require a wide opening, a single leaf may be more reliable than an elaborate pair.

20.74 Vision panels and retained glazing

A vision panel introduces glass, beads, gaskets and a cut-out in the leaf; the tested construction must match pane type, thickness, area, bead, seal and fire listing; larger panels can lower leaf stiffness and add coincidence behaviour. Retaining systems must resist operational and security loads without loosening.

Field inspection checks gasket continuity, bead fasteners and rattles; a replacement pane of nominally equal thickness may have different laminate or density; the door record should control the complete panel assembly.

20.75 Acoustic sound locks as two-door systems

A sound lock is not simply two doors in series; its performance depends upon each door, vestibule absorption, wall and ceiling paths, spacing, pressure and the probability that both leaves are open; hard vestibule finishes can store and redistribute sound. Services and access-control equipment can bypass one or both boundaries.

The design should define sequence and occupancy; interlocks can reduce simultaneous opening but must comply with life safety and operational requirements; storage in the vestibule can damage seals or alter absorption; commissioning includes separate-door tests, two-door system tests and operational observation.

Integrated worked example 20.35. Two-door system with a vestibule flank

Door A provides 36 dB insertion loss and Door B provides 34 dB under a simplified independent screen; their ideal series sum is 70 dB; a vestibule ceiling flank provides only 46 dB; linear addition gives a combined result close to 46 dB because the flank dominates. The exercise assumes compatible reference conditions and does not model vestibule reverberation. It shows that adding a second door cannot overcome an untreated common path.

20.76 Door pressure, HVAC modes and smoke-control operation

Pressure differential changes user force, seal contact and leakage direction; normal HVAC, night setback, smoke control and emergency exhaust can create different regimes; a door should close and latch under every authorised mode that can coincide with sensitive use. Testing only with plant off can miss the operational condition.

The pressure record should include sign, magnitude, stability and measurement location; if an automatic operator is present, final closing and latch action are verified under each mode; changes to air balancing become lifecycle triggers. [31]

20.77 Field measurement strategy for doors

ASTM E2964 provides a field method based on normalised insertion loss of doors. Its result is not interchangeable with laboratory STC or a whole-room field rating; test planning should control source positions, receiving positions, background, door state and adjacent paths; the method's precision research helps bound interpretation, while project decision rules should be established before testing. [32]

Local scans support diagnosis but should not be substituted for the defined field metric; a near-seal microphone can identify a leak while exaggerating its room-level significance; conversely, a room-average result can conceal a concentrated path important to an accessible listener. Both scales may be needed.

20.78 Door remediation hierarchy

Remediation should proceed from geometry and contact to component replacement; the sequence usually includes cleaning, fastener and hinge inspection, frame survey, latch adjustment, closer adjustment, seal contact mapping, bottom adjustment and local leakage testing; added mass is considered only after leaf transmission has been shown to govern. Replacing seals without correcting sag can provide only temporary improvement.

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31 MB-1035. National Fire Protection Association, ANSI/BHMA A156.4-2024.
32 MB-0273. ASTM International, ASTM E336-25a, ASTM E2964-26.

Every intervention is recorded so that cause and effect remain visible. Adjustments are reversible where practicable. Fire labels, listings and security certifications are preserved.

20.79 Door lifecycle baseline and maintenance intervals

A lifecycle baseline includes gap measurements, seal profile, contact map, operating force, closing time, latch engagement, pressure state and acoustic result; inspection frequency follows cycle rate, consequence and observed drift; high-use doors may need frequent geometry checks even if full acoustic testing is less frequent.

Maintenance records should distinguish cleaning, adjustment, part replacement and structural repair; a repeated need for adjustment can indicate frame movement or undersized hardware; the trend is more informative than one isolated failure.

20.80 Chapter synthesis. The door as a maintained boundary

An acoustic door is an operable mechanical system whose weakest state can arise from leaf vibration, frame movement, seal discontinuity, hardware wear, pressure or user behaviour; laboratory evidence, field insertion loss, whole-room performance, occupied speech security and formal approval remain distinct propositions. Reliable use requires exact configuration, commissioning and lifecycle maintenance; a heavy leaf alone is not a secure opening.

20.81 Automatic operators and powered closing systems

Powered operators can improve accessibility and consistent movement, but they add sensors, controls, power transfer and failure modes; the operator must bring the leaf through the latch and seal-compression stage under the relevant pressure differential; a system that merely moves the leaf to the stop can leave an acoustically significant gap. Emergency release, fire alarm and access-control modes should be tested as configured. [33]

The commissioning record includes opening time, closing time, final approach speed, latch engagement, contact map and force-limiting behaviour; battery or standby modes are included where the room may remain in use; changes to software parameters are configuration-controlled.

20.82 Magnetic locks, electric strikes and cable paths

Electrified hardware can alter frame and leaf preparation; electric strikes require cut-outs and wiring cavities; magnetic locks can apply holding force without drawing the leaf into compression; power-transfer loops or concealed hinges create penetrations. The acoustic design should identify where air closure is maintained around each device.

Security performance and acoustic closure must be coordinated; a device selected for access control may need complementary mechanical latching to maintain seals; wiring routes should not connect frame cavities to wall or ceiling plenums. [34]

20.83 Door monitoring sensors and evidence quality

Position switches can confirm that a leaf is near the closed position, but they may not confirm latch engagement or seal compression; additional monitoring can include latch status, operator fault, interlock state and door-open duration; the data can support lifecycle management if sensor calibration and event semantics are documented.

33 MB-0377. Builders Hardware Manufacturers Association, ANSI/BHMA A156.4-2024, ANSI/BHMA A156.25-2023.
34 MB-0374. Builders Hardware Manufacturers Association, ANSI/BHMA A156.25-2023, ANSI/BHMA A156.31-2024.

A green access-control indication should not be treated as acoustic evidence; commissioning should correlate sensor states with physical measurements; after adjustment, the relationship is rechecked.

20.84 Fire-door inspection and acoustic maintenance

Fire doors require inspection and maintenance under the applicable fire-door standard and building code; acoustic adjustments must not remove labels, alter clearances outside permitted limits or substitute unlisted components where a listing applies; conversely, passing a fire-door inspection does not prove acoustic performance; the two obligations overlap at geometry, hardware and seals but retain distinct acceptance criteria. [35]

A combined inspection form can avoid contradictory work. It records fire, smoke, egress, accessibility, security and acoustic findings separately, then identifies coordinated corrective action.

20.85 Sound-lock geometry, absorption and simultaneous-opening risk

Vestibule length and absorption influence the sound field between doors; a very small hard vestibule can retain high levels and make the second door more important; absorptive treatment should be durable, fire-compatible and protected from damage; it must not obstruct sensors, closers or access.

Simultaneous opening can be assessed as an operational probability rather than ignored; traffic volume, meeting procedures and interlock logic determine exposure; where life-safety rules prohibit locking both doors, procedural control and adjoining-space management may be required.

35 MB-1036. National Fire Protection Association, NFPA 80, Standard for Fire Doors and Other Opening Protectives.

Integrated worked example 20.36. Simultaneous-opening exposure fraction

A sound lock experiences 120 passages during a workday; observation shows that both doors are simultaneously open for an average of 1.8 seconds on 15 passages; total simultaneous-open time is 27 seconds; over a ten-hour day, the time fraction is 27/36,000 = 7.5 x 10^-4, or 0.075 per cent. The fraction appears small, but exposure consequence depends on whether sensitive speech occurs during those intervals and whether an observer has recording capability. The calculation is an operational screen, not an acoustic rating.

20.86 Door-system fault trees

A fault tree can separate failure to close, failure to latch, failure to compress seals, leaf transmission, frame leakage, threshold leakage and sound-lock bypass. Each branch has observable tests. This prevents the common response of replacing seals whenever a door performs poorly.

The tree should include interacting causes. Frame movement can cause both latch and seal failures; pressure can prevent closure and increase leakage; a floor alteration can change the automatic bottom and accessibility; corrective action follows the supported branch and is verified after repair.

20.87 Environmental ageing of seals and finishes

Elastomer properties change with temperature, ultraviolet exposure, cleaning chemicals, compression and time; surface coatings can increase friction or contaminate contact; dust and fibres can hold a seal away from the stop; maintenance instructions should therefore identify approved cleaners and inspection intervals.

Accelerated product tests may inform selection but do not reproduce every field condition; the lifecycle baseline and periodic contact map reveal installed drift; a seal can remain visually intact while losing recovery.

20.88 Temporary acoustic controls during door repair

When a critical door is removed or cannot latch, the room may need to leave sensitive service; temporary barriers, guards or operational restrictions can reduce risk during repair, but they are not assumed equivalent to the accredited condition. The decision should identify duration, adjoining access and prohibited activities.

Repair work also creates opportunities for inspection of frame cavities, anchors and wiring; findings are recorded before the opening is closed; temporary controls are removed and final testing completed before unrestricted use resumes.

20.89 Integrated failure case. Door passes local scan but fails room test

A door shows continuous seal contact under a local high-frequency scan, yet the room-level field result remains weak at 250 Hz; vibration measurements reveal that the heavy steel frame is rigidly connected to a continuous structural column and radiates through the receiving-side wall. Adding seal compression produces no meaningful gain.

The remedy uses receiver-side isolation at the column return and a controlled flexible frame-perimeter detail compatible with structural and fire requirements; the room-level band improves while local seal results remain unchanged; the case demonstrates why local leakage tests and whole-room measurements answer different questions.

20.90 Door final acceptance dossier and residual-risk statement

The dossier includes product and laboratory evidence, leaf and frame identity, hardware schedule, fire and accessibility status, installation photographs, geometry, seal contact, pressure states, field results, uncertainty, adjustments and maintenance requirements; it records parts that may be replaced only with approved equivalents.

The final statement distinguishes door insertion loss, room-level isolation, occupied speech performance and formal approval; residual risks, such as simultaneous sound-lock opening or pressure changes, are assigned operational controls and retest triggers; this evidence structure allows the door to remain a maintained boundary rather than a one-time procurement item.

20.91 Gap sensitivity and the leverage of small perimeter defects

A door leaf and frame may have substantial mass, yet a narrow open gap can dominate transmission; gap width, length, tortuosity and local seals determine impedance; the highest-frequency effect is often greatest, but a long threshold gap can also support lower-frequency duct behaviour. A gap survey should record the complete perimeter rather than one average clearance.

Integrated worked example 20.37. Area-weighted effect of a threshold gap

A door leaf area is 2.1 m^2 and its solid construction screens at 42 dB in a selected band; a 900 mm wide threshold gap has effective height 1.0 mm, so open area is 0.0009 m^2. The solid transmission coefficient is 10^-4.2 = 6.31 x

10^-5; treating the gap conservatively as open, combined coefficient is [(2.1 - 0.0009)(6.31 x 10^-5) + 0.0009]/2.1 = 4.91 x 10^-4, corresponding to 33.1 dB. The gap occupies only 0.043 per cent of area but reduces the screen by nearly 9 dB; real gap impedance is frequency-dependent; the example shows why threshold contact deserves measurement.

20.92 Hardware interoperability and controlled substitutions

Hinges, closers, latches, operators, access-control devices and seals interact; replacing one component with a nominal equivalent can change geometry, closing force or compression; a new electric strike may not pull the leaf to the same position; a closer with different arm geometry can leave insufficient final moment under pressure.

The hardware schedule should identify tested or approved combinations and acceptable substitutions; field changes require review against fire, accessibility, security and acoustic functions; the procurement record should retain exact model and adjustment information. [36]

20.93 Commissioning with representative users and operating states

A door can close reliably for a technician who deliberately pulls it into latch yet fail during ordinary use; commissioning should include representative users, traffic direction, pressure states and access-control sequences; measurements of operating force and closing time support accessibility and reliability decisions.

The test should include normal, night, emergency and power-loss states where relevant; door pairs and sound locks are observed as systems; user

36 MB-1034. National Fire Protection Association, ANSI/BHMA A156.4-2024, ANSI/BHMA A156.17-2025.

behaviour is documented without converting one short observation into a universal claim.

20.94 Reacceptance after maintenance and renovation

Reacceptance scope should match the change. Replacing a seal with the approved part may require geometry and contact verification; rehanging a leaf, replacing a frame, changing flooring, modifying access control or rebalancing HVAC can justify field acoustic testing; the change record should state what was altered and why the selected tests are sufficient.

Maintenance should not reset the evidence history; earlier baselines remain available so that drift can be distinguished from one repair; a room returns to sensitive use only after the required engineering, fire, accessibility and authority reviews are complete.

20.95 Door-system design and review checklist

The final review identifies leaf construction and size, frame, anchorage, perimeter seal, bottom, threshold, hinges, closer, latch, access control, vision panel, pressure regime, fire and smoke status, accessibility, sound-lock sequence, test method, uncertainty and lifecycle parts; every item points to a drawing, submittal, inspection or test record.

The checklist's purpose is not administrative bulk; it prevents the opening from being reduced to a catalogue STC; the door remains an operable boundary whose geometry, force and configuration must be controlled throughout its life.

Table 20-R1. Door subsystem, failure signature, commissioning control and lifecycle trigger.

Subsystem	Failure signature	Commissioning control	Lifecycle trigger
Perimeter seal	Local upper-band hot spot	Contact map and pressure-state scan	Tear, compression set or frame movement
Automatic bottom	Leak concentrated at one corner or threshold joint	Full-width contact and cycle test	Floor change, debris or plunger drift
Hinges and pivots	Progressive gap and latch misalignment	Geometry, torque and sag survey	Cycle accumulation or loose fasteners
Frame perimeter	Broad jamb or head leakage	Pre-trim inspection and local pressure test	Wall movement or hardware modification
Sound lock	Performance loss when both doors operate	Sequence, absorption and operational test	Interlock change or storage in vestibule

20.96 Door-system technical schedules

These schedules convert the preceding door-system analysis into a controlled chain of identity, construction, operation and proof. Table 20-1 identifies the physical components that must remain traceable. Table 20-2 states what each evidence class establishes and, equally importantly, what it cannot establish. Table 20-3 governs the chronological order of delivery. Table 20-4 addresses the additional variables created when two doors operate as a sound lock. The schedules must be read together, because a complete submittal does not excuse defective installation, a careful installation does not excuse poor adjustment, and a favourable acoustic test does not retrospectively prove concealed work that was never observed.

Table 20-1. Door component and failure signature

Component	Primary function	Characteristic acoustic failure	Diagnostic evidence
Leaf	Mass, stiffness, security and fire separation	Panel resonance, core debonding, hardware pocket or warp	Exact test report, flatness survey, modal response and local scan

Component	Primary function	Characteristic acoustic failure	Diagnostic evidence
Frame	Supports leaf and defines seal plane	Twist, unfilled perimeter, anchor cavity or deformation	Plumb and square survey, anchor record, perimeter opening and scan
Hinges or pivots	Carry load and preserve geometry	Sag, wear, loose fasteners or changed tested configuration	Gap map, hardware identification, cycle history and adjustment record
Latch and strike	Draw leaf into compression seals	Incomplete engagement, uneven compression or excessive force	Latch force, contact map, strike position and repeated closure test
Head and jamb gasket	Continuous perimeter closure	Corner gap, under-compression, contamination or compression set	Visual contact, paper or feeler test, profile and local acoustic scan
Automatic bottom	Deployable floor closure	Short length, uneven threshold contact, drag or timing error	Contact imprint, deployment measurement, cycle test and bottom scan
Threshold	Stable bottom sealing surface and transition	Rocking, low spot, loose anchor or isolation bridge	Flatness survey, bedding inspection, anchor and accessibility review
Vision panel	Observation and fire or security function	Weak pane, loose stop, gasket leak or substitution	Pane and stop identity, test configuration and perimeter scan

The component schedule is deliberately physical. A doorset is not the leaf alone; it is the coupled system formed by the opening, frame, anchors, leaf, hardware, seals, threshold, glazing, controls, pressure regime and adjoining construction; failure can emerge as an air path, a vibrating panel, a distorted seal plane, incomplete latching, a rigid bridge or an operating state that prevents repeatable closure. Each component therefore requires stable identity and a stated diagnostic method.

Table 20-2. Performance evidence and its boundary

Evidence	Establishes	Does not establish
ASTM E90 laboratory report	Transmission-loss spectrum of the exact operable specimen in a laboratory opening	Field installation, room flanking, speech security or formal approval
ASTM E413 STC	Reference-contour classification of the laboratory spectrum	Performance below the rating range or local field defects
ASTM E2964 NDIL or DTC	Installed door insertion-loss spectrum and field class under the test setup	Whole-room isolation where other paths dominate
ASTM E336 or ISO 16283-1 room test	Configured room-to-room attenuation including door and flanking	Door contribution without additional discrimination
Local leakage scan	Spatial, frequency-specific indication of weak perimeter regions	A standardised class or complete room result
Light, paper or feeler test	Gross contact and compression continuity	Acoustic performance at all frequencies
Fire-door inspection	Compliance of the listed opening protective with applicable installation and maintenance criteria	Acoustic rating unless separately tested
Occupied speech assessment	Audibility or intelligibility under defined source and listener conditions	Formal governmental accreditation

The evidence schedule prevents category error; laboratory evidence supports the tested specimen; field door evidence supports the installed doorset within the method; room-pair evidence includes the door and other paths; local scans identify regions for diagnosis; functional or visual checks support geometry and contact; fire-door inspection addresses mandatory life-safety duties. Occupied speech assessment addresses a defined source, listener and operating state; none of these propositions silently becomes another.

20.96.1 Governing chronological sequence

The governing sequence is Submittal, Rough opening, Frame installation, Leaf hanging, Seal adjustment, and Operational and acceptance testing; this order is mandatory because each stage creates the reference state for the next; fire, smoke, egress, accessibility, security, electrical and acoustic duties remain parallel obligations at every stage. They are not postponed to a separate late review after the hardware and seals have been adjusted.

Table 20-3. Commissioning sequence and acceptance record

Sequence	Inspection or test	Acceptance question	Required record
Submittal	Exact laboratory report; leaf, frame, hardware, seal, threshold and vision-panel schedules; access-control interfaces; fire and accessibility data; proposed substitutions.	Does the proposed complete doorset, including every acoustic, security, fire, egress and accessibility interface, match the required and tested configuration?	Reviewed report, component schedule, deviation and substitution matrix, delegated-design evidence and signed approvals.
Rough opening	Survey dimensions, plumb and square, wall construction, backing, structural support, floor elevation, threshold recess, service routes and movement joints.	Can the approved frame and threshold be installed without distortion, unsealed cavities, conflicts, loss of required clearance or later rework?	Dimensioned survey, wall and floor interface photographs, backing and anchor verification, and nonconformance closure.
Frame installation	Anchors, welds or fasteners, grout or backing, frame alignment, perimeter air-seal plane, fire and smoke interface, cable transfer and access-control preparation.	Is frame geometry stable, continuously supported and sealed, while preserving listed, egress, accessibility, security and movement duties?	Concealed-work checklist, anchor and fill record, perimeter photographs, geometry map, material identifiers and hold-point release.

Sequence	Inspection or test	Acceptance question	Required record
Leaf hanging	Hinges or pivots, leaf identity, flatness, clearances, vision-panel and hardware installation, closer, latch and strike, and cable transfer.	Does the correct leaf move through its full cycle without binding, sag or interference, and preserve the design gap and hardware configuration?	Leaf and serial record, gap grid, plumb and warp survey, torque and fastener record, cycle observations and operating-force observations.
Seal adjustment	Head and jamb gasket, automatic bottom, threshold contact, latch pull, closer speed, pressure effects, final floor finish, access-control and power states.	Is contact continuous and repeatable in every authorised operating state without excessive force, drag, incomplete latching, fire or egress conflict, or accessibility failure?	Contact map, deployment and threshold profile, latch and closer settings, force measurements, pressure state, cycle test and final adjustment record.
Operational and acceptance testing	Functional door cycles; normal, night, HVAC, pressure, access-control, emergency and power-loss states; local leakage scan; ASTM E2964 or room test as specified; uncertainty and decision rule.	Does the completed and adjusted doorset meet the predeclared functional, life-safety, accessibility, security and acoustic requirements in the exact as-tested state?	Witnessed functional report, raw acoustic data, calibration, uncertainty, operating-state matrix, deviations, authority disposition and accepted configuration identifier.

20.96.2 Hold points and the prohibition against backward inference

The sequence establishes five hold points before final acceptance; procurement or fabrication should not proceed on an unresolved submittal; frame installation should not begin until the rough opening, backing, floor line and service interfaces are accepted; concealed frame anchors, fill and perimeter closure should not be covered before inspection. Seal adjustment should not be accepted until the final leaf, hardware, threshold, floor finish, access-control logic and representative pressure state are present. Operational and acoustic acceptance should not begin until the earlier records are closed or their limitations are formally carried into the decision; a later favourable test can demonstrate performance in the as-tested state, but it cannot prove the correctness of unobserved anchors, hidden fill, proprietary substitutions or other concealed details. When a material change is introduced, the process returns to the earliest stage affected by that change.

20.96.3 Lifecycle baseline after acceptance

Lifecycle baselining follows acceptance. It is not a seventh installation stage and it must not be used to blur incomplete construction evidence into a maintenance record; the baseline captures the accepted leaf, frame, seals, threshold, hardware, controller, pressure state, settings, photographs, test identifiers, spares, inspection interval, cycle history where available, maintenance restrictions and retest triggers. Alteration of flooring, hinges, closer, latch, access control, power transfer, frame anchorage, wall finishes, pressure, fire function, seals or leaf construction reopens the applicable stage; the retained record should allow a future engineer to determine what changed, which earlier evidence remains valid, and what must be re-inspected or retested.

20.96.4 Sound-lock integration

A sound lock adds a second movable boundary and a coupled vestibule. Its performance is governed not only by the ratings of the two doors, but also by separation, absorption, offset, sequence, pressure relief, threshold transitions and authorised failure states. The variables in Table 20-4 therefore remain subordinate to the same six-stage sequence. Each leaf and frame passes through its own submittal and construction records, while the pair is finally tested as one operational system.

Table 20-4. Sound-lock design variables

Variable	Beneficial direction	Constraint	Verification
Door separation	Greater separation generally reduces direct coupling	Space, circulation and egress	Dimensioned plan and system field test
Vestibule absorption	Greater broad-band absorption reduces reverberant build-up	Fire, durability, cleanability and security	Absorption specification and decay measurement
Door offset	Removes direct line of sight and changes incidence	Accessibility, manoeuvring and occupant flow	Plan review and operational trial
Door ratings	Balanced performance avoids one dominant leaf	Weight, hardware, fire and cost	Exact reports and installed tests
Sequencing	One door closed before the other improves system state	Emergency egress and user behaviour	Access-control logic and fail-safe test
Pressure relief	Silenced equalisation prevents closure resistance	Duct space, airflow noise and security	Mechanical calculation and acoustic insertion-loss evidence
Threshold transitions	Continuous seals at both doors	Accessibility and floor isolation	Full-scale mock-up and contact survey

These schedules place the doorset in its proper evidentiary order. Proposed configuration precedes physical preparation. Physical preparation precedes installation. Installation precedes adjustment. Adjustment precedes operational and acoustic acceptance. Acceptance precedes lifecycle baselining. No later stage erases an unresolved discrepancy in an earlier one.

20.97 Conclusions

An acoustic door is a maintained mechanical system; its performance depends on the complete tested and installed configuration, alignment, compression, threshold geometry, operational force and surrounding wall; fire, smoke, egress, accessibility, security and acoustic requirements must be coordinated rather than traded informally.

Laboratory STC, field DTC or NDIL, whole-room attenuation, occupied speech security and formal approval remain separate propositions. Commissioning and lifecycle inspection are indispensable because the opening changes every time it moves.

Chapter 20 Glossary

Automatic door bottom. Mechanism that deploys a sealing element against the threshold as the door closes.

Door transmission class. Single-number field rating derived from normalised door insertion loss under ASTM E2964.

Meeting stile. Vertical interface between leaves of a paired door assembly.

Normalised door insertion loss. Frequency-dependent field measure comparing door-open and door-closed states with correction for source-side level change.

Primary perimeter seal. Designated continuous seal between frame and wall or leaf and frame responsible for acoustic closure.

Sound lock. Vestibule with two door boundaries arranged to reduce direct sound transmission and control access.

Threshold. Component at the floor line providing transition, protection and a contact surface for bottom sealing.

Cam-lift hinge. Specialised hinge mechanism that raises the leaf during opening and lowers it onto seals during closing.

Compression set. Permanent loss of elastomer recovery after sustained compression.

Door pressure regime. Defined differential-pressure state under which the door must close, latch and maintain contact.

Leaf mode. Natural bending or torsional vibration pattern of a door leaf.

Power transfer. Hardware that carries electrical conductors from frame to leaf while accommodating door motion.

Seal contact map. Documented spatial record of perimeter seal contact, compression or leakage around a door.

Chapter 21. Glazing, Vision Panels, Frames, Façades, and Secondary Glazing

21.1 Glazing is a framed dynamic system, not a transparent mass

A glazed opening is often scheduled by nominal pane thickness and a single laboratory rating. That description is inadequate for acoustic-security engineering; the transparent field acts as a bending plate whose response depends on surface mass, elastic modulus, Poisson ratio, residual stress, dimensions, support, damping, temperature and incident angle; the frame contributes cavities, thin webs, thermal breaks, gaskets, pressure plates, fasteners and anchors. Perimeter joints connect the assembly to the wall, slab, door leaf or façade. Drainage and pressure-equalisation paths can conduct sound; the total result belongs to the complete tested or measured configuration, not to glass as a generic commodity.[37]

The same glass make-up can perform differently when pane area, aspect ratio or support changes; a small laboratory specimen can have higher modal frequencies and shorter seal length than a full-height field panel; a laboratory mounting may be more massive and more airtight than the project frame. A vision lite set into an acoustic door changes the leaf mass distribution and introduces stops, beads and gaskets; a curtain wall can flank around a room partition through mullion cavities, transoms, spandrels and slab-edge closures. These variations define the path rather than merely decorating it.

37 MB-0413. Carl Hopkins, Sound Insulation.

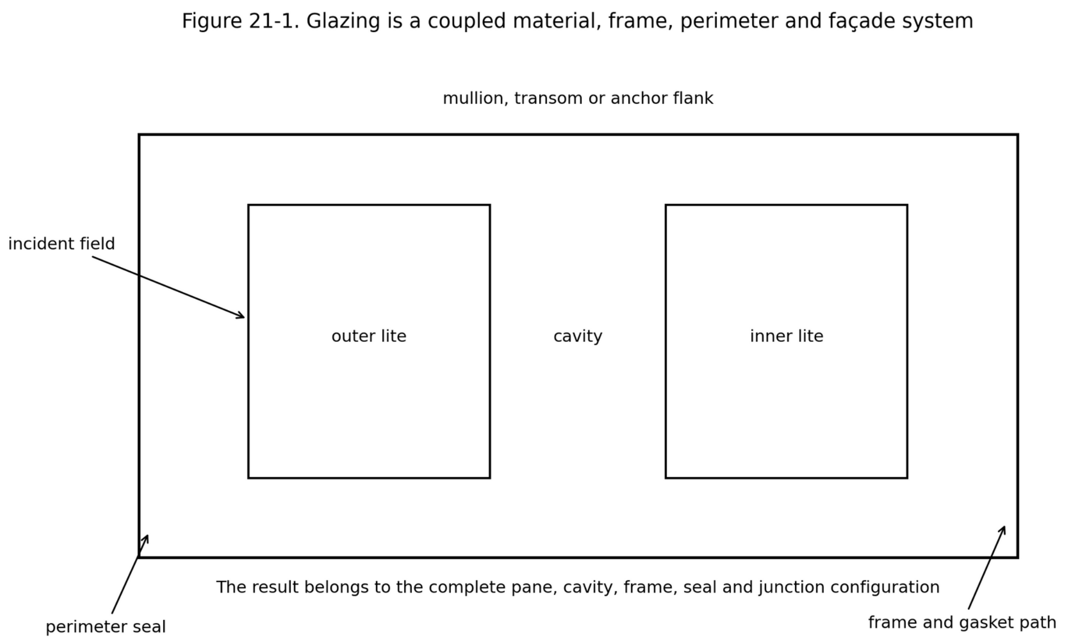

Figure 21-1. Glazing is a coupled material, frame, perimeter and façade system. Author's original diagram.

21.2 Evidence classes and bounded conclusions

The evidence record should separate product identity, laboratory specimen configuration, field installation and occupied-room performance; product standards can establish glass type, heat treatment, laminate construction, insulating-glass durability or structural load resistance; acoustic standards can establish transmission loss or façade attenuation under stated conditions. Field inspection can establish visible construction and seal condition; none of those records, standing alone, establishes that protected speech is unintelligible outside the room or that an authority has accepted the space for classified use.

Table 21-1. Evidence classes and the bounded propositions they support

Evidence class	**Principal question answered**	**Material limitation**	**Minimum record**
Glass product specification	What glass type, quality and treatment was supplied?	Does not establish acoustic performance of the installed opening	Manufacturer, standard, nominal and measured thickness, heat treatment, laminate or coating identity
Complete laboratory acoustic test	How did the tested pane, frame, seal and mounting perform in the laboratory?	Belongs only to the specimen and method	Full report, dimensions, mounting, one-third-octave data, background limits and rating calculation
Field façade or element test	How did the installed opening perform under defined source geometry and room conditions?	Includes field geometry and may include flanking	Source position, incidence, outdoor and indoor positions, room state, uncertainty and photographs
Occupied speech-security assessment	Can defined speech content be recovered at accessible receiving locations?	Does not itself confer accreditation	Source state, listener assumptions, background, masking, repeated access, results and limitations
Authority decision	Has the competent authority accepted the room for a defined use?	Does not transform the underlying test data	Decision record, scope, date, conditions, exceptions and change-control triggers

The proof chain is cumulative. A product certificate cannot establish perimeter workmanship; a laboratory test cannot establish a curtain-wall flank; a field sound-insulation result cannot establish listener capability under every operational condition; an occupied speech test cannot establish structural adequacy, fire compliance or security glazing performance. Each proposition must retain its own source, scope and uncertainty.

21.3 Glass material properties and plate response

Architectural soda-lime silicate glass is stiff, dense and comparatively lightly damped. For a homogeneous isotropic pane, flexural rigidity is approximated by

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

where D is flexural rigidity in newton metres, E is Young's modulus in pascals, h is pane thickness in metres and ν is Poisson ratio. Thickness enters as the cube, so a modest increase changes bending stiffness much more rapidly than surface mass. The pane therefore does not behave as a limp barrier merely because its density is high. Stiffness, finite dimensions and edge conditions shape modal behaviour below coincidence, while radiation efficiency and damping govern the response around and above coincidence.[38]

The plate model is a controlled abstraction; real glass can have residual stress, coatings, laminate interlayers, edge damage, holes, notches and non-uniform support; a curtain-wall pane may be supported continuously by gaskets, locally by setting blocks and laterally by pressure plates or structural silicone. The acoustic model should identify which conditions are represented and which remain uncertain.

Worked example 21.1. Surface mass of a monolithic pane

Engineering question. What is the preliminary surface mass of a 10 mm glass pane?

Take glass density $\rho_g = 2,500\, kg/m^3$ and thickness $h = 0.010\, m$. Surface mass is

$$m' = \rho_g h = (2,500)(0.010) = 25.0\, kg/m^2.$$

The units reduce from kilograms per cubic metre multiplied by metres to kilograms per square metre. A density uncertainty of 1 per cent and thickness tolerance of 2 per cent produce an approximate relative standard

38 MB-0973. John L. Davy, "Predicting the Sound Insulation of Single Leaf Walls: Extension of Cremer's Model".

uncertainty near 2.2 per cent when treated as independent. The result supports a mass balance and preliminary prediction, but it does not include frame, seal, edge support, coincidence or flanking and therefore does not establish a laboratory rating or speech-security condition.

21.4 Bending stiffness, thickness and finite dimensions

Because D varies with h^3, doubling pane thickness increases ideal flexural rigidity by a factor of eight while doubling surface mass only by a factor of two. The resulting plate is harder to bend at low frequency, but its critical frequency moves because the ratio of mass to stiffness changes. Thick glass is not acoustically equivalent to two thin plies having the same total glass thickness if the plies are separated by an interlayer or cavity. Coupling changes the effective bending stiffness, damping and modal density.

Finite dimensions create discrete modes. Aspect ratio controls degeneracy and modal spacing; larger panes place more modes in the low-frequency range and may radiate efficiently over a greater area; a laboratory test opening and a project façade bay should therefore be compared geometrically, not merely by glass make-up. Where a project pane is materially larger, model uncertainty and the need for a representative mock-up increase.

Worked example 21.2. Flexural-rigidity ratio

For the same glass, compare 6 mm and 10 mm panes. With all other terms equal,

$$\frac{D_{10}}{D_6} = \left(\frac{10}{6}\right)^3 = 4.63.$$

The 10 mm pane is about 4.6 times stiffer in bending, while its surface mass ratio is only $10/6=1.67$. Thickness tolerance, edge support and residual stress are omitted. The calculation explains why a thickness change can shift modal and coincidence behaviour rather than simply adding a uniform number of decibels.

21.5 Critical frequency and coincidence

Coincidence occurs when the trace wavelength of incident airborne sound matches a bending wavelength in the pane. Coupling increases, radiation efficiency rises and transmission loss can fall below an ideal mass-law trend. For an ideal thin isotropic plate, a useful screening expression is

$$f_c=\frac{c_0^2}{2\pi}\sqrt{\frac{m'}{D}},$$

where f_c is critical frequency in hertz, c_0 is sound speed in air, m' is surface mass and D is flexural rigidity. The equation is sensitive to the assumptions of thin-plate theory, homogeneous material, ideal boundary conditions and diffuse incidence. Finite panes show a transition region rather than a single discontinuity.[39]

39 MB-0435. Davy, ISO 12354-1:2017.

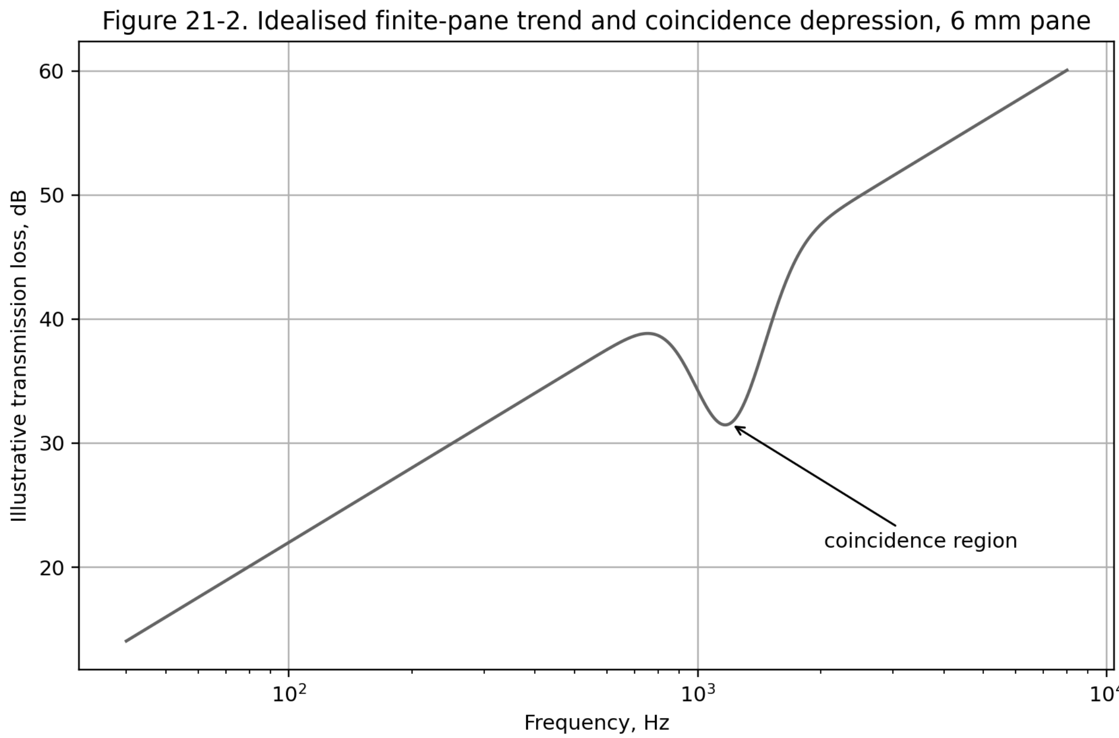

Figure 21-2. Idealised finite-pane trend and coincidence depression. Author's original diagram.

Worked example 21.3. Critical-frequency scaling with thickness

For one material, $m' \propto h$ and $D \propto h^3$. Therefore $f_c \propto 1/h$. If a 6 mm pane has a critical-frequency screening value of 2,000 Hz, a geometrically similar 10 mm pane gives

$$f_{c,10} = 2,000 \frac{6}{10} = 1,200\,Hz.$$

The scaling is dimensionally consistent because the thickness ratio is dimensionless. The estimate identifies the direction and approximate magnitude of the shift. It does not predict the depth of the coincidence dip, which depends on damping, pane dimensions, support and field incidence.

21.6 Mass-law screening and its limits

For a limp infinite barrier under a stated incidence model, transmission loss increases approximately 6 dB for each doubling of surface mass and 6 dB for each doubling of frequency. Glass is neither limp nor infinite, so mass law is a screening tool rather than a final design method. It can compare broad trends away from resonance and coincidence, but it cannot describe finite-pane modes, frame transmission, laminate damping or double-leaf cavity behaviour.

A specification that says only “10 mm acoustic glass” is consequently defective. It omits pane area, heat treatment, laminate identity, cavity, frame, mounting, seal and test report. Product descriptions should be tied to a complete assembly and a frequency-resolved evidence record.

Worked example 21.4. Ideal mass-law difference

Compare 6 mm and 10 mm monolithic panes at a frequency well away from resonant and coincidence effects. Ideal mass-law difference is

$$\Delta R = 20\log_{10}\left(\frac{10}{6}\right) = 4.44\,dB.$$

The result is independent of density because the material is the same; an uncertainty of plus or minus 0.2 mm in each thickness changes the ratio slightly, but model-form uncertainty dominates; the calculation does not justify adding 4.44 dB to every measured band or to a single-number rating.

21.7 Annealed, heat-strengthened and fully tempered glass

Heat treatment changes residual stress, strength, breakage pattern and fabrication constraints. It does not create a universal acoustic benefit. Panes of equal thickness and dimensions have similar surface mass, but residual stress, roller-wave distortion, edge condition and support may alter modes and damping modestly. The principal reasons for specifying heat-strengthened or fully tempered glass usually arise from structural, thermal or human-impact requirements rather than sound insulation.[40]

All cutting, drilling, notching and edgework must be coordinated before tempering; a later field attempt to alter heat-treated glass is not a permissible acoustic adjustment; substitution review must preserve the structural design, safety classification, coatings, heat treatment and acoustic evidence. The engineer should resist the claim that “tempered is more acoustic” unless a complete comparative test supports it.

21.8 Laminated glass as a viscoelastic composite

Laminated glass comprises two or more plies bonded by one or more polymer interlayers. The interlayer transfers shear between plies and dissipates energy. Its effective stiffness and loss depend on frequency, temperature, load duration, interlayer formulation, ply thickness and boundary condition. A laminate can behave closer to a monolithic pane in one regime and closer to partially coupled plies in another. The word “laminated” therefore identifies a construction class, not a sound rating.[41]

40 MB-0109. ASTM International, ASTM C1036-25, ASTM C1048-25.
41 MB-0110. ASTM International, ASTM C1172, ISO 12543-1:2021.

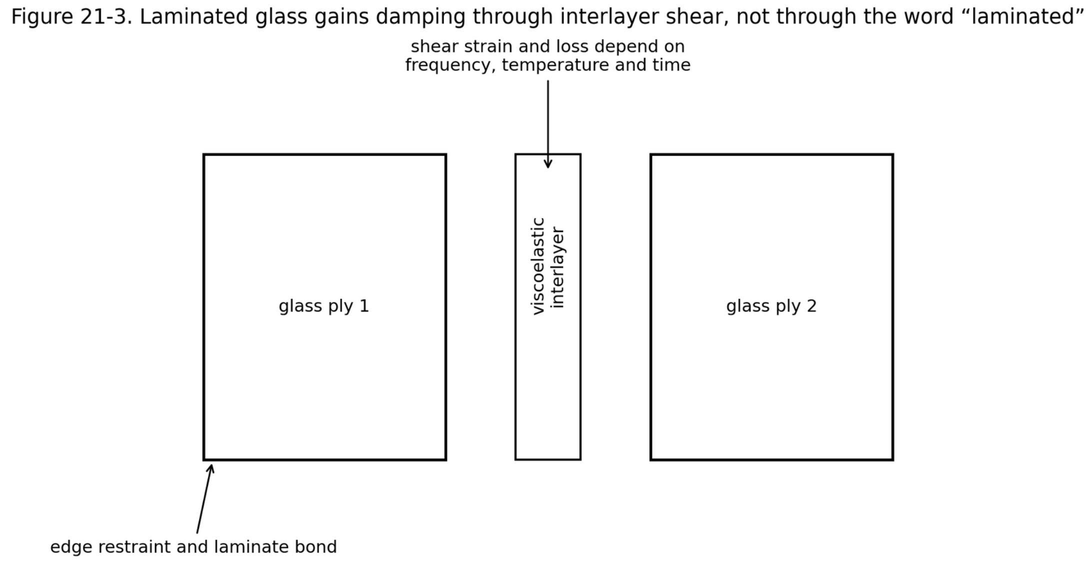

Figure 21-3. Laminated glass gains damping through interlayer shear, not through the word laminated. Author’s original diagram.

Acoustic laminates often use interlayers formulated for higher damping around speech and traffic frequencies; performance claims must identify the exact ply and interlayer make-up and the test temperature; a generic substitute having the same overall thickness may have a different shear modulus and loss factor. Heat, cold and solar exposure can move the viscoelastic operating point.

Worked example 21.5. Laminate surface mass

A laminate contains two 5 mm glass plies and a 0.76 mm interlayer. Take glass density $2{,}500\,kg/m^3$ and polymer density $1{,}070\,kg/m^3$:

$$m' = 2(2{,}500)(0.005) + (1{,}070)(0.00076) = 25.81\,kg/m^2.$$

Only 0.81 kg/m² comes from the interlayer. Its acoustic value can nevertheless be much larger than that mass fraction because damping arises from shear deformation. The calculation is a mass balance only and cannot predict laminate loss factor or transmission loss.

21.9 Temperature, frequency and time dependence of interlayers

Viscoelastic response is not fixed. A warmer interlayer generally softens and can shift the frequency range over which shear damping is effective; a colder interlayer can couple plies more stiffly; time-temperature superposition may be used in material characterisation, but a building pane experiences non-uniform temperature, solar gradients, ageing and edge constraints. Laboratory data obtained at one condition should not be represented as invariant field behaviour.

Durability standards address resistance to temperature, humidity and radiation, while acoustic tests address the complete specimen under the recorded environmental state. These evidence classes should not be conflated. Passing durability tests does not establish sound insulation, and a favourable acoustic test does not establish long-term laminate durability.[42]

Worked example 21.6. Sensitivity of a damping-controlled band

Suppose two tests of the same laminate report 38 dB and 34 dB at 1,600 Hz under materially different pane temperatures; combined repeatability uncertainty is 1.2 dB; the observed difference is 4 dB, or 3.3 times the stated uncertainty. That supports investigation of temperature and state, but it does not prove causation because mounting, source field and specimen history may also differ; a controlled paired test is required.

21.10 Pane asymmetry and separation of weaknesses

Using unequal pane thicknesses can separate coincidence regions and change cavity coupling; the objective is not asymmetry for its own sake; it is

42 MB-0849. International Organization for Standardization, ISO 12543-4:2021, ASTM C1172.

to avoid aligning strong weaknesses while preserving structural, optical and fabrication requirements; the effect must be examined by band, because moving one dip can expose another band or increase frame dominance.

Asymmetry also changes load sharing in an insulating-glass unit and may alter which lite is laminated, heat-treated or coated; the acoustic consultant, structural glass designer and façade engineer must coordinate the full make-up; an acoustic schedule that ignores coating surface, laminate side or exterior load direction is incomplete.

Worked example 21.7. Separation of critical-frequency estimates

If critical frequency scales approximately as $1/h$, 6 mm and 10 mm panes with a 6 mm screening value of 2,000 Hz give estimates of 2,000 Hz and 1,200 Hz. Equal 8 mm panes would both screen near 1,500 Hz. Asymmetry separates the two coincidence regions by about 800 Hz in this simplified model. Damping and frame coupling remain omitted, so the estimate directs test review rather than specifying performance.

21.11 Insulating-glass units as narrow-cavity systems

An insulating-glass unit contains two or more lites separated by sealed cavities. The cavity provides thermal performance and creates a coupled acoustic system. At low frequency, the enclosed gas acts as a spring between pane masses. At higher frequency, cavity modes, pane coincidence, spacers, seals and frame connections contribute. Narrow cavities typical of thermal IGUs should not be analysed as though they were deep independent secondary glazing.[43]

43 MB-0977. John L. Davy, ASTM E2190-19.

The sealed edge system, desiccant, spacer and secondary seal are essential to durability. They also provide mechanical coupling. Gas fill changes density and sound speed modestly but is usually secondary to pane mass, cavity depth and frame transmission for airborne sound insulation. A performance claim should remain tied to the tested unit and frame.

Worked example 21.8. Ideal mass-air-mass resonance of an IGU

For two leaves of surface masses $m'_1 = 15\,kg/m^2$ and $m'_2 = 25\,kg/m^2$, separated by $d = 0.016\,m$, use

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{\rho_0 c_0^2}{d}\left(\frac{1}{m'_1} + \frac{1}{m'_2}\right)}.$$

With $\rho_0 = 1.20\,kg/m^3$ and $c_0 = 343\,m/s$,

$$f_0 \approx \frac{1}{2\pi}\sqrt{\frac{1.20(343)^2}{0.016}(0.0667 + 0.0400)} \approx 154\,Hz.$$

The units reduce to inverse seconds. The result is an ideal normal-incidence screen. Frame coupling, finite dimensions, sealed-cavity thermodynamics and damping can shift and broaden the measured weakness.

21.12 Triple glazing and the triple-leaf penalty

Three lites create two cavities and several coupled modes; additional glass can increase high-frequency mass yet introduce low-frequency resonances that perform worse than a well-designed double-leaf system; thermal objectives may justify triple glazing, but the acoustic evidence must come from the complete configuration. It is unsafe to infer that three lites always outperform two.

Where one cavity contains a suspended film, or where the middle lite differs materially in mass and stiffness, the modal structure changes; edge spacer continuity and frame cavities may couple all leaves; prediction should be checked against laboratory data and, for unusual large systems, against a representative mock-up.

21.13 Secondary glazing as a deep independent system

Secondary glazing places an additional pane or framed window inside or outside an existing opening; a large separation can lower the ideal mass-air-mass resonance and reduce direct coupling, while absorbent reveal treatment can damp cavity modes; independence of the frames and continuous perimeter sealing are decisive. A decorative trim, blind bracket, cable or common sill fastener can bridge the leaves.

Figure 21-4. Narrow IGU cavities and deep secondary-glazing cavities require different resonance and frame models

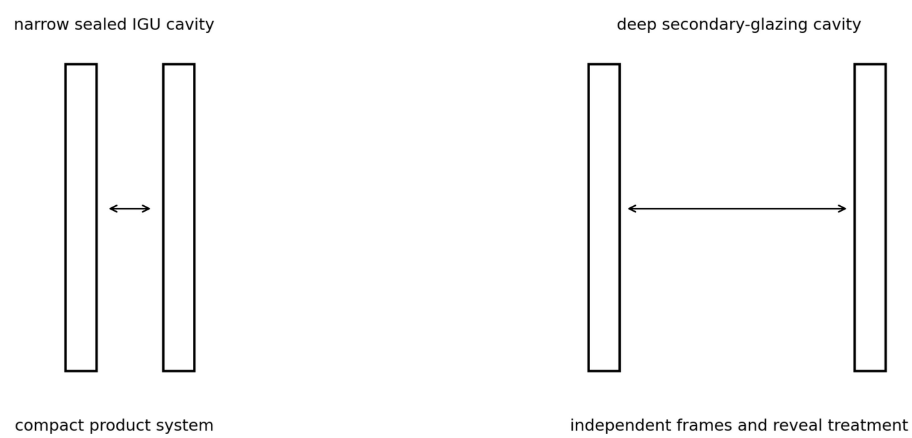

Figure 21-4. Narrow IGU cavities and deep secondary-glazing cavities require different resonance and frame models. Author's original diagram.

Secondary glazing is particularly valuable in heritage work because it can be reversible. The design must preserve ventilation, moisture movement, cleaning access, condensation control, egress and historic fabric. The cavity cannot simply be enlarged without considering temperature and water vapour.

Worked example 21.9. Resonance shift with cavity depth

Using the same leaves as Worked Example 21.8, increase separation from 16 mm to 160 mm. Because $f_0 \propto d^{-1/2}$,

$$f_{0,160} = 154\sqrt{\frac{0.016}{0.160}} = 48.7\,Hz.$$

The deeper cavity moves the ideal resonance below much of the ordinary speech band. Large-cavity modes, reveals, frame bridges and room modes remain. The result supports deeper independent construction but does not establish field performance.

21.14 Cavity modes, absorption and reveal treatment

A deep cavity supports standing waves whose frequencies depend on depth and lateral dimensions; porous absorption on reveals can reduce modal persistence and high-order reflections, but it should not bridge the panes or interfere with drainage; absorber placement is most effective where particle velocity is appreciable. A thin decorative fabric applied at a pressure antinode may contribute little.

Cavity access panels, blinds and services change the acoustic state; a blind headbox attached to both frames can create a mechanical bridge; a ventilation opening can dominate transmission; the as-tested state should record every object in the cavity and the position of operable components.

Worked example 21.10. First depth mode of a secondary-glazing cavity

For a cavity depth $d=0.300\,m$, a simple axial half-wave estimate is

$$f_1=\frac{c_0}{2d}=\frac{343}{0.600}=572\,Hz\,.$$

The estimate identifies a possible cavity feature in a speech-relevant band. Real cavities are three-dimensional, leaky and bounded by compliant panes, so measured modes can shift and overlap. The calculation indicates where additional absorption and measurement resolution may be useful.

21.15 Pane size, aspect ratio and modal density

The natural frequencies of a simply supported rectangular plate scale with thickness and with the inverse square of span; real glazing support is neither perfectly simply supported nor perfectly clamped, but the relation explains why full-height panes require separate attention. Increasing height and width lowers modal frequencies and increases low-frequency modal density; local source position and angle can excite modes selectively.

The laboratory report should record clear pane dimensions, edge bite, frame opening and specimen orientation. A product test on a compact window should not be extrapolated to a floor-to-ceiling lite without an engineering model and uncertainty allowance. Where the field panel is much larger, vibration measurement can help determine whether a modal path is controlling.

Worked example 21.11. Frequency scaling with span

If a plate mode is 160 Hz at a 1.2 m characteristic span, a geometrically similar pane at 2.4 m has a screening frequency proportional to $1/L^2$:

$$f_2 = 160\left(\frac{1.2}{2.4}\right)^2 = 40\,Hz.$$

The result shows a fourfold reduction. Edge stiffness, aspect ratio and residual stress are omitted. The calculation does not predict transmission loss, but it explains why large lites can move structural response into lower bands.

21.16 Edge support, bite and setting blocks

Glass is held within a glazing pocket by gaskets, tapes, sealants, stops, beads, pressure plates or structural silicone; edge bite defines the captured width. Clearance accommodates tolerance and movement. Setting blocks carry dead load and establish position; their stiffness, spacing and compatibility influence force transfer; a pane resting hard on one corner does not have the same boundary condition as a uniformly supported specimen.

Setting blocks should not be treated as acoustical isolators without evidence; their primary duties concern support and compatibility; excessively hard blocks can concentrate force; overly soft or undersized blocks can creep; field inspection should verify location, length, material condition and edge clearance where accessible.

Worked example 21.12. Setting-block bearing stress

A 180 kg glazing unit is supported by two blocks, each 100 mm long by 12 mm wide. Total bearing area is

$$A = 2(0.100)(0.012) = 0.00240\,m^2.$$

Static average stress is

$$\sigma = \frac{m\,g}{A} = \frac{180(9.81)}{0.00240} = 0.736\,MPa.$$

The dimensional result is newtons per square metre. Dynamic loads, edge contact, block compression, temperature and manufacturer limits remain. The calculation is a support screen, not an acoustic performance value.

21.17 Dry glazing, wet glazing and gasket compression

Dry-glazed systems use preformed gaskets, wedges or tapes; wet-glazed systems use sealants or bedding compounds. Many assemblies combine both. Acoustic closure requires continuous contact, correct compression and compatible surfaces; a visually neat exterior cap may conceal an unsealed interior path; corners, gasket splices and pressure-plate joints are recurrent weaknesses.

Compression should be sufficient to close microgaps without overstressing the glass or making operable systems unusable. Gaskets age through compression set, ultraviolet exposure, temperature cycling and contamination. The maintenance programme should identify inspection intervals and replacement criteria rather than assuming permanent elasticity.

Worked example 21.13. Gasket compression

A glazing gasket has an uncompressed thickness of 8.0 mm and an installed thickness of 6.6 mm. Compression is

$$C = 100\,\frac{8.0 - 6.6}{8.0} = 17.5\,\%.$$

Thickness measurement uncertainty of plus or minus 0.2 mm produces several percentage points of uncertainty. The result should be compared with the gasket system's specified compression range. It does not establish acoustic closure at corners or splices.

21.18 Perimeter seals and rough openings

The rough-opening perimeter joins the manufactured fenestration system to site construction; laboratory tests often use carefully prepared mounting walls and controlled seals; field openings can contain shims, anchors, packers, membranes, foams, mineral wool, backer rods, sealants and discontinuities. A superficial bead at the room face does not prove a deep continuous air barrier.

The primary acoustic seal should be shown in section and coordinated with the air, water, vapour, fire and movement systems; three-sided sealant adhesion should be avoided where movement is expected; foam alone may not provide durable acoustic closure unless its density, depth, continuity and protection are controlled. Construction surveillance should photograph the concealed perimeter before trim.

Worked example 21.14. Small perimeter opening in a strong façade

A 12 m² glazed assembly has 48 dB transmission loss at a selected band. A continuous unsealed slot 2 m long and 0.5 mm wide has area $0.0010\, m^2$. Treating the slot conservatively as open,

$$\tau_c = \frac{(12 - 0.001)\, 10^{-4.8} + 0.001}{12} = 9.92 \times 10^{-5},$$

and

$$R_c = -10 \log_{10}(\tau_c) = 40.0\, dB.$$

An opening representing 0.008 per cent of area reduces this idealised band result by roughly 8 dB. Real slots have impedance, but the example demonstrates why perimeter continuity can dominate.

21.19 Frame materials and hollow sections

Aluminium, steel, timber and composite frames differ in surface mass, stiffness, cavities, thermal behaviour, joints and damping; a thermally broken aluminium section may have several chambers connected by webs and polymer bridges; a steel frame can be stiff and continuous. Timber may provide higher material damping but can move with moisture; composite systems can combine all three behaviours.

Frame cavities can transmit along their length; screws, pressure plates and anchors can connect exterior and interior caps; internal baffles, foam fills or localized dampers may help only when compatible with drainage, ventilation, structural and fire functions. Unapproved cavity filling can trap water or impair pressure equalisation.

21.20 Thermal breaks are not acoustic breaks

A thermal break interrupts heat flow through a metal frame; its geometry and polymer properties may reduce some mechanical coupling, but it does not necessarily create acoustic independence; fasteners, corner keys, pressure plates, anchors, gaskets and glass can bridge across the break. The hollow frame can still support longitudinal waves.

A specification should therefore avoid statements such as “thermally broken frame, therefore acoustically isolated”. The complete tested frame and glazing assembly is required. Field vibration measurements can compare exterior and interior frame surfaces under controlled excitation, but interpretation must consider local modes and sensor mounting.

21.21 Mullions, transoms and longitudinal flanking

Mullions and transoms divide the façade into bays and carry wind, dead and seismic loads. They can also carry vibration around partitions and slabs. A partition that terminates against the interior face of a common mullion may appear sealed while structural energy passes along the hollow section to the adjoining room. The path can be horizontal between rooms or vertical between floors. Caps, pressure plates, infill panels and backpans can radiate on the receiving side.[44]

Figure 21-5. Curtain-wall framing can flank partitions horizontally and vertically

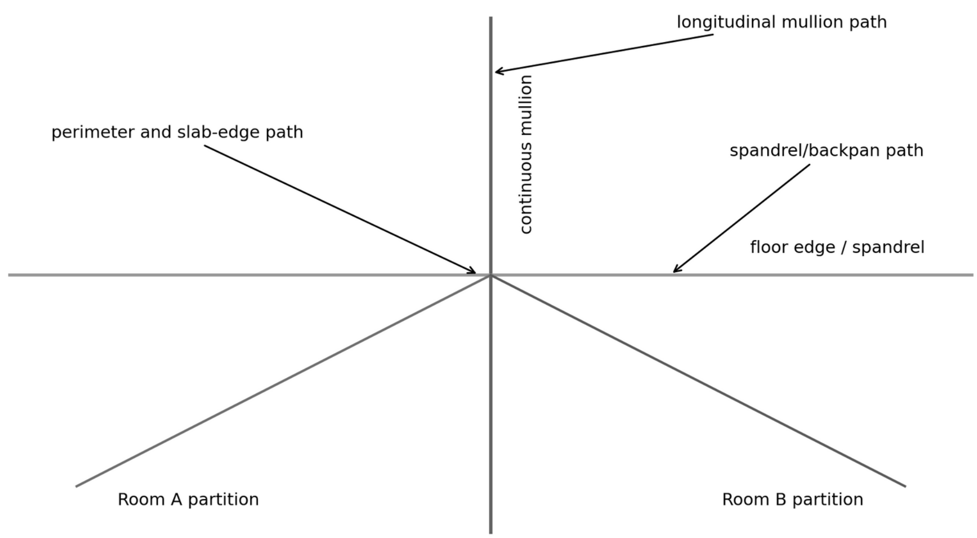

Figure 21-5. Curtain-wall framing can flank partitions horizontally and vertically. Author's original diagram.

Diagnosis should combine airborne measurements with vibration or intensity mapping; high vibration coherence along the mullion, together with receiving-side radiation near the same section, supports a structural

44 MB-1156. Simone Secchi, "Complexities of Curtain Wall Flanking Transmission, A Case Study".

flank; temporary damping, mass, resilient separation or local barrier tests can discriminate among the mullion, spandrel and perimeter paths. Each intervention should be reversible until the causal model is sufficiently strong.

Worked example 21.15. Line-path dominance

A room boundary has a direct glazed-path contribution of 33 dB, a door path of 31 dB and a mullion flank of 27 dB at one band. Converting to linear energy ratios and summing,

$$L_{total} = 10\log_{10}\left(10^{3.3} + 10^{3.1} + 10^{2.7}\right) = 35.7\,dB,$$

when the values are treated as receiving-level contributions on the same reference basis; if mullion remediation lowers that path by 10 dB, the total becomes 35.2 dB; the improvement is only 0.6 dB because the direct glazing and door then control. The calculation demonstrates path competition; it is not a substitute for a measured transfer model.

21.22 Pressure plates, caps and fastener bridges

A pressure-plate curtain wall clamps glazing gaskets against the mullion or transom with a line of screws; exterior caps provide weather protection and appearance; the screw line can couple exterior pressure-plate motion into the interior framing; discontinuous pressure plates at floor lines, corners and expansion joints can alter the path. Missing fasteners, excessive screw torque or uneven gasket compression can also create local air leakage.

The acoustic drawing should identify whether any interior trim or room partition bears against the frame; a rigid trim angle attached to both the partition and mullion can bypass a carefully designed perimeter seal; conversely, a soft perimeter joint without structural restraint can fail under building movement. The required detail must separate acoustic closure from structural load transfer rather than asking one bead of sealant to perform every function.

21.23 Structural silicone glazing

Structural silicone glazing transfers specified loads between glass and frame through an adhesive joint; the joint has geometric, mechanical and durability requirements; its viscoelastic behaviour can contribute damping, but its primary role is structural and environmental; acoustic predictions should not assign a generic loss factor without product and geometry data.

The silicone bite, thickness, cure, adhesion and substrate preparation influence both structural performance and edge boundary condition; a four-sided structurally glazed system differs from two-sided structural glazing with mechanical capture on the other edges; field replacement must reproduce the approved structural system and cannot be justified solely by matching glass thickness. The acoustic record should include shop drawings, sealant identification, joint dimensions and replacement history.

Worked example 21.16. Sealant shear-strain screen

A structural silicone joint 6 mm thick accommodates a differential in-plane movement of 1.2 mm. Average engineering shear strain is

$$\gamma = \frac{1.2}{6.0} = 0.20\,,$$

or 20 per cent. This is a geometric screen, not a design acceptance calculation. Actual strain distribution, joint shape, temperature, ageing and manufacturer limits govern. The example shows why a movement joint cannot be treated as a rigid acoustic boundary or adjusted casually to reduce vibration.

21.24 Curtain-wall anchors and slab-edge junctions

Curtain-wall anchors transfer façade loads to slabs, beams or columns; they can introduce concentrated structural paths into the protected room; slab-edge fire safing, smoke seals, backpans and interior closures fill the visual gap but do not necessarily interrupt vibration. At floor lines, the façade can connect rooms above and below through mullions, anchors and spandrel assemblies.

The junction should be reviewed as a three-dimensional system; architectural details show finishes and seals; structural details show anchors and movement; fire details show safing; façade details show drainage and pressure equalisation; no single drawing usually contains the full path. A coordinated junction schedule should identify which component provides load transfer, air closure, water control, fire resistance, acoustic separation and access for inspection.

Worked example 21.17. Anchor-path sensitivity

Suppose a vibration model assigns a nominal transfer mobility Y_a to six identical façade anchors. If one anchor is isolated and the remaining five act independently, a simple uncorrelated power screen predicts a reduction of

$$\Delta L = 10\log_{10}\left(\frac{6}{5}\right) = 0.79\,dB.$$

Removing or altering one anchor is structurally unacceptable unless redesigned, and coherent response can differ from the uncorrelated assumption. The calculation explains why treating isolated anchors one at a time may yield little acoustic benefit; the topology of the whole junction matters.

21.25 Spandrels, backpans and opaque façade zones

A spandrel zone may contain glass, metal backpan, insulation, fire safing, slab edge, anchors and interior finish; its exterior appearance can match vision glass while its acoustic mechanism is entirely different; thin metal sheets can radiate efficiently. Backpans can create cavities and drum-like modes; gaps at panel joints or slab edges can connect the interior to mullion cavities.

Opaque zones should be tested or modelled as actual systems; assigning the vision-glass rating to the spandrel is unsupported; conversely, a massive insulated spandrel can outperform adjacent vision glass for exterior transmission yet create a stronger interroom flank through continuous framing. Whole-façade and interroom objectives should be examined separately.

Worked example 21.18. Composite façade transmission

A façade bay contains 70 per cent glazing at 38 dB, 25 per cent spandrel at 46 dB and 5 per cent frame at 28 dB in a selected band. Area-weighted transmission coefficient is

$$\tau = 0.70\left(10^{-3.8}\right) + 0.25\left(10^{-4.6}\right) + 0.05\left(10^{-2.8}\right) = 1.96 \times 10^{-4}.$$

Composite transmission loss is

$$R = -10\log_{10}(\tau) = 37.1\,dB.$$

The small frame area materially controls the result. Line-junction effects and non-uniform incident field are omitted, so the calculation is a screening model rather than a field prediction.

21.26 Façade cavities, baffles, drainage and pressure equalisation

Curtain walls manage water through drained and pressure-equalised cavities; weeps, vents, compartment seals and baffles are functional openings; blocking them to improve sound isolation can cause water accumulation and façade damage; the design task is to preserve drainage while increasing path length, impedance and compartmentalisation where permitted.

A cavity that runs continuously past several rooms can become an airborne transfer path; internal seals at mullions or floor lines may be incomplete, damaged or omitted; acoustic investigation should use drawings, borescope inspection where safe, airflow or smoke tracing under controlled conditions, and local sound measurements. The evidence should distinguish a longitudinal air path from structural vibration in the frame.

Worked example 21.19. Weep-opening area screen

Four weeps each measure 25 mm by 6 mm, giving total open area

$$A_o = 4(0.025)(0.006) = 0.00060\,m^2.$$

For a 4 m² façade element, the open fraction is 0.015 per cent. If treated as ideal open holes against a 45 dB panel, composite transmission loss in a high-frequency screening band becomes approximately

$$R_c = -10\log_{10}\left[\frac{(4-0.0006)10^{-4.5}+0.0006}{4}\right) = 37.4\,dB.$$

Real weeps have tortuous geometry and exterior termination. The example shows why tiny functional openings require explicit acoustic consideration but must not be sealed without façade-engineering approval.

21.27 Operable windows and hardware

Operable windows add hinges, balances, locks, keepers, weatherstrips and user-dependent closure. Laboratory performance can depend on latching force and adjustment. A specimen tested with exceptional compression may not represent a window that occupants can operate safely. ASTM E1425 therefore connects acoustical performance with operating force, latching force and air leakage for applicable systems.[45]

Field inspection should record sash alignment, hardware engagement, gasket contact and drainage. Seasonal movement can change compression. A tilt-turn window has different seal lines in its two operating modes; security restrictors and sensors can interfere with closure; the lifecycle plan should define who may adjust hardware and what evidence is required after adjustment.

Worked example 21.20. Latch-compression imbalance

A four-point locking sash shows measured gasket compression of 18, 17, 9 and 16 per cent; mean is 15 per cent, but the 9 per cent corner is the likely leakage location. Averages conceal local failure. If measurement uncertainty is plus or minus 2 percentage points, the weak corner remains materially different; the result supports local adjustment and acoustic scanning, not replacement of the entire window without further evidence.

45 MB-0215. ASTM International, ASTM E1425-14.

21.28 Vision panels in acoustic doors

A vision panel removes door-leaf material and inserts glass, stops, beads, gaskets and local framing; it can change mass distribution, bending response and seal paths; fire-rated, smoke-control, forced-entry or ballistic door assemblies may allow only specific glazing systems and dimensions. Field enlargement or substitution can invalidate the tested doorset.

Figure 21-6. A vision panel alters leaf mass, local stiffness, seals and fire or security listings

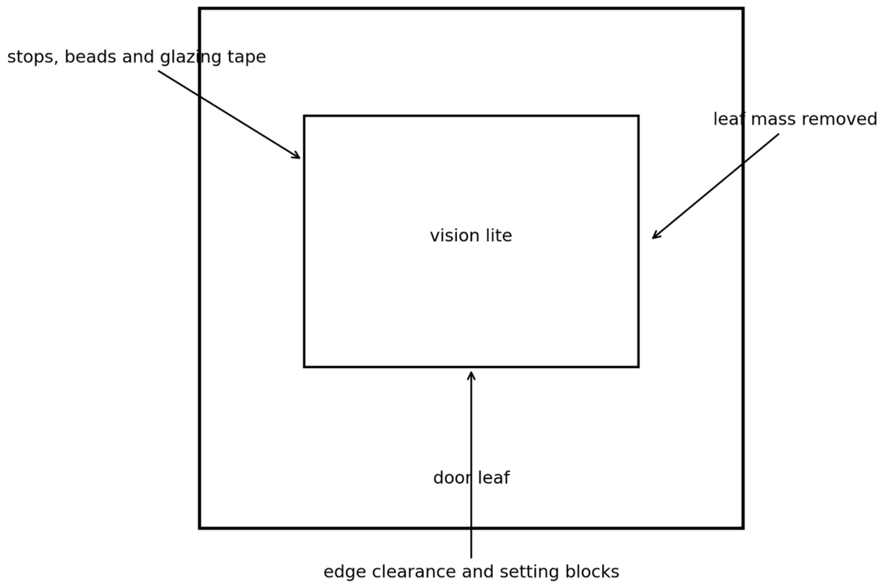

Figure 21-6. A vision panel alters leaf mass, local stiffness, seals and fire or security listings. Author's original diagram.

The acoustic design should identify the complete leaf and vision-lite assembly; glass rating alone is insufficient because the perimeter length can control; stops should remain tight and compatible with required inspection or replacement; where privacy requires blinds or switchable glazing, their operating state and penetrations must be included.

Worked example 21.21. Area-weighted vision-panel penalty

A 2.1 m^2 door leaf has 42 dB band transmission loss. A 0.20 m^2 vision panel has 34 dB. Treating areas as parallel paths,

$$\tau_c = \frac{1.90\left(10^{-4.2}\right) + 0.20\left(10^{-3.4}\right)}{2.10} = 9.50 \times 10^{-5},$$

so

$$R_c = 40.2\,dB.$$

The vision panel reduces the idealised leaf result by 1.8 dB before adding its frame leakage. The calculation does not establish the installed door rating or the effect of hardware and perimeter seals.

21.29 Interior glazed screens and borrowed lights

Interior glass partitions may provide visual supervision, daylight or openness; they can also create long perimeter lengths and rigid intersections with ceilings, floors and adjacent walls; a frameless appearance often conceals channels, patch fittings, silicone joints and head tracks. A small discontinuity can bypass an otherwise heavy pane.

Borrowed lights above doors or partitions are vulnerable at heads, corners and mullion intersections; where the partition stops at a suspended ceiling, the glazing may visually reach the ceiling yet leave a plenum bypass; the drawing should show the complete deck-to-deck boundary and the relation between glazing frame and adjoining opaque construction.

21.30 Fire-rated glazing and smoke-control interfaces

Fire-rated glazing is a listed system comprising glass, frame, beads, setting blocks, seals, anchors and surrounding construction; acoustic modification must preserve the listing; additional tapes, cavity fills, films or replacement gaskets can be impermissible even if they seem acoustically beneficial. The fire-resistance and smoke-control functions must be reviewed by the responsible design professionals and authority.

Fire-protective and fire-resistive glazing differ in capability and permitted application. The acoustic chapter does not substitute for code analysis. Its contribution is to identify the approved assembly, review available acoustic evidence, protect the perimeter from uncontrolled alteration and include the fire-system state in commissioning.

21.31 Security, blast and forced-entry glazing

Laminated and multi-ply glazing may be designed for human impact, forced entry, ballistic resistance or blast hazard reduction. These functions involve different test methods, load histories, support requirements and failure criteria. An assembly that performs well acoustically may not satisfy a security requirement, and a thick security laminate can introduce mass, stiffness and interlayer behaviour not represented by ordinary glazing data.[46]

Publicly available security and blast standards can define test methods and reporting, but they do not reveal controlled project threat criteria. The design team should keep acoustic, structural and security propositions separate and coordinate the common physical assembly. A change in frame bite or anchor spacing can affect all three.

Worked example 21.22. Added security-laminate mass

A replacement laminate adds 6 mm of glass and 1.52 mm of interlayer to an existing make-up. Added surface mass is approximately

$$\Delta m' = 2,500(0.006) + 1,070(0.00152) = 16.6\, kg/m^2.$$

Ideal mass-law screening suggests a potential increase away from resonances, but the new laminate also changes bending stiffness, frame

46 MB-0345. ASTM International, ASTM F1642, ASTM F1233-21.

load, edge bite and modal behaviour. Structural and security checks control before any acoustic benefit is credited.

21.32 Condensation, thermal gradients and hygrothermal compatibility

Secondary glazing and deep reveals change surface temperatures and vapour paths; an interior pane can warm the existing glass while reducing air movement; an exterior secondary pane can cool an inner cavity differently; condensation can damage frames, seals, timber reveals and historic finishes. Desiccants in an IGU serve a different function from ventilation of a site-built secondary cavity.

Thermal gradients can also curve panes and change gasket contact; solar exposure can heat laminate interlayers and move their viscoelastic response; acoustic tests should record representative environmental conditions where temperature sensitivity is material; a favourable winter result should not be assumed to persist under summer solar load.

Worked example 21.23. Dew-point margin

Suppose cavity air has dew point 9 degrees Celsius and the coldest predicted glass-edge temperature is 11 degrees Celsius; nominal margin is 2 degrees Celsius; if dew-point and surface-temperature uncertainties are each 1.5 degrees Celsius, combined standard uncertainty is about 2.1 degrees Celsius. The apparent margin is not robust. The calculation supports better hygrothermal analysis and monitoring, not an acoustic conclusion.

21.33 Structural loading, deflection and acoustic state

Wind, stack pressure and mechanical pressurisation deflect panes and frames. Deflection changes cavity depth, gasket compression and the distance between leaves. Structural glass design under ASTM E1300 or other applicable standards must be completed independently of the acoustic model. The acoustic assessment should use the resulting make-up and support state rather than treating a sound rating as structural evidence.[47]

Large IGUs can bow under barometric and temperature changes; differential deflection can reduce cavity depth near the centre or alter edge seals; in extreme cases, panes can touch; even smaller changes can shift low-frequency behaviour. Field testing should record pressure state and obvious bowing where relevant.

Worked example 21.24. Cavity-depth sensitivity

An IGU has nominal 16 mm cavity. Pressure-induced deflection reduces centre separation to 13 mm. Since ideal mass-air-mass resonance varies as $d^{-1/2}$, resonance increases by

$$\sqrt{\frac{16}{13}}=1.109\,,$$

or about 11 per cent. The cavity is not uniform and frame restraint matters, so the calculation is a sensitivity screen. It shows that structural state can influence acoustic response.

21.34 Product identity, markings and submittal evidence

A defensible submittal identifies each lite, nominal and measured thickness, heat treatment, coating surface, laminate plies, interlayer, cavity depth,

47 MB-0207. ASTM International, ASTM E1300-24.

spacer, gas fill where relevant, frame series, gaskets, sealants, setting blocks, hardware, anchors and tested specimen dimensions. A catalogue phrase such as “acoustic laminated IGU” is not enough.

Markings can confirm safety glazing or heat treatment but seldom encode the complete acoustic make-up; insulating-glass labels may identify manufacturer and date while omitting interlayer formulation or exact spacer; shop drawings and test reports must be reconciled with delivery documentation. Where glass cannot be destructively identified, the record should state what is observed, what is documented and what remains inferred.

Table 21-2. Glazing configurations, dominant mechanisms and minimum evidence

Glazing configuration	Dominant acoustic mechanisms	Frequent hidden weakness	Minimum evidence
Monolithic pane	Surface mass, finite modes, coincidence, edge support	Frame or perimeter leakage	Pane thickness and size, frame, mounting and full band test
Laminated pane	Ply mass, partial composite action, viscoelastic damping	Unverified interlayer substitution or temperature dependence	Exact ply and interlayer make-up, temperature and test report
Insulating-glass unit	Two-leaf coupling, narrow-cavity resonance, frame transmission	Common spacer and frame path, edge-seal condition	Pane asymmetry, cavity, spacer, frame and complete unit test
Secondary glazing	Deep-cavity resonance, reveal modes, frame independence	Common sill, trim or service bridge	Clear separation, independent frames, reveal treatment and field verification
Curtain-wall bay	Vision and spandrel fields, mullions, transoms, anchors and slab edge	Longitudinal frame flanking	Bay elevation, sections, anchor map, spandrel and junction evidence

21.35 Laboratory airborne sound-insulation testing

ASTM E90 and ISO 10140-2 provide laboratory methods for airborne sound insulation. ISO 10140-1 supplies product-specific application rules and mounting information, while ISO 10140-5 addresses facilities and equipment. The specimen is installed between source and receiving rooms designed to suppress flanking. The result describes the specimen under the recorded boundary conditions.[48]

Laboratory evidence should include one-third-octave transmission-loss data, background limitations, receiving-room absorption, source and microphone positions, specimen size, mounting wall, seal details and rating calculation; a single certificate or marketing number is inadequate; where bands are background-limited, the report should preserve lower-bound status rather than presenting exact values.

Worked example 21.25. Background-limited receiving level

At a band, receiving level with source operating is 28.0 dB and background is 27.0 dB. Energetic correction gives

$$L_c = 10\log_{10}\left(10^{2.8} - 10^{2.7}\right) = 21.1\,dB.$$

The 1 dB separation makes correction unstable and uncertainty large. Many methods restrict or flag such conditions. The band should be reported according to the governing method, often as a limit, rather than treated as a precise transmission-loss value.

21.36 System-level laboratory testing under ASTM E1425

ASTM E1425 differs in purpose from a general partition test because it is directed to windows, doors, curtain walls and related exterior building elements as complete systems. The acoustic specimen is therefore not merely the transparent infill. It includes the frame, mullions, transoms, stops, gaskets, sealants, hardware and interfaces represented in the laboratory opening. For operable products, the method also directs

48 MB-0339. ASTM International, ASTM E90-23, ISO 10140-1:2021.

attention to operation, latching and air leakage, matters that materially affect whether the tested state can be reproduced in service.[49]

This system orientation is especially important for secure rooms; a highly damped laminate mounted in a light, hollow or poorly sealed frame can yield a result governed by the frame; conversely, a robust frame can be undermined by a corner gasket, a drain path or a discontinuous perimeter seal. The test report should identify which parts were factory assembled, which were site applied, how the specimen was supported, whether operable leaves were adjusted before test and what forces were required to close and latch them; a result obtained after exceptional laboratory adjustment should not be assumed to describe routine operation by occupants.

The laboratory state should also record pressure, temperature and humidity where they can affect gaskets or laminated interlayers. If the product is intended to operate under a building pressure differential, the test programme should consider whether seal contact changes under that differential. An acoustic test at nominally balanced pressure answers a narrower question than a test that includes credible operating states.

Worked example 21.26. Latching force and repeatable seal contact

Engineering question. Does an operable window achieve repeatable closure within the permitted operating-force range?

Five closing trials produce latching forces of 72, 76, 80, 84 and 99 N. Mean force is

49 MB-0214. ASTM International, ASTM E1425-14.

$$\acute{F} = \frac{72+76+80+84+99}{5} = 82.2\,N\,.$$

The range is 27 N. The high final trial coincides with a visible corner misalignment; if the project limit is 90 N, the mean alone would suggest compliance while one trial fails; the correct disposition is to investigate the corner, repeat the sequence after adjustment and compare acoustic leakage before and after. The calculation does not establish sound insulation; it evaluates whether the mechanical state required for the acoustic result is operationally repeatable.

21.37 Field façade testing and installed-condition evidence

Field façade testing under ASTM E966 or ISO 16283-3 evaluates the installed relation between an exterior source field and an interior receiving space. The methods differ in terminology, source arrangement, processing and rating pathway, but both require a defined façade, source geometry, receiving-room condition and measurement record. The result is an installed quantity. It can include frame leakage, perimeter joints, mullion transmission, spandrel paths, slab-edge flanking, room absorption and source-angle effects that were absent or controlled in the laboratory.[50]

A loudspeaker field can be more repeatable than traffic, yet it remains an approximation to operational exposure; loudspeaker location, height, distance, angle and directivity must be recorded; where the protected concern is an external listener rather than exterior noise intrusion, reciprocity can guide engineering interpretation, but the actual listener geometry, façade radiation, reflections and background must still be

50 MB-0341. ASTM International, ASTM E966-18, ISO 16283-3:2016.

modelled. An outdoor-indoor result should not be described automatically as an indoor-outdoor speech-security result.

The receiving room should be furnished and operated in a documented state; reverberation correction, microphone positions and background limits affect the derived level difference; a small room with a strong local mode can show large spatial variation. Multiple microphone and source positions reduce dependence on one favourable coordinate, but averaging can also conceal a local frame leak; the programme should therefore combine room-average quantities with local diagnostic scans.

Figure 21-7. Field façade testing depends on source geometry, incidence angle, room averaging and local path scans

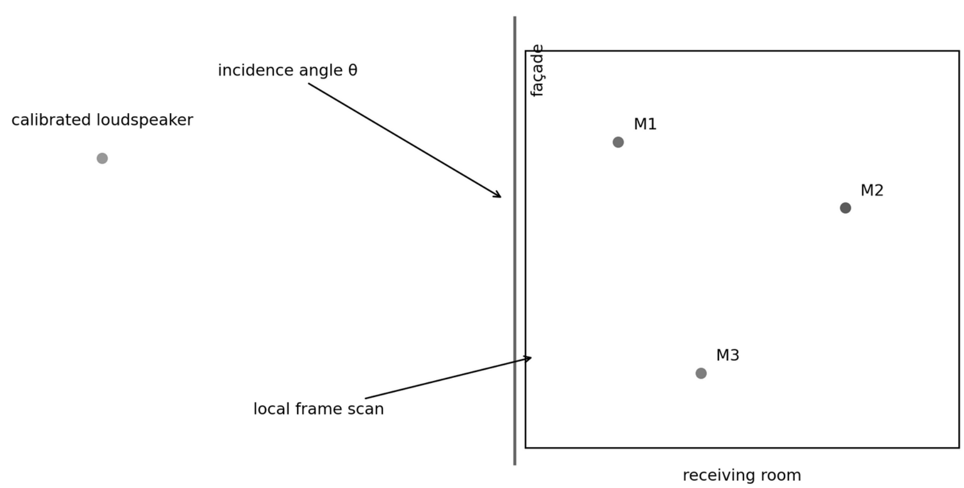

Figure 21-7. Laboratory and field glazing tests answer different questions because specimen boundaries, source geometry, room absorption and flanking differ. Author's original diagram.

Worked example 21.27. Oblique source distance correction

Engineering question. How much can geometric spreading alter comparison between two exterior source positions?

A point-source screening model gives level change

$$\Delta L = 20\log_{10}\left(\frac{r_2}{r_1}\right).$$

For distances of 5.0 m and 8.0 m,

$$\Delta L = 20\log_{10}(8/5) = 4.08\,dB.$$

Distance is measured in the same units, so the ratio is dimensionless; the estimate is valid only where point-source spreading is a reasonable approximation and reflections, ground effects, source directivity and façade angle are treated separately; it shows why source-position changes cannot be compared as though input level were constant.

Worked example 21.28. Reverberation-normalised receiving correction

A receiving room has measured level difference 45 dB at a band. Reverberation time is 0.80 s and the reference condition is 0.50 s. A simplified standardisation term is

$$10\log_{10}\left(\frac{0.80}{0.50}\right) = 2.04\,dB.$$

Depending on the defined metric, the measured difference is adjusted by the prescribed sign and reference convention; the calculation must follow the exact method rather than an improvised correction; the example demonstrates that room absorption is part of the reported field quantity and should not be silently ignored.

21.38 Classification, spectrum adaptation and the loss of frequency detail

Laboratory or field spectra are frequently reduced to STC, Rw, OITC or another single-number descriptor. Each descriptor uses a prescribed frequency range, contour or weighting and answers a bounded comparison question. STC and Rw are not interchangeable, and OITC is intended to represent outdoor-indoor performance under a transportation-type spectrum. None of these ratings alone establishes speech privacy, façade flanking control or formal approval.[51]

For secure-room analysis, the one-third-octave curve should remain primary; a glazing system may have a favourable integer rating while retaining a deep coincidence depression, a low-frequency cavity weakness or a high-frequency frame leak; the significance of that weakness depends on source spectrum, talker orientation, amplification, receiving background and listener access. A single-number value can organise schedules and procurement, but it cannot replace the protected-speech model.

Spectrum-adaptation terms can improve comparison with selected source classes; they do not eliminate the need to understand the residual spectrum; a design review should show the laboratory or field curve, the applicable rating, any adaptation terms, the assumed source spectrum and the residual receiving level. This layered presentation permits the reader to identify whether a favourable rating masks a consequential band.

Worked example 21.29. Equal ratings, unequal residual speech bands

Two glazing systems both carry a nominal rating of 45; at 2,000 Hz, System A has 49 dB transmission loss and System B has 38 dB; a speech component at the source side is 66 dB. Ignoring other paths, received band levels are 17 dB and 28 dB respectively; if receiving background is 20 dB, System A is

51 MB-0287. ASTM International, ASTM E413-22, ASTM E1332-22.

below background while System B is 8 dB above it. The equal integer ratings therefore do not imply equal information exposure.

The arithmetic assumes direct subtraction of a band transmission quantity from a compatible source level and omits room, incidence and flanking corrections. It is a screening comparison, not an occupied speech-security test.

21.39 Incidence angle, source directivity and exterior listener geometry

Plate coincidence depends on the trace component of the incident wave, so angle affects coupling; a façade exposed to a loudspeaker normal to the pane can respond differently from one exposed to traffic at grazing incidence; the laboratory diffuse field averages many angles, while a field source may emphasise one. The protected-speech problem reverses the direction, but the radiating pane and frame remain directional structures whose exterior field depends on modes, boundaries and reflections.

A listener near the façade can occupy the acoustic near field of a large pane or mullion; pressure may vary sharply with distance and position; a listener farther away receives a combination of direct radiation, ground reflection, neighbouring façades, recesses, balconies and urban background. The assessment should identify accessible positions rather than selecting a convenient reference distance; where access changes over time, the threat model should distinguish ordinary public space, controlled grounds, adjacent roofs and maintenance platforms.

Talker directivity inside the room also matters; a person facing the glazing can excite it more strongly in high-frequency bands than a person facing away; a ceiling loudspeaker near the façade can create a sustained and repeatable source unlike ordinary speech. Furniture and absorptive finishes change the incident field; the operational state matrix should therefore include credible source position, orientation and amplification.

Worked example 21.30. Directivity-sensitive incident level

A talker produces 68 dB at a reference position when facing the glazing; turning 120 degrees away reduces the relevant high-frequency band by 7 dB; if glazing transmission loss is 40 dB, the idealised received contributions differ by the same 7 dB before room and exterior corrections. A test using only the favourable orientation can overstate robustness; directivity uncertainty must be part of the state matrix, not treated as random measurement noise.

21.40 Local diagnostics: intensity, vibration and air-path discrimination

A room-average field result identifies a deficit but may not locate it; local sound-intensity scanning can estimate net energy flow across pane fields, mullions, transoms and perimeter joints when probe limitations and field conditions are respected; surface vibration measurements can identify a radiating pane or frame member. Temporary local sealing can test an air-path hypothesis; each method observes a different feature and should be combined through a documented causal sequence.

A high vibration level on a mullion does not by itself prove that the mullion controls transmitted sound; the mullion may move strongly but radiate inefficiently, or it may be responding to a nearby pane; coherence with the source, intensity on the receiving side and a controlled intervention strengthen attribution. Conversely, a small perimeter gap can transmit substantial sound with little structural vibration; airflow, smoke-pencil or pressure methods can identify leakage, but they do not quantify acoustic transmission directly.

Diagnostic interventions should be reversible wherever possible; a removable membrane over a joint, temporary mass loading on a frame cover or a change in source position can discriminate mechanisms; the investigator should record the baseline, intervention, environmental state and post-intervention result. Permanent sealant applied before the hypothesis is tested can destroy evidence and create a new condition that is difficult to interpret.

Worked example 21.31. Local intervention and path attribution

Room-average level difference at 1,250 Hz is 42 dB. Temporarily sealing one jamb improves the result to 47 dB. The corresponding transmitted-power ratio is

$$\frac{\tau_{after}}{\tau_{before}} = 10^{-(47-42)/10} = 0.316.$$

The intervention removed about 68 per cent of the previously transmitted power at that band if all other paths remained stable. This strongly implicates the jamb, but it does not prove the exact permanent repair or exclude other paths. Repeatability, intervention leakage and source stability must be checked.

21.41 Air leakage, pressure differentials and acoustic state

Air leakage and acoustic leakage share physical openings, but the metrics are not interchangeable. ASTM E283/E283M provides a laboratory procedure for air leakage through exterior windows, curtain walls and doors, while ASTM E783 addresses installed exterior windows and doors in the field. These methods quantify steady airflow under a specified pressure difference. Sound transmission involves oscillatory pressure, frequency-dependent impedance and often much smaller excursions. A low air-leakage rate is useful evidence of closure, but it does not establish acoustic performance.[52]

Pressure differential can alter gasket compression, sash position and automatic hardware; a positively pressurised room may push an inward-opening sash more firmly against one seal line while reducing contact elsewhere. Wind can reverse the effect. An acoustic test made under one favourable pressure state should not be treated as proof for all operating modes; pressure, fan status, exterior wind and operable-window state should be recorded.

Air-testing apparatus can also create extraneous paths; a chamber attached to the interior or exterior may bypass trim or wall cavities differently from normal service; the test boundary must be defined; when the purpose is to investigate the perimeter installation rather than the product alone, the protocol should deliberately include that boundary and distinguish it from product leakage.

Worked example 21.32. Power-law air leakage and pressure-state sensitivity

Assume an illustrative leakage relation

$$Q = C\left(\Delta P\right)^{n},$$

52 MB-0242. ASTM International, ASTM E283, ASTM E783-02.

with exponent $n=0.65$. If airflow is 0.40 L/s at 25 Pa, the predicted flow at 75 Pa is

$$Q_{75}=0.40\left(\frac{75}{25}\right)^{0.65}=0.82\,L/s\,.$$

The ratio is dimensionless. The result shows that a threefold pressure increase more than doubles flow for this exponent. The model is empirical and does not predict acoustic transmission. It helps define whether pressure-sensitive seal behaviour warrants testing at more than one state.

21.42 Replacement glazing and configuration control

Glazing is frequently altered during the life of a room; a broken pane may be replaced with the same nominal thickness but a different heat treatment, laminate, interlayer, coating or spacer; a façade repair may change gaskets, pressure plates or structural silicone. A window hardware campaign may alter compression; the change-control process should treat the complete make-up and installation as configuration-controlled information.

Replacement submittals should cross-reference the accepted schedule and identify every departure; where the exact original product is unavailable, equivalence should be demonstrated through product identity, structural review, fire or security listing and acoustic evidence; a supplier statement that the substitute is “equal or better” is not sufficient. The relevant comparison is frequency resolved and system specific.

Post-replacement inspection should verify dimensions, markings, edge clearances, setting blocks, gasket engagement, sealant continuity and drainage; field acoustic retesting may be required where the opening is consequential or the change is extensive; a small vision lite in a door can warrant local testing because its perimeter is long relative to area and because the doorset is repeatedly operated.

Worked example 21.33. Nominally equal replacement mass

An original laminate is 5 mm glass, 0.76 mm interlayer and 5 mm glass. A proposed substitute is 4 mm glass, 1.52 mm interlayer and 6 mm glass. Using densities of 2,500 kg/m^3 and 1,070 kg/m^3, original surface mass is 25.81 kg/m^2 and substitute mass is

$$(2,500)(0.004+0.006)+(1,070)(0.00152)=26.63\,kg/m^2.$$

The substitute is 3.2 per cent heavier, but mass equality does not establish equal bending stiffness or damping. The asymmetrical plies and thicker interlayer can shift modal and coincidence behaviour. The complete test evidence remains necessary.

21.43 Construction surveillance and first-of-type mock-ups

Glazing defects become concealed as stops, caps, covers and finishes are installed. Construction surveillance should therefore use hold points before glass placement, before pressure plates or stops are closed, before perimeter joints are concealed, before spandrel covers are installed and before adjacent partitions or ceilings hide junctions. Each hold point should identify the required evidence and responsible reviewer.

A first-of-type mock-up should reproduce the critical pane, frame, mullion, spandrel, slab-edge and perimeter conditions rather than an isolated ideal window. The mock-up can be used for water, air, structural and acoustic testing in a coordinated sequence, provided one test does not damage or alter the specimen before another without documentation. Acoustic testing after repeated pressure or water cycling can reveal seal movement that an initial pristine test misses.

Photographic records require scale, location and orientation; a close image of a sealant bead without bay number or elevation is weak evidence; the record should show edge bite, setting blocks, gasket corners, weeps, fasteners, anchors, backer rods and sealant depth where visible. Nonconformances should remain open until correction and reinspection are documented.

Worked example 21.34. Risk-based mock-up coverage

A project has four façade types. Type A covers 70 per cent of area but contains no protected rooms; type B covers 15 per cent and forms one wall of six secure rooms; type C covers 10 per cent and includes operable units. Type D covers 5 per cent and contains a complex corner mullion; an area-proportional sampling plan would overemphasise Type A. A consequence-weighted plan assigns mock-ups to B, C and D despite their smaller area, then uses routine quality control for A. The example shows why mock-up selection is a risk decision rather than a simple percentage calculation.

21.44 Commissioning and acceptance architecture

Commissioning should begin with document reconciliation. The approved make-up, installed markings, frame series, hardware, sealants and field changes are compared; visual inspection and operational testing follow; air leakage, local acoustic scanning, room-pair testing and occupied speech assessment are then selected according to the project risk. Each stage answers a different proposition.

Acceptance criteria should identify the metric, frequency range, source state, receiving state, uncertainty and decision rule before testing. A requirement such as “STC 50 glazing” does not define whether the criterion applies to the laboratory pane, laboratory framed assembly, installed façade bay, room pair or occupied speech condition. The contract should avoid such ambiguity.

The competent authority may consider evidence beyond acoustics, including physical security, fire safety, emergency egress, TSCM findings and operational controls. Acoustic commissioning should provide a bounded technical record rather than a declaration of governmental accreditation. Conditions of acceptance, maintenance intervals and change triggers should be explicit.

Table 21-3. Glazing commissioning state matrix

State	**Mechanical and environmental condition**	**Acoustic observation**	**Acceptance implication**
Factory-closed specimen	New gaskets, adjusted hardware, balanced pressure	Laboratory spectrum and rating	Product evidence only
Installed ordinary mode	Normal HVAC, ordinary exterior pressure, clean seals	Field façade and local scan	Installed baseline
Adverse pressure mode	Credible positive or negative pressure, wind or stack state	Seal-contact and receiving-level change	Robustness check
Maintenance mode	Access panels open or covers removed where authorised	Temporary path identification	Not an operating acceptance state
Occupied maximum-effort mode	Defined talker or calibrated surrogate, furnished room, accessible listener positions	Speech-relevant residual spectrum	Consequence evidence
Post-replacement mode	Verified new pane, seals and hardware	Targeted comparison with baseline	Change-control closure

Worked example 21.35. Guarded acceptance near a threshold

An installed façade requirement is 44 dB at a critical one-third-octave band. The measured estimate is 45.1 dB with expanded uncertainty 1.8 dB. Under a conservative rule requiring estimate minus expanded uncertainty to meet the limit,

$$45.1 - 1.8 = 43.3\, dB,$$

so the result does not pass. A different decision rule could produce a different disposition, which is why the rule must be specified before measurement. The calculation addresses conformity with one criterion, not occupied speech security or formal accreditation.[53]

21.45 Forensic case study: the high-rated pane and the speaking mullion

A corporate boardroom uses a glazed façade with a tested laminated IGU and a nominally high outdoor-indoor rating; after hours, portions of amplified conference audio are audible on an adjacent maintenance balcony; room-average field testing shows a broad deficit between 500 and 2,000 Hz. The glazing fields vibrate, but the strongest receiving sound occurs along a vertical mullion aligned with the partition return.

Drawings show that the room partition terminates at the interior mullion cap rather than at an acoustically separated façade interface; the mullion cavity continues past the partition, and a cover plate bridges both rooms; accelerometer coherence is high along the mullion. Temporary cavity blocking and a removable cover treatment improve selected bands by 7 to 11 dB; pane surface treatment produces little change.

53 MB-0853. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

The conclusion is bounded. The IGU is not shown to be defective; the dominant installed path is the mullion and partition interface; permanent remediation requires façade, fire, moisture and movement review; the case illustrates why a favourable pane rating cannot compensate for longitudinal frame flanking.

21.46 Forensic case study: secondary glazing with a concealed sill bridge

A historic meeting room receives an independent interior secondary window with a 220 mm cavity; initial tests improve most speech bands substantially, but a narrow weakness remains near 630 Hz; inspection shows that the new timber sill is screwed through packers into the original metal frame at six locations. The bridge was added to control deflection and was concealed by trim.

Mobility testing shows correlated motion at the original and secondary frames; removing one accessible screw during a controlled investigation changes local response, but the system cannot be left structurally incomplete; a revised sill detail uses an independent support and defined resilient separation while retaining structural capacity. Retesting shows a broader improvement around the previous weakness.

The mass-air-mass calculation correctly predicted a low resonance below the main speech band, but it did not predict the bridge. The defect was geometric and construction-specific. The case demonstrates that deep cavities deliver their intended benefit only when frame independence survives construction.

21.47 Forensic case study: field replacement and summer degradation

A laminated exterior lite is replaced after breakage; winter acceptance testing appears equivalent to the baseline; during summer, occupants report greater exterior audibility during afternoon meetings; records show that the replacement has the same nominal glass thickness but a different interlayer and a darker solar coating. Afternoon pane temperature is materially higher than during the original test.

Paired measurements are made in morning and afternoon conditions, with source and receiving geometry held constant; the replacement system shows a repeatable reduction around its coincidence region as temperature rises; the evidence does not prove the interlayer alone is responsible because seal compression and pane bow also vary. Nevertheless, the state dependence is real and the substitution record was inadequate.

Remediation options include an interlayer-supported replacement, external solar control that does not compromise security or façade function, and operational restrictions pending repair. The case shows why acoustic equivalence must include environmental range, not merely room-temperature laboratory data.

21.48 Forensic case study: a vision panel outside the tested doorset

A secure conference-room door was specified as a tested acoustic doorset; during construction, a larger vision panel was introduced to improve supervision; the fabricator used fire-rated glass and compliant stops, but the revised size was outside the acoustic test configuration. Field scanning identifies leakage around one upper corner and a reduction in leaf isolation near the lite.

The change affected more than glass area; the cut-out reduced leaf mass and stiffness, the stop geometry differed from the tested system, and the expanded perimeter increased sensitivity to gasket discontinuity; temporary corner sealing improves the local path, but the remaining deficit persists because the altered leaf assembly is different from the tested doorset.

The accepted remedy is either a tested larger-vision configuration or restoration of the original design. A local seal repair alone cannot establish equivalence. The case illustrates why fire compliance, acoustic performance and security supervision are separate propositions that must converge in the same approved assembly.

21.49 Representative specimen selection and transferability

A test programme should select specimens by consequence and by difference from the available evidence; the most common pane make-up is not necessarily the most informative specimen; a corner bay with a two-directional mullion, a spandrel transition, an operable sash or a large vision lite may carry more uncertainty than a repetitive central bay. Selection should account for pane dimensions, aspect ratio, frame family, anchorage, junctions, hardware, environmental exposure and protected-room location.

Transfer from one tested specimen to another project condition should be stated as an engineering inference, not as identity; differences can be grouped into material, geometric, boundary, environmental and operational classes; some differences are likely conservative, some adverse and some indeterminate. A thicker pane may add mass but lower critical frequency; a larger cavity may improve low-frequency decoupling but introduce reveal modes. A stiffer frame may reduce local motion yet transfer more force into the adjoining structure.

A transfer matrix should therefore record each departure and its expected direction, confidence and supporting evidence; where several departures interact, a new test or mock-up can be more reliable than compounding judgemental allowances; the cost of one representative test is often smaller than the cost of a façade-wide retrofit after occupancy.

Worked example 21.36. Geometric transfer screen for a larger pane

A laboratory pane is 1.2 m by 1.5 m. The project pane is 1.8 m by 3.0 m. Area ratio is

$$\frac{1.8(3.0)}{1.2(1.5)}=3.0\,.$$

If a simply supported modal frequency scales approximately with inverse span squared, doubling the long dimension can reduce corresponding modal frequencies by a factor near four. The tested pane is therefore not geometrically representative merely because its make-up is identical. The screen does not quantify the project transmission loss because real support, damping and aspect ratio remain.

21.50 Speech-security interpretation at exterior and adjoining positions

The acoustic consequence of glazing depends on the listener and source scenario; an exterior listener may have line of sight to a pane, access to a recess that shields wind noise or proximity to a mullion that radiates locally. An adjoining internal listener may receive sound through a curtain-wall cavity that bypasses the pane; the assessment should map accessible positions and identify whether access is continuous, intermittent, supervised or technologically assisted.

Speech analysis should retain frequency and time structure; average A-weighted level can be low while isolated names, numbers or repeated phrases remain recoverable; maximum unamplified vocal effort, installed loudspeaker modes and after-hours background are separate states; a room may be acceptably private during daytime traffic yet vulnerable during a quiet night maintenance window.

Public descriptions of secure-speech testing can inform the need to test demanding vocal states, but they do not publish or replace controlled acceptance criteria. The report should state the public basis used, the source and listener assumptions, the measurement uncertainty and the authority boundary.[54]

Worked example 21.37. Quiet-hour change in speech-to-background ratio

A residual speech band is 24 dB at an exterior recess; daytime background is 31 dB, giving a speech-to-background ratio of minus 7 dB; at night, background falls to 19 dB, giving plus 5 dB; the same façade therefore presents materially different detection conditions without any change in transmission. This arithmetic does not establish intelligibility. It identifies the quiet-hour state that requires a speech-relevant metric or controlled listener test.

54 MB-1071. National Protective Security Authority, “Secure Speech Environments”.

Worked example 21.38. Repeated-access probability screen

Suppose a consequential token has a 0.08 probability of correct recovery during one independent exposure. Over ten comparable exposures, the probability of at least one recovery is

$$P = 1 - (1 - 0.08)^{10} = 0.566\,.$$

The independence assumption is often unrealistic because context and learning can increase later probability. The example shows why one short test cannot represent repeated access and why listener opportunity is part of the security model.

21.51 Uncertainty, model discrepancy and acceptance decisions

Measurement uncertainty is only one part of the decision problem; configuration uncertainty concerns whether the tested pane, frame, seal and operating state represent the accepted installation; model discrepancy concerns the difference between the simplified acoustic model and the actual coupled façade. Mission uncertainty concerns source behaviour, listener access and consequence; these components should not be hidden within one generic allowance.

A field result near a limit should be evaluated under the specified decision rule; if a spectrum contains background-limited bands, the rating or band result may be a lower bound rather than an exact value; if the tested bay differs from the most consequential bay, the transfer uncertainty should be stated separately. A pass under one laboratory classification cannot be used to waive an installed-condition defect found by local diagnosis.

The acceptance dossier should preserve raw and processed spectra, calibration, source geometry, environmental state, photographs, as-built details, deviations, uncertainty budget, decision rule and authority disposition. A future replacement or investigation should be able to reconstruct the accepted configuration without relying on personal memory.

Worked example 21.39. Combined measurement and transfer uncertainty

A field result is 46.0 dB. Standard measurement uncertainty is 0.9 dB and an independently assessed specimen-transfer uncertainty is 1.4 dB. If covariance is negligible,

$$u_c = \sqrt{0.9^2 + 1.4^2} = 1.66\, dB.$$

Using coverage factor two gives expanded uncertainty about 3.3 dB. The calculation is valid only if the transfer term has a defensible probabilistic interpretation and independence is justified. It demonstrates that a precise instrument result can still support a broad decision interval when representativeness is weak.

21.52 Lifecycle inspection, incident response and evidence preservation

Glazing systems age through ultraviolet exposure, thermal cycling, gasket compression set, sealant movement, hardware wear, corrosion, water intrusion, glass replacement and repeated cleaning; façade access work can disturb caps, gaskets and perimeter joints; interior fit-out can attach blinds, displays or partitions to the frame. The accepted acoustic state should therefore be treated as a configuration baseline with scheduled inspection and event-driven review.

Inspection frequency should follow consequence, exposure and observed degradation; operable units and acoustic doors with vision panels may require more frequent checks than fixed central bays; coastal, high-rise or high-solar-load façades can experience different ageing mechanisms; the inspection record should distinguish cosmetic findings from paths likely to affect transmission.

Incident response should preserve evidence before repair; if a complaint follows façade maintenance, the investigator should secure work orders, photographs, discarded gaskets, product labels and access logs; baseline acoustic data, if available, support comparison; temporary protective measures may be necessary, but every intervention should be documented because it changes the system under examination.

Figure 21-8. Glazing diagnosis requires configuration control and discriminating interventions

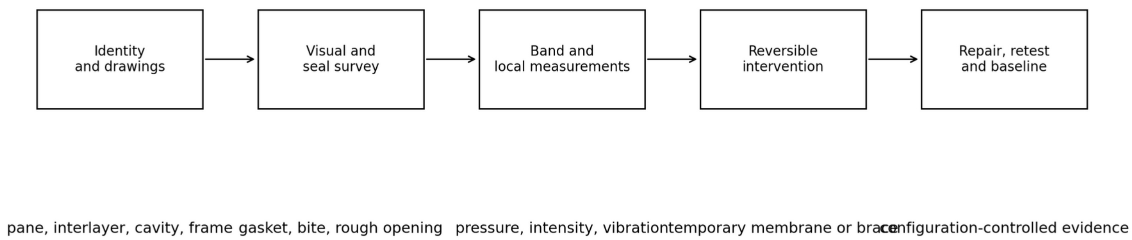

Figure 21-8. Lifecycle control links accepted configuration, inspection, incident triage, reversible diagnosis, repair and verified recommissioning. Author's original diagram.

Worked example 21.40. Inspection interval from a simple hazard rate

Assume an illustrative annual probability of consequential seal degradation of 0.06 for one operable unit. For five independent units, probability that at least one degrades within a year is

$$P = 1 - (1 - 0.06)^5 = 0.266 .$$

The model ignores common environmental causes and maintenance quality, so independence may understate risk. The result does not prescribe an interval by itself. It demonstrates why several operable units in one boundary can justify more frequent inspection than a single fixed pane.

21.53 Slab-edge, fire-safing and partition-return interfaces

The junction between a secure-room partition and an exterior curtain wall is frequently more consequential than the glazing field; the partition may meet a mullion, an insulated spandrel panel, a backpan or a slab-edge safing system; each condition carries different movement, fire, moisture and acoustic obligations. A rigid partition return can transfer vibration into the mullion; a soft closure can preserve movement but leave an air path. A fire-safing system can interrupt the cavity at the slab while a longitudinal mullion path remains open above and below.

The design should identify the three-dimensional boundary, not merely a plan line; enlarged plan, section and isometric details should show the partition leaves, mullion cavities, pressure plates, backpans, perimeter seals, fire safing, smoke seals, deflection allowances and access for inspection. The details should distinguish the primary air seal from decorative trim; if a proprietary façade system limits alteration, the acoustic solution may require an independent internal return rather than filling the mullion.

Movement compatibility is essential. Curtain walls deflect under wind, thermal change and building drift. Interior partitions can move differently. A seal that is acoustically effective on the day of installation can tear or debond if it cannot accommodate differential movement. Joint design should specify width, backing, sealant depth, adhesion surfaces and expected movement rather than a vague instruction to seal continuously.

Fire safing and smoke containment are independent life-safety systems; acoustic materials cannot be inserted into those systems without approved evidence; conversely, a code-compliant safing assembly is not automatically an acoustic closure; the project should coordinate tested fire details with acoustic mock-up and field verification.

Worked example 21.41. Differential movement demand at a façade return

A floor edge moves 12 mm laterally under design drift while the interior partition head permits 8 mm; if the façade return is rigidly fixed to both systems, differential demand can reach 4 mm before local tolerances. A 10 mm sealant joint would therefore experience at least 40 per cent nominal shear deformation; the calculation is geometric and does not replace structural drift analysis or sealant qualification; it demonstrates why a thin cosmetic bead is unlikely to remain a durable acoustic seal at a moving façade junction.

21.54 Mock-up sequencing with structural, water and air testing

Façade mock-ups often undergo structural loading, water penetration, air leakage and acoustic tests. The sequence can influence results. Structural cycling can seat gaskets, move anchors or crack seals; water testing can wet absorptive materials or reveal drainage paths; temporary test chambers can cover perimeter conditions; acoustic testing performed only before these exposures may not describe the service-aged state.

The test plan should identify the purpose and possible effect of each test; a useful sequence may include initial visual and air testing, baseline acoustic measurement, structural and water cycling, post-cycling air testing, repeated acoustic measurement and controlled dismantling. Where a test is destructive, separate specimens may be required; the specimen should remain traceable through photographs, seal maps, adjustment records and environmental data.

Acceptance should distinguish product qualification from project mock-up verification. A manufacturer may provide a laboratory acoustic report for a standard bay, while the project mock-up verifies the actual slab edge, corner, spandrel and partition return. Neither should be discarded. The product report supplies controlled comparative evidence; the project mock-up tests representativeness and workmanship.

Worked example 21.42. Before-and-after cycling comparison

A mock-up measures 47.2 dB before structural cycling and 44.8 dB after cycling at a critical band; combined standard uncertainty for the difference is 1.1 dB; the 2.4 dB change is about 2.2 times the uncertainty. It warrants inspection of seals, anchors and frame movement; it does not prove permanent degradation without repeat measurements and source-stability checks. The physical inspection should precede an attempt to readjust the specimen.

21.55 Coatings, films, switchable glazing and embedded functions

Coatings and applied films alter optical, thermal, safety and sometimes acoustic behaviour; a thin solar or low-emissivity coating contributes negligible mass but can change thermal gradients and pane temperature; a post-applied safety or security film can retain fragments when correctly anchored, yet it does not reproduce a factory laminate unless the complete film, attachment and frame system has been tested. Acoustic benefit should not be inferred from marketing language.

Switchable glazing can contain polymer-dispersed liquid crystal, electrochromic layers, conductive coatings, bus bars, edge connectors and control wiring; these additions may have little direct acoustic effect, but their electrical penetrations and edge constructions can change the system. Control equipment can generate noise or require access panels; the privacy state of switchable glass is visual, not acoustic; an opaque state does not prevent sound transmission.

Embedded antennas, transparent conductors, heating elements and sensors create further configuration obligations; their wiring should cross the acoustic boundary through controlled routes; replacement and software updates should be recorded; where electronic functionality is part of a secure room, TSCM and cyber review remain separate from acoustic assessment.

Worked example 21.43. Applied-film mass significance

An applied polymer film has thickness 0.20 mm and density 1,200 kg/m³. Surface mass is

$$m' = (1,200)(0.00020) = 0.24\,kg/m^2.$$

On a 10 mm glass pane of approximately 25 kg/m², the film adds less than one per cent mass; any acoustic change is therefore unlikely to follow simple mass law alone; adhesion, damping, edge attachment and measurement uncertainty would need to be examined. The calculation does not assess fragment retention or forced-entry performance.

21.56 Specification language, submittals and delegated design boundaries

A publication-quality specification should identify the required evidence rather than rely on adjectives such as acoustic, secure or high performance; the product section should state glass type, ply and interlayer identity, heat treatment, coatings, cavity, frame series, gaskets, sealants and permitted substitutions. The performance section should state the test method, specimen scope, frequency data, rating, field requirement, uncertainty and decision rule; the execution section should state setting, support, seal geometry, movement, inspection and change control.

Delegated façade design does not remove the owner's acoustic requirement; the delegated designer should receive the room-use assumptions, boundary diagrams and required interfaces; submittals should show how the partition return, spandrel, slab edge and services preserve the acoustic boundary. Calculations and test reports should be reviewed for applicability rather than merely filed.

The specification should also define prohibited inferences; a pane-only test is not accepted as evidence for a framed curtain wall; an OITC value is not accepted as an occupied speech-security criterion; an air-leakage test is not accepted as acoustic proof. A security-glazing classification is not accepted as evidence of sound insulation. These exclusions prevent different compliance systems from being collapsed into one misleading label.

Worked example 21.44. Submittal completeness score as an administrative screen

A project requires ten evidence items: full test report, pane make-up, dimensions, frame section, seals, anchors, mounting, environmental state, field method and substitution statement. A submittal provides seven. Administrative completeness is 70 per cent, but the missing items are frame section, seals and mounting, all of which are high consequence; the score therefore cannot justify approval; a risk-weighted review rejects the submittal until the missing system information is supplied.

21.57 Corners, returns and multi-directional façade flanking

Façade corners are not acoustically equivalent to straight central bays; two glazed elevations can meet through a corner mullion containing connected cavities, reinforcement, pressure plates and caps; sound entering the corner from one room can propagate along either elevation or radiate into the corner cavity. An interior partition that terminates on one face may leave the orthogonal face continuous; the three-dimensional detail should therefore be analysed as a network rather than as two independent wall sections.

Re-entrant corners, bay windows and projecting façades create exterior reflection and shelter; a listener can stand in a recess where wind and traffic background are reduced while reflected radiation from two panes adds; conversely, a projecting corner may expose one face to strong wind noise. Exterior geometry should be included in the listener-access map and field source plan.

Corner testing should include local source positions on both interior sides and receiving positions near both exterior faces; vibration measurements on the corner mullion and adjacent panes can reveal whether energy crosses the junction; temporary cavity blocking may discriminate a hollow-frame path, but permanent treatment must preserve drainage, movement and structural requirements.

Worked example 21.45. Addition of two correlated corner paths

Two façade faces each produce a 26 dB receiving contribution at a sheltered exterior position. If they are incoherent, energetic addition gives

$$L = 10\log_{10}\left(10^{2.6} + 10^{2.6}\right) = 29.0\,dB.$$

If they are strongly coherent and in phase, pressure addition could approach 32 dB. Real phase varies with frequency and position. The 3 to 6 dB range shows why a one-face test can understate a corner listener condition.

21.58 Repair hierarchy and validation of remedial work

Glazing remediation should address the demonstrated path with the least consequential intervention; a loose stop or discontinuous perimeter seal may be corrected locally; a longitudinal mullion cavity may require internal blocking or an independent partition return; a pane coincidence weakness may require a different laminate or pane asymmetry. A site-built secondary window may be preferable to replacing protected historic glass. Each remedy changes different physical and regulatory functions.

The repair hierarchy begins with configuration verification and operational adjustment; hardware, gasket contact and removable caps are inspected before destructive work; reversible diagnostic sealing then tests air-path hypotheses; structural vibration and intensity measurements test frame and pane hypotheses. Only after the mechanism is supported should permanent work be designed.

Validation should reproduce the baseline source and receiving states, not merely demonstrate an improvement under a new favourable arrangement; results should be compared by band with uncertainty; a repair can improve one path and expose another, so the entire room boundary should be reviewed after local success. Updated drawings, photographs, product records and maintenance instructions complete the remedial evidence.

Worked example 21.46. Sequential remediation and residual dominance

At one band, transmitted power is divided among pane 25 per cent, mullion 45 per cent and perimeter 30 per cent. A perimeter repair reduces that path by 12 dB, a factor of 0.063. New total relative power is

$$0.25+0.45+0.30(0.063)=0.719.$$

Improvement is

$$-10\log_{10}(0.719)=1.43\,dB.$$

The excellent local repair yields only modest room improvement because the mullion dominates; treating the mullion by 10 dB as well would reduce total to about 0.314 and improve the band by 5.0 dB; the example demonstrates why remedial priorities should follow linear path power rather than visual severity.

21.59 Cleaning, access equipment and maintenance-induced change

Glazed boundaries are touched repeatedly after acceptance; window-cleaning cradles, façade-access anchors, removable internal screens, blinds and maintenance panels can alter local conditions or provide temporary listener access; cleaning chemicals can affect sealants, coatings and gaskets; repeated removal of pressure caps or interior trim can disturb the primary seal. Maintenance procedures should therefore form part of the acoustic lifecycle record rather than being treated as external housekeeping.

Access equipment can also change the exterior acoustic environment; a suspended platform may occupy a position close to a pane or mullion that is otherwise inaccessible; during maintenance, façade covers can be removed and plant can be shut down, reducing background noise. Protected discussions should be restricted or relocated when credible access or temporary boundary changes exist; this is an operational control, not a substitute for construction quality.

The maintenance specification should identify components that may be removed, approved cleaning products, torque or reinstallation requirements, inspection after work and circumstances requiring retesting. Contractors should not drill frames, route cables through weeps or attach equipment to mullion caps without approved review. Photographs before and after work help distinguish pre-existing conditions from maintenance damage.

Worked example 21.47. Temporary access-state consequence

A façade location normally has 34 dB background from mechanical plant; during scheduled maintenance the plant is shut down and background falls to 22 dB; residual speech at the platform position remains 27 dB; the speech-to-background ratio changes from minus 7 dB to plus 5 dB. No change in glazing performance has occurred, yet the consequence is materially different. The maintenance permit should therefore control meeting use during the temporary access and quiet-state window.

21.60 Digital records, photographs and model provenance

A modern glazing record can contain façade models, shop drawings, test reports, glass optimisation files, sealant calculations, photographs, inspection forms and maintenance data; these records should be linked to the accepted physical bay through stable identifiers; a three-dimensional model without revision history can misrepresent the installed anchors or perimeter seals; a photograph without location and orientation can be evidentially weak.

The information model should distinguish design intent, approved submittal, field observation and inferred concealed condition; acoustic calculations should identify the source files and software versions used, while preserving the underlying band data in open tabular form; proprietary analysis may be necessary, but the project should retain enough input and output information for independent review.

Digital records also support later incident investigation; time-stamped photographs can show whether a gasket corner was intact before maintenance; a serialised pane schedule can identify whether a replacement used the accepted interlayer; access permissions and change logs should be controlled because the model can disclose protected-room locations and construction details even when it contains no classified threshold.

Digital preservation should include format strategy and checksum control; native modelling files can become unreadable as software changes, while exported drawings can lose object identity and revision history; the project should retain both native and durable open representations, together with a manifest that records file name, revision, author, date, relationship to the accepted bay and cryptographic checksum. This is especially important for test spectra and photographs that may later support expert analysis.

Records should also preserve negative findings. A local scan that did not identify a mullion path can be as important as a positive intervention, provided the method and detection limits are recorded. Deleting unsuccessful tests creates hindsight bias and can lead a later investigator to repeat work or overstate the certainty of the surviving evidence. The archive should therefore distinguish raw data, processed data, interpretation and authority decision.

Where security policy limits distribution of drawings or room locations, access control should be applied without destroying provenance; redacted issue copies can coexist with a controlled master; the acoustic report should identify its information boundary and avoid embedding more sensitive construction detail than is necessary for the intended audience.

Worked example 21.48. Record reconciliation across three sources

A façade bay is described as 10 mm laminated glass in the architectural schedule, 6 mm plus 6 mm laminated glass in the shop drawing and 5 mm plus 5 mm in the laboratory report; these are not three interchangeable descriptions. The discrepancy must be resolved through approved revisions, delivery records and field identification; averaging the thicknesses or selecting the strongest rating would be evidentially indefensible; the example shows why document reconciliation precedes acoustic inference.

21.61 Technical schedules for glazing, frames and façade evidence

Table 21-4. Frame and façade components, principal failure signatures and evidence

Component	Principal function	Characteristic acoustic weakness	Minimum diagnostic evidence
Gasketed stop	Retains pane and provides compliant contact	Corner opening, compression loss, hardening	Contact map, corner photographs, local scan, replacement history
Structural silicone joint	Transfers load and seals perimeter	Voids, adhesion loss, altered bead geometry	Joint dimensions, adhesion record, inspection and local intervention
Mullion cavity	Carries loads and services along façade	Longitudinal flanking past partition returns	Sections, cavity continuity, vibration coherence and blocking trial
Thermal break	Limits heat flow between frame halves	Thin polymer web and coupled cavities	Frame section, material identity, band-resolved test or model

Component	Principal function	Characteristic acoustic weakness	Minimum diagnostic evidence
Pressure plate and cap	Retains IGU and distributes pressure	Fastener periodicity, cap cavity radiation	Fastener map, vibration scan, representative system test
Spandrel zone	Conceals slab edge and opaque backing	Cavity radiation, slab-edge flank, discontinuous fire safing	Elevation, slab-edge section, safing record, local measurement
Weep or vent	Provides drainage and pressure equalisation	Open acoustic path or cavity coupling	Geometry, termination, functional review and targeted test
Perimeter seal	Closes interface between frame and wall	Hidden deep gap beneath surface bead	Backer-rod depth, adhesion, temporary membrane test and photographs

Table 21-5. Measurement and classification methods used in glazing assessment

Method or quantity	Primary proposition	Important limitation	Secure-room use
ASTM E90 / ISO 10140-2	Laboratory airborne sound insulation of a specimen	Laboratory boundary and specimen size	Product and mock-up evidence
ASTM E1425	Laboratory system performance of windows, doors and curtain walls	Tested operating and latching state	Complete framed-system comparison
ASTM E966 / ISO 16283-3	Installed façade sound insulation	Source geometry, room absorption and field flanking	Installed-condition evidence
ASTM E413 / ISO 717-1	Single-number classification	Suppresses detailed band structure	Scheduling and comparison only
ASTM E1332	Outdoor-indoor transmission class	Transportation-type source weighting	Façade comparison, not speech-security proof
ASTM E283/E283M / E783	Laboratory or field air leakage	Steady airflow is not acoustic transmission	Closure and fault-screening evidence
Local sound intensity	Net directional energy flow at a surface	Probe phase and field limitations	Path localisation
Surface vibration	Structural response of pane or frame	Motion does not prove radiation dominance	Modal and frame-path diagnosis
Occupied speech assessment	Recoverability under a defined operational state	Listener and source assumptions	Consequence assessment

21.62 Conclusions

Glazing should be specified, tested and maintained as a complete framed system. Pane mass, stiffness, coincidence, laminate damping and cavity coupling matter, but so do gaskets, setting blocks, stops, mullions, transoms, thermal breaks, anchors, spandrels, drainage paths and perimeter joints. The installed result belongs to the actual bay, door lite or secondary window under its documented environmental and operating state.

Laboratory spectra establish bounded specimen performance. Field façade tests establish installed relations under defined source and room conditions. Local diagnostics identify paths. Occupied speech assessment evaluates consequence. Formal approval remains a separate authority decision. These layers should be preserved rather than collapsed into a single rating.

The design obligation is consequently broader than selecting “acoustic glass”; it requires product identity, representative testing, system-level details, construction surveillance, commissioning, change control and lifecycle verification. Where evidence is incomplete, the conclusion should state the uncertainty rather than assume that transparency or thickness carries an acoustic guarantee.

21.63 Chapter 21 glossary

Airblast hazard rating. A classification derived under a specified blast-test method for glazing or glazing systems. It is not an acoustic rating.

Asymmetric glazing. A multiple-pane construction using different pane masses or thicknesses to separate resonant or coincidence features.

Edge bite. The depth by which glazing is engaged within a frame, stop or structural-silicone support condition.

Exterior façade level difference. A field quantity relating exterior source level to interior receiving level under the specified method and geometry.

Glazing stop. A removable or fixed member that retains glass against a frame and usually carries a gasket or sealant interface.

Insulating-glass unit. Two or more sealed lites separated by spacers and gas cavities for thermal and other performance.

Interlayer. A polymeric layer bonding glass plies in laminated glazing and contributing adhesion, post-breakage retention and frequency-dependent shear behaviour.

Mullion. A principal vertical frame member within a glazed wall or curtain-wall system.

Outdoor-indoor transmission class. A single-number classification based on outdoor-indoor transmission loss and a prescribed source weighting. See also whole-volume glossary.

Pane coincidence. Enhanced coupling where the trace wavelength of incident sound matches a bending wavelength in a glass pane.

Pressure-equalised cavity. A façade cavity intentionally connected to the exterior through vents or weeps to manage water and pressure.

Secondary glazing. An additional independently framed glazing layer installed apart from an existing window or façade opening.

Setting block. A support element carrying glass dead load and maintaining edge clearance within a frame.

Spandrel zone. The opaque or concealed façade area commonly associated with slab edges, insulation, safing and backpans.

Structural silicone glazing. A system in which silicone adhesive transfers defined loads between glazing and frame while also contributing to the perimeter condition.

Thermal break. A low-conductivity frame element separating interior and exterior metal components, with mechanical and acoustic consequences.

Vision panel. A glazed opening within a door or opaque partition, including glass, frame, stops and seals.

Chapter 22. Floors, Ceilings, Roofs, Raised Floors, Plenums, and Structural Junctions

22.1 Horizontal boundaries are systems rather than planes

Architectural drawings often depict a floor or roof as a few horizontal lines; the physical system is more complicated; a concrete slab may carry a floating screed, raised access floor, resilient underlay, ceiling grid, service plenum, fire-resistive spray, ducts, pipework and cable routes. A timber floor may combine decking, joists, blocking, cavity absorption, resilient channels, ceiling leaves, service battens and finishes; a roof may add membrane, insulation, air and vapour control layers, structural deck, suspended ceiling, hatches, drains and plant curbs. Each component creates mass, stiffness, damping, air volume, discontinuities and junctions.

The source also changes the governing mechanism. Airborne speech acts principally through pressure loading and structural radiation; footfall, dropped objects and furniture motion introduce localised force and mobility; rooftop plant injects periodic and broadband forces through curbs, pipes and ducts; rain, hail and maintenance traffic excite the roof surface directly; services carry vibration and provide openings. A single laboratory classification cannot represent all these source-path-receiver relationships.[55]

The engineer should therefore create a horizontal-boundary schedule; it identifies the structural system, span, support, finish layers, resilient interfaces, cavities, suspended elements, services, penetrations, adjoining rooms and accessible listener locations; it separately records the as-designed, as-built and as-tested states. A ceiling tile changed after commissioning, a pedestal added beneath equipment or a pipe support

55 MB-0322. ASTM International, ASTM E90-23, ASTM E492-25.

fixed through a floating floor can alter the path without changing the room name or wall schedule.

Figure 22-1. Floor-ceiling and roof systems form a network of direct, impact, plenum and junction paths

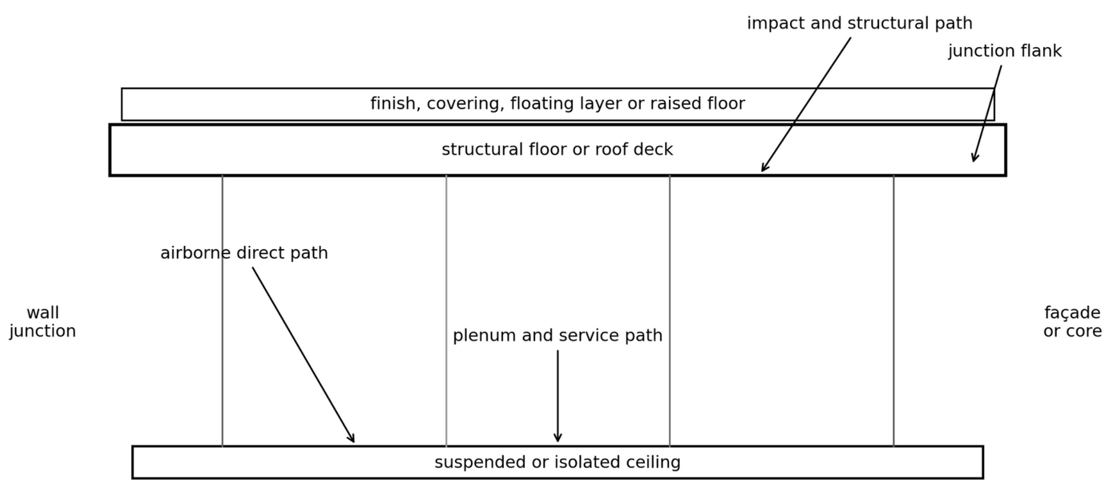

Figure 22-1. Floor-ceiling and roof systems form a network of direct airborne, impact, plenum, service and junction paths. Author's original diagram.

22.2 Evidence hierarchy and the questions each test answers

The evidence hierarchy begins with product identity, continues through complete assembly description, laboratory measurement, field verification, occupied-state assessment and formal authority disposition; ASTM E492-25 measures tapping-machine impact transmission through a floor-ceiling specimen under laboratory conditions; ASTM E1007-25 measures installed impact transmission and expressly includes associated support structures and flanking. ASTM E90-23 and ASTM E336-25a address airborne transmission in laboratory and field contexts; ASTM E1414/E1414M-21a addresses a particular ceiling-plenum laboratory configuration; none of those methods, alone, establishes occupied speech security or accreditation.[56]

Product evidence is narrower still. A suspension-grid specification establishes structural classification and tolerances within its scope. A ceiling-tile absorption test reports performance under a stated mounting; a resilient layer's dynamic stiffness describes one input to a floating-floor model; a fire-resistance listing establishes performance of the exact listed assembly under the prescribed fire exposure; these records are necessary, but they answer different questions and are not interchangeable.[57]

A publication-grade report should state the proposition before presenting the number; "the tested floor achieved IIC 56 under ASTM E492-25" is a laboratory proposition; "the installed room pair produced AIIC 50 under ASTM E1007-25" is a field proposition. "Protected speech remained unintelligible at the authorised listener positions during stated operational tests" is an occupied-performance proposition; "the competent authority accepted the room for the defined use" is an administrative proposition. Each requires its own evidence and uncertainty.

Table 22-1. Evidence classes for horizontal boundaries and the propositions they establish.

Evidence class	What it establishes	What it does not establish
Product or material standard	Identity, material properties or structural class within its scope	Completed floor, ceiling, roof or room acoustic performance
Laboratory airborne or impact test	Frequency-resolved behaviour of the exact specimen and mounting	Installed flanking, altered services, occupied speech security or accreditation
Field room-pair test	Installed apparent performance under recorded geometry and state	Unmeasured states, every adjoining space or formal acceptance
Absorption or ceiling-plenum test	Absorption or prescribed ceiling-plenum attenuation under the method	A universal material constant or complete secure-room isolation

56 MB-0297. ASTM International, ASTM E492-25, ASTM E1007-25.
57 MB-0146. ASTM International, ASTM C423, ASTM E795-23.

Evidence class	What it establishes	What it does not establish
Operational source assessment	Response to defined walking, plant, rain, rolling or speech states	General performance outside the tested state
Authority decision	Acceptance or authorisation for a defined use	A transferable laboratory or field property

22.3 Direct airborne transmission through floor and roof structures

Direct airborne transmission through a homogeneous slab is influenced by surface mass, bending stiffness, damping, modal behaviour, radiation efficiency, finite dimensions and boundary restraint; the familiar mass-law relation is a screening model for an ideal limp and infinite partition. Real floors and roofs depart from that model through plate modes, coincidence, joints, penetrations and flanking; a thick concrete slab can have excellent direct airborne insulation while the field room pair remains limited by a façade, stair, duct, raised-floor plenum or wall head.[58]

For lightweight systems, the distinction between leaves is essential; a timber deck and suspended plasterboard ceiling form a double-leaf system with a cavity; the joists, resilient channels, battens and services determine mechanical coupling; cavity absorption can reduce resonant severity but cannot repair rigid bridging. A composite steel deck and concrete topping has corrugation, ribs, fasteners, edge details and potentially a ceiling below. Its apparent mass is not a complete description of bending or junction behaviour.

Roof sound insulation also depends on the incident field. Aircraft and traffic noise require an outdoor-indoor spectrum and angle distribution different from indoor speech; rain and hail are impact sources, not merely airborne

58 MB-0324. ASTM International, ASTM E90-23, ISO 10140-2:2021.

sources; rooftop plant creates structure-borne and duct-borne paths; a roof classification derived from airborne laboratory data must therefore be supplemented by source-specific analysis and field verification where the consequence warrants it.[59]

Worked example 22.1. Surface mass of a reinforced concrete slab

Engineering question. What is the first-order surface mass of a 180 mm normal-weight reinforced concrete slab?

Let slab thickness be $h = 0.180\,m$, concrete density be $\rho_c = 2,400\,kg/m^3$, and distributed reinforcement allowance be $m'_s = 8\,kg/m^2$. The surface mass is

Equation 22.1

$$m' = \rho_c h + m'_s = (2,400)(0.180) + 8 = 440\,kg/m^2.$$

The dimensional check gives $kg/m^3 \times m = kg/m^2$. Density, moisture, voids and topping are uncertain; an illustrative combined uncertainty of 4 per cent gives approximately $440 \pm 18\,kg/m^2$. The result supports mass and structural models. It does not establish transmission loss, because stiffness, coincidence, cracks, penetrations, restraints and flanking remain omitted.

Worked example 22.2. Ideal mass-law screening

Engineering question. What ideal normal-incidence mass-law value is suggested at 250 Hz for the slab in Worked Example 22.1?

Using the common screening form

$$R \approx 20\log_{10}(m' f) - 47,$$

where $m' = 440\,kg/m^2$ and $f = 250\,Hz$,

59 MB-0208. ASTM International, ASTM E1332-22, ISO 12354-1:2017.

$$R \approx 20\log_{10}(440 \times 250) - 47 = 53.8\,dB.$$

The logarithm is applied to the numerical quantity expressed in the conventional SI reference implicit in the empirical relation; an uncertainty of 4 per cent in mass changes the result by only about 0.35 dB, but model discrepancy can be much larger near coincidence, finite-panel modes, openings and junctions. This is a screening value, not a laboratory prediction or secure-room acceptance result.

22.4 Impact excitation and the standard tapping machine

Impact sound begins with a force-time history and the driving-point mobility of the surface; the standard tapping machine provides repeatable impacts so that floor-ceiling systems can be compared. It does not reproduce a particular adult, child, heel, rolling chair, dropped object or moving equipment item; ASTM E1007-25 and ASTM E989-21 explicitly caution that the machine does not adequately evaluate the low-frequency boom, squeak, crunch or rattle that can occur in lightweight construction under human walking.[60]

The measured receiving-room spectrum is shaped by the floor's local mobility at each source position, wave propagation through the assembly, flanking into associated structure, radiation from the ceiling and the receiving room's acoustic response; a source position over a joist, rib, beam, pedestal or open bay can produce materially different results. Laboratory tests suppress flanking and seek a controlled receiving field; field tests preserve flanking and therefore describe the installed system more honestly, but with greater uncertainty and configuration dependence.[61]

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60 MB-0201. ASTM International, ASTM E1007-25, ASTM E989-21.
61 MB-0298. ASTM International, ASTM E492-25, ASTM E1007-25.

The tapping-machine rating remains useful when its limits are respected; it supports procurement and comparison, especially for concrete floors and conventional assemblies; it should be supplemented by low-frequency metrics, soft-impact sources, instrumented footfall or operational measurements when the threat model includes lightweight floors, sensitive listeners or high-consequence spaces. The selection of supplementary source must be documented, because an unstandardised test can be diagnostically powerful without being suitable for contractual classification.

Figure 22-2. Laboratory and field impact measurements require a defined source, specimen, receiving room and metric

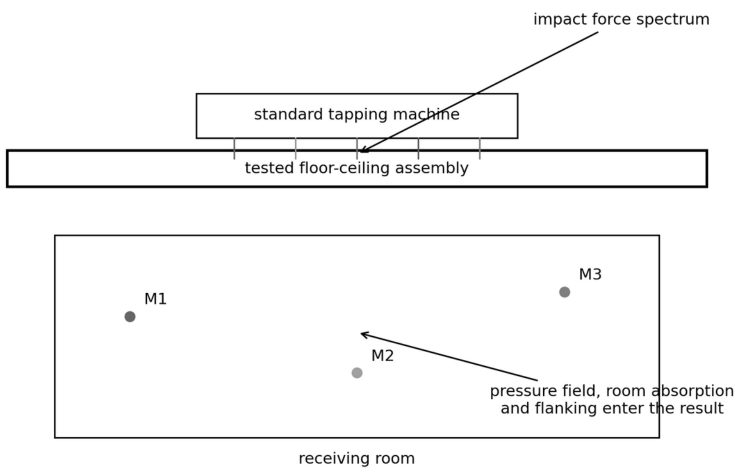

Figure 22-2. Laboratory and field impact measurements require a defined source, specimen, receiving room, microphone distribution and reportable metric. Author's original diagram.

Worked example 22.3. Absorption-normalised impact level

Engineering question. How does receiving-room absorption affect a normalised impact level?

Suppose the spatially averaged impact sound pressure level in one band is $L_i = 47.0\, dB$, the equivalent absorption area is $A = 18.0\, m^2$, and the reference absorption area is $A_0 = 10.0\,m^2$. A representative absorption-normalised form is

$$L_n = L_i + 10\log_{10}\left(\frac{A}{A_0}\right) = 47.0 + 10\log_{10}(1.8) = 49.6\,dB.$$

Both areas use square metres, so the ratio is dimensionless. If A has 10 per cent relative standard uncertainty and level repeatability is 0.6 dB, first-order combination gives roughly 0.75 dB standard uncertainty before method and spatial terms. The calculation shows why room absorption must be measured or otherwise controlled. It does not transform a field result into a laboratory specimen property.[62]

22.5 Low-frequency footfall, soft impacts and occupant perception

Human walking produces forces governed by body mass, stride, footwear, gait, cadence, floor compliance and behavioural context; the force contains a fundamental near the step frequency and harmonics that can excite floor modes. Lightweight timber and steel systems often radiate strongly below the conventional tapping-machine emphasis, and the subjective response can be influenced by both audible sound and felt vibration; research on timber floors has therefore examined frequencies down to 20 Hz, source-position sensitivity and the imperfect correlation between standard ratings and natural impacts.[63]

A secure-room threat model differs from a residential annoyance model, yet the physics remains relevant; footfall above a room can modulate ceiling fixtures, create rattles, alter microphone noise floors and mask or reveal

62 MB-0296. ASTM International, ASTM E492-25, ASTM E1007-25.
63 MB-1001. Jorgen Olsson and Andreas Linderholt, Low-frequency impact sound of timber floors: A finite element-based study of conceptual designs.

speech in time-varying ways. Conversely, low-frequency vibration from the protected room can travel through a lightweight floor and radiate in an accessible space; standard impact ratings should not be used as a proxy for information recovery, but low-frequency weaknesses can identify paths that deserve speech-correlated measurement.

Soft-impact sources, instrumented hammers and operational walking trials can supplement the standard tapping machine; their force spectra and reproducibility must be recorded; a heavy ball may better excite low-frequency modes, but the resulting metric belongs to that source and procedure. Natural walkers improve operational realism but introduce person-to-person variability; a bounded programme can use a standard source for comparison, a calibrated force input for transfer functions and representative operational sources for consequence assessment.

Worked example 22.4. Stride frequency and structural harmonics

Engineering question. Which periodic forcing components arise from a person walking at 108 steps per minute?

The step frequency is

$$f_s = \frac{108}{60} = 1.80\, Hz\,.$$

The first five harmonics occur at 1.8, 3.6, 5.4, 7.2 and 9.0 Hz; frequency has units of inverse seconds; a floor mode at 7.0 Hz lies close to the fourth harmonic and may be excited efficiently, depending on modal overlap and force distribution. Cadence variation of plus or minus 5 per cent moves the fourth harmonic from 6.84 to 7.56 Hz; this calculation identifies a resonance risk; it does not predict radiated sound without modal mass, damping, force spectrum and radiation data.

22.6 Heavy concrete floors and their limits

Concrete floors provide surface mass, continuity and robustness, but they also couple large areas of the structure; direct airborne transmission through the slab may be small while impact energy travels into walls, columns, beams and façade anchors; post-tensioning, ribbed construction, transfer slabs, construction joints and penetrations alter mobility. The relevant apparent result is therefore not the isolated slab's laboratory curve but the sum of direct and flanking paths in the completed building.[64]

Floating toppings can improve impact performance, but a stiff perimeter bridge, pipe penetration, threshold or equipment anchor can short-circuit the resilient layer; a thick screed also changes structural load and may influence slab modes; if the protected room lies below a mechanical floor, impact and machinery forces require separate source models. A tapping-machine result does not describe pump, chiller, transformer or rolling-load excitation.

Concrete construction is often treated as dimensionally stable; in practice, shrinkage, creep, deflection, thermal movement and cracking influence the interfaces to walls and ceilings; a movement joint that is acoustically sealed at handover may open under seasonal or long-term deformation. A rigid seal can crack; an over-soft seal can transmit air through an excessive gap or fail fire requirements; the construction record must therefore preserve joint geometry, movement range, backing and compatible sealant.

64 MB-0845. International Organization for Standardization, ISO 12354-1:2017, ISO 12354-2:2017.

Table 22-2. Principal floor and roof systems, dominant mechanisms and recurrent field limits.

System	Dominant mechanisms	Recurrent field limits
Monolithic concrete slab	Mass, plate modes, coincidence, structural continuity	Cracks, slab-edge flanking, penetrations and attached plant
Hollow-core or ribbed unit	Directional stiffness, voids, keys and end conditions	Core continuity, topping, service penetrations and bearing junctions
Timber joist or mass-timber floor	Orthotropy, low mass, discrete ribs, fastener slip and cavity response	Low-frequency footfall, joints, service paths and ceiling bridges
Composite steel-deck floor	Ribbed steel, concrete topping, beams and directional plate behaviour	Deck orientation, fire protection, supports and ceiling condition
Floating floor	Distributed mass-spring-damper isolation	Edge bridges, point loads, penetrations, creep and threshold details
Raised access floor	Removable panel radiation, pedestal paths and plenum continuity	Perimeter gaps, grommets, service changes and rattle
Roof-ceiling system	Exterior airborne loading, rain impact, plant force and deck radiation	Curbs, hatches, drains, wind, seasonal state and wall-head paths

22.7 Hollow-core, post-tensioned and composite floors

Hollow-core units introduce longitudinal voids, grouted keys, end bearings and closure conditions; air and vibration can propagate along cores, especially where services penetrate or end seals are incomplete; a topping may improve continuity and mass, but it can also couple units and create a broad radiating plate. Field diagnosis should compare response along and across the unit direction and inspect end conditions rather than assuming isotropy.

Post-tensioned slabs contain tendons, anchorages and stressed continuity; coring and later penetrations require structural control, and an acoustic remediation must never compromise tendon safety; from an acoustic perspective, post-tensioning can alter cracking and stiffness, but the room result remains dominated by the complete structural topology. Transfer plates and drop panels can create low-frequency flanking paths into cores and columns.

Composite steel-deck floors combine a ribbed steel sheet, concrete, shear connection and supporting beams; the deck geometry creates directional stiffness and cavities; spray-applied fire protection, ceiling systems and services add further layers. A suspended ceiling can reduce radiation into the room below, but hangers, edge contacts and penetrations determine whether the improvement survives installation; laboratory data for a nominal deck depth and topping should not be transferred to a different span, rib orientation or ceiling without evidence.[65]

Worked example 22.5. Directional bending-stiffness screen

Engineering question. How should a directional floor be flagged when one axis is four times as stiff as the other?

Let the effective flexural rigidities be $D_x = 48\,kNm$ and $D_y = 12\,kNm$ per representative strip. The stiffness ratio is

$$\gamma_D = \frac{D_x}{D_y} = 4.0\,.$$

The ratio is dimensionless. For otherwise similar mass and span, bending-wave and modal behaviour will differ by direction; natural frequencies scale approximately with the square root of stiffness, giving an indicative ratio $\sqrt{4} = 2$. This is not a complete plate solution because boundary conditions, orthotropy, span and coupling are omitted. It justifies directional source positions and vibration measurements.

65 MB-0323. ASTM International, ASTM E90-23, ASTM E492-25.

22.8 Timber joist, mass-timber and hollow-box floors

Lightweight timber floors combine low mass, directional stiffness, discrete joists or ribs, cavity modes, fastener slip and potentially strong low-frequency radiation; a ceiling below may create a double-leaf system whose performance depends on resilient suspension and cavity absorption. Additional mass can improve airborne isolation and alter impact response, but it can also lower modes or increase force transmission if added without decoupling.

Mass-timber panels and hollow-box elements do not behave as scaled concrete slabs; their orthotropy, joints, splines, screws, rib cavities and edge supports matter. Research has shown that hollow-box timber systems can achieve a wide range of performance depending on cavity fill, added mass and the dynamic stiffness of the floating floor; the best laboratory configuration does not eliminate field risks at panel joints, service openings and façade connections.[66]

Low-frequency impact is especially important. ASTM E989-21 states that the conventional rating does not address the boom below 100 Hz often associated with lightweight joist floors. ASTM E3207-21 provides supplemental low-frequency ratings but cautions that they are not interchangeable with IIC and that uncertainty increases at low frequencies. A design should therefore preserve the full spectrum and, where consequences justify it, include operational footfall and vibration assessments.[67]

66 MB-1000. Jorgen Olsson and Andreas Linderholt, Low-frequency impact sound of timber floors: A finite element-based study of conceptual designs.
67 MB-0344. ASTM International, ASTM E989-21, ASTM E3207-21.

Worked example 22.6. Approximate modal frequency of a simply supported joist

Engineering question. What first bending frequency is suggested for an ideal joist span?

For an illustrative simply supported beam,

$$f_1 = \frac{\pi}{2L^2}\sqrt{\frac{EI}{\mu}},$$

where $L = 5.0\,m$, $EI = 5.0 \times 10^6\,N\,m^2$, and mass per unit length $\mu = 55\,kg/m$. Then

$$f_1 = \frac{\pi}{2(5.0)^2}\sqrt{\frac{5.0 \times 10^6}{55}} = 18.9\,Hz.$$

The units reduce from $\sqrt{N\,m^2/(kg/m)}/m^2$ to s^{-1}. Real floors include sheathing, composite action, continuity, damping and distributed joists. The value is a modal screen and supports low-frequency test planning; it does not predict room sound level.

22.9 Floating floors as distributed isolation systems

A floating floor comprises a rigid or semi-rigid upper plate supported by a resilient layer and separated from the base structure at its perimeter and penetrations; its first-order behaviour resembles a distributed mass-spring-damper system; useful isolation occurs above resonance; below resonance, the upper mass follows the base; near resonance, response can be amplified. The design therefore seeks sufficient floating mass, low and stable dynamic stiffness, suitable damping and complete edge isolation.[68]

The resilient layer is not characterised adequately by static compressibility alone; dynamic stiffness depends on material, thickness, preload, frequency,

68 MB-0907. International Organization for Standardization, ISO 9052-1:1989.

temperature, ageing and contact condition; a material that is soft initially may creep under sustained load and become thinner or stiffer; research over extended periods has demonstrated that time-dependent changes can reduce impact performance. The design should therefore include long-term load, construction moisture, equipment point loads and replacement access.[69]

The floating plate also requires structural design; screeds need reinforcement or fibres, crack control, curing and load distribution; dry systems need board joints, staggered layers, fasteners and load-spreading plates; a discontinuous upper plate can radiate locally or rock on the resilient layer. A very rigid plate can distribute load favourably but transfer force efficiently through any bridge.

69 MB-0014. Alessandro Schiavi, Andrea Pavoni Belli and Francesco Russo, Estimation of Acoustical Performance of Floating Floors from Dynamic Stiffness of Resilient Layers.

Figure 22-3. A floating floor is a distributed mass-spring-damper system vulnerable to local bridges

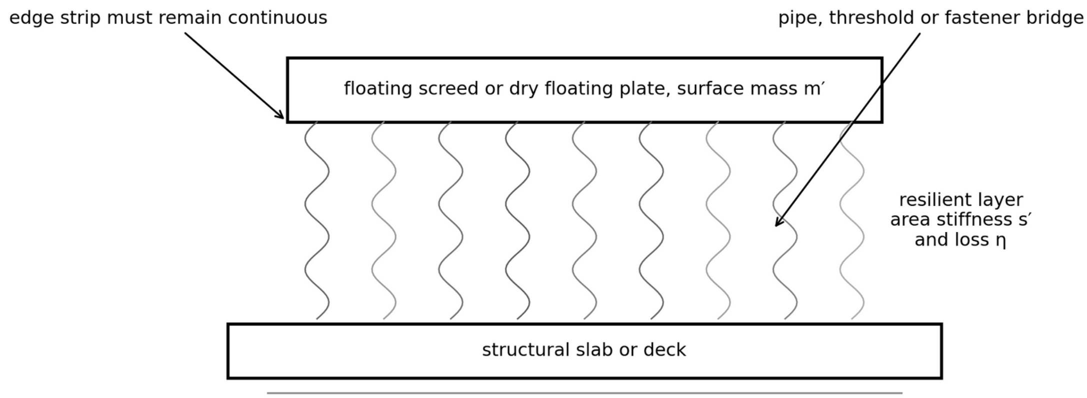

Figure 22-3. A floating floor is a distributed mass-spring-damper system whose useful isolation depends on dynamic stiffness, surface mass, damping and complete edge isolation. Author's original diagram.

Worked example 22.7. Floating-floor natural frequency

Engineering question. What ideal resonance is suggested by a floating plate with surface mass $m'=110\,kg/m^2$ over a resilient layer of dynamic stiffness per unit area $s'=18\,MN/m^3$?

For a rigid plate over a distributed spring,

Equation 22.2

$$f_0=\frac{1}{2\pi}\sqrt{\frac{s'}{m'}}.$$

Substitution gives

$$f_0=\frac{1}{2\pi}\sqrt{\frac{18\times10^6}{110}}=64.4\,Hz.$$

Because s' has units $N/m^3=kg/\left(m^2 s^2\right)$, division by kg/m^2 gives s^{-2}. A 15 per cent standard uncertainty in dynamic stiffness and 5 per cent in mass produce about 8 per cent relative uncertainty in frequency, or roughly 5 Hz. The model omits finite plate modes, air stiffness, bridges, nonlinear compression and damping. It identifies a critical band but does not establish impact rating.

Worked example 22.8. Ideal force transmissibility above resonance

Engineering question. What ideal force transmissibility occurs at 160 Hz for the system in Worked Example 22.7 with damping ratio $\zeta = 0.08$?

The frequency ratio is $r = 160/64.4 = 2.48$. For a damped single-degree system,

$$T_F = \frac{\sqrt{1 + (2\zeta r)^2}}{\sqrt{(1 - r^2)^2 + (2\zeta r)^2}} = 0.207.$$

This corresponds to $20 \log_{10}(0.207) = -13.7\, dB$ in force amplitude. The ratio is dimensionless. Distributed plates, resilient-layer waves, perimeter bridges and service penetrations can make the actual result worse. The calculation supports resonance and isolation-band interpretation only.

22.10 Perimeter strips, thresholds and local bridges

The perimeter is the most common point at which a floating-floor concept becomes an ordinary rigid floor; the resilient layer must continue beneath the plate and rise at walls, columns, curbs and penetrations; screed, grout, skirting, door frames, thresholds and finishes must not create a rigid connection. Edge strips are often cut too early, buried by wall finishes or bridged by sealant that cures much stiffer than anticipated.

Doors are especially difficult. The floating finish may need to meet a fixed threshold and automatic door bottom; a rigid threshold anchor can bridge the system; a soft or discontinuous threshold can impair accessibility, latching, fire or smoke performance; the solution must coordinate Chapter 20's door system with the floor's movement and isolation. The tested door assembly and the floating-floor detail cannot be designed independently.

Penetrations create similar conflicts. Pipe sleeves need fire stopping, movement and acoustic closure. Equipment anchors need structural capacity. Raised bases and cabinets need point-load distribution; a bridge that occupies only a minute fraction of area can dominate high-isolation performance because transmission coefficients combine linearly before conversion to decibels.

Worked example 22.9. Composite effect of a rigid bridge

Engineering question. How can a small bridged area affect a floating floor's band performance?

Assume 40 m² of floating floor has effective transmission coefficient $\tau_f = 10^{-55/10} = 3.16 \times 10^{-6}$. A rigidly bridged service base occupies 0.010 m² and has $\tau_b = 10^{-15/10} = 0.0316$. The area-weighted coefficient is

$$\tau_c = \frac{(39.99)\tau_f + (0.010)\tau_b}{40} = 1.11 \times 10^{-5},$$

so

$$R_c = -10 \log_{10}(\tau_c) = 49.5\, dB.$$

A bridge occupying 0.025 per cent of area reduces the illustrative result by about 5.5 dB; real bridge transmission is not purely area controlled and can inject structure-borne energy beyond its footprint; the example demonstrates sensitivity, not a field prediction.

Table 22-3. Floating-floor failure modes, expected signatures and discriminating evidence.

Failure mode	Likely signature	Discriminating evidence	Repair constraint
Perimeter screed bridge	Broad reduction in improvement, often near walls	Edge tapping, vibration and controlled saw-cut or temporary separation	Maintain fire, finish and movement requirements
Pipe or conduit bridge	Localised response near penetration with structural coherence	Local impact, accelerometers and temporary decoupling	Preserve support, fire stopping and service movement
Threshold bridge	Weakness at door line and repeated impact response	Threshold contact survey and comparative source positions	Coordinate accessibility, latching and Chapter 20 door performance
Resilient-layer creep or stiffening	Resonance shifts upward and impact reduction declines	Dynamic-stiffness data, load history and repeated spectra	Verify long-term load capacity and material compatibility
Upper plate cracking or rocking	Position-dependent response, rattles or nonlinear behaviour	Modal scan, visual mapping and amplitude variation	Structural repair must preserve isolation
Equipment point-load bypass	Local high mobility and pedestal or base transmission	Load map, support inspection and mobility comparison	Provide independent support or load spreading

22.11 Floor coverings and the limits of delta ratings

Carpet, resilient sheet, underlay, rubber, cork and other floor coverings can reduce the force transmitted by the tapping machine, particularly at mid and high frequencies; ASTM E2179-25 provides a laboratory method for characterising coverings on a standard concrete floor; it warns that difference spectra should not be used to estimate performance on lightweight joist floors or certain concrete-topped lightweight systems. The same product can therefore produce different IIC outcomes on different base floors.[70]

A delta rating should be preserved with its spectrum and reference floor. Applying a catalogue ΔIIC to an unrelated assembly can create a numerically precise but physically invalid prediction. The covering also ages, compresses, becomes wet, is replaced or is interrupted beneath partitions

70 MB-0225. ASTM International, ASTM E2179-25.

and thresholds. In secure facilities, operational requirements may favour hard and cleanable finishes, so impact control must be achieved through the complete floor rather than assumed from carpet.

High-frequency improvement can coexist with low-frequency weakness; a soft covering reduces contact force for the tapping machine but does not necessarily control whole-floor deflection or a heavy dropped object; it may also alter rolling noise and static generation. Selection should consider the source spectrum, maintenance, fire, accessibility, durability and the building's base floor.

Worked example 22.10. Applying a difference spectrum cautiously

Engineering question. What preliminary covered-floor spectrum follows from a measured bare concrete level and a valid covering difference spectrum?

At 500 Hz, let the bare normalized impact level be 70 dB and the laboratory covering reduction be 18 dB. The preliminary estimate is

$$L_{n,covered} = 70 - 18 = 52\,dB.$$

If the bare-floor result has 1.2 dB standard uncertainty and the covering difference has 1.5 dB, independent combination gives $\sqrt{1.2^2 + 1.5^2} = 1.9\,dB$. Base-floor mismatch, installation and ageing add model uncertainty. The calculation is admissible only for a compatible concrete reference context and does not justify transfer to timber or composite floors.[71]

71 MB-0226. ASTM International, ASTM E2179-25, ISO 717-2:2020.

22.12 Raised access floors and removable plate radiation

Raised access floors provide flexibility but create a second horizontal boundary above the structural slab. Panels rest on pedestals and sometimes stringers; perimeter cut panels, service outlets, grommets, ramps and access hatches interrupt continuity; the underfloor plenum can connect rooms and carry power, fibre, copper, air distribution and controls; the system therefore combines plate radiation, pedestal force paths, air leakage and service continuity.[72]

Panel construction matters. Steel-encapsulated, cementitious-filled, wood-core and calcium-sulphate panels have different mass, stiffness, damping and fire behaviour; the removable joint is integral to the system; a gasket can reduce rattle and leakage but may age or be omitted after maintenance. A heavy panel can have good local airborne performance while the perimeter gap or cable opening governs.

ISO 10848-2:2017 treats access floors as Type B elements and notes that sound may transmit through the test element and the plenum simultaneously, without separation in the measured total. That limitation is directly relevant to secure-room diagnosis. A good panel is not proof of a secure underfloor boundary.[73]

72 MB-0831. International Organization for Standardization, ISO 10848-2:2017.
73 MB-0828. International Organization for Standardization, ISO 10848-2:2017.

Figure 22-4. Raised access floors combine removable plate radiation, pedestal coupling and plenum continuity

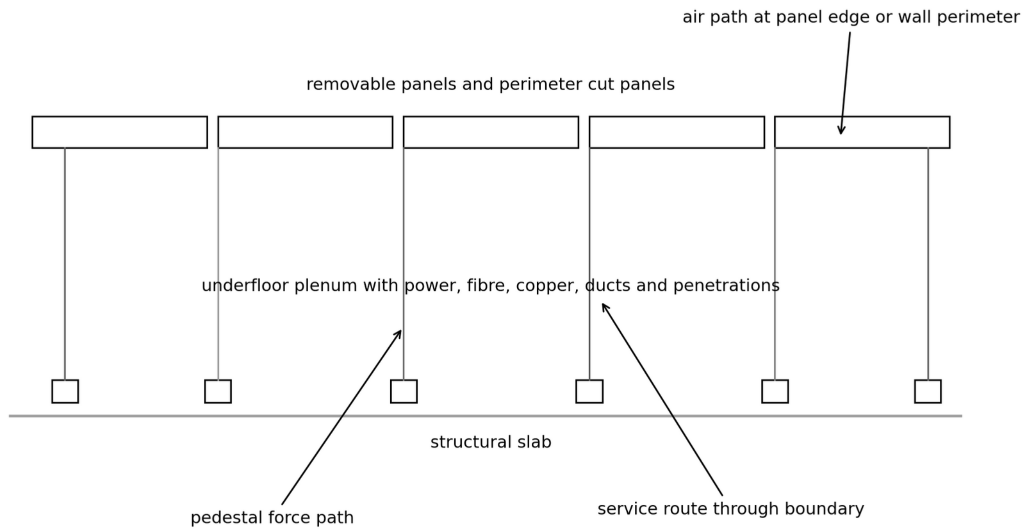

Figure 22-4. Raised access floors combine removable plate radiation, pedestal coupling, perimeter gaps and service-plenum continuity. Author's original diagram.

Worked example 22.11. Cable-grommet opening fraction

Engineering question. What open-area fraction is created by four unsealed 50 mm diameter cable holes in a 36 m² raised-floor zone?

Total opening area is

$$S_o = 4\pi(0.025)^2 = 0.00785\, m^2.$$

The fraction is

$$\alpha_o = \frac{0.00785}{36} = 2.18 \times 10^{-4},$$

or 0.0218 per cent. The area ratio is dimensionless. At high isolation, treating the holes as open can produce a dominant transmission coefficient despite the small fraction; cable fill, tortuosity and underfloor geometry reduce transmission from the ideal-open assumption, but the calculation justifies sealing and field verification.

22.13 Pedestals, stringers and equipment support

Pedestals are discrete structural contacts. Their spacing, base adhesive, head connection, stringers, bracing and slab attachment determine stiffness and force transmission; a cabinet placed across several panels can distribute load; a heavy safe or equipment rack can concentrate it, crush gaskets or require separate support. An isolated pedestal system designed for ordinary office loads may be unsuitable for large static or seismic loads.

The acoustic effect is not captured by panel surface mass alone; impact on a panel excites bending, joint motion and pedestal forces; pedestal bases inject energy into the structural slab, which can flank into walls and adjacent rooms. Loose heads or stringers rattle. Adhesive degradation changes mobility. A floor that tested well when new can become noisier after repeated access or reconfiguration.

For secure rooms, equipment support should be classified as either part of the raised floor, independently supported through it or isolated from it; each option changes vibration and penetration control; a penetration through the raised floor may also breach a fire or air boundary at the structural slab. Drawings must show the full load and path, not merely the equipment footprint.

Worked example 22.12. Pedestal load and resilient-pad pressure

Engineering question. What static pressure acts on a 100 mm by 100 mm pedestal pad supporting 4.8 kN?

Pad area is $A_p = 0.100 \times 0.100 = 0.0100\, m^2$. Pressure is

$$p = \frac{4,800}{0.0100} = 480\, kPa.$$

The units are newtons per square metre; if load uncertainty is 10 per cent and effective contact area 8 per cent, combined relative standard uncertainty is about 13 per cent; the pressure must be compared with the pad's static and long-term compression properties. It does not establish dynamic stiffness or acoustic isolation.

22.14 Underfloor services, air distribution and boundary crossings

The underfloor plenum often becomes a distribution space. Low-voltage cables may cross the protected perimeter through brush strips, sleeves or open gaps; power conduits, floor boxes, air diffusers and sensors add further openings; an air-distribution plenum requires pressure control and leakage management; the same opening that supplies conditioned air can transmit speech.[74]

The design should distinguish a room-local raised-floor cavity from a shared plenum; a room-local cavity terminates at a sealed perimeter and at controlled penetrations through the structural slab or wall; a shared plenum may bypass partitions, doors and upper wall construction. A barrier installed beneath a partition must accommodate pedestals, stringers, cables, floor movement and fire stopping; it requires inspection before panels are closed.

Maintenance is a major risk. Panels are removed, cables added and grommets displaced; the original photograph may no longer describe the state; a controlled access procedure should record panel location, service changes, seal condition and reinstatement; periodic underfloor inspection should be proportionate to the classification or sensitivity of use and the rate of change.

74 MB-0829. International Organization for Standardization, ISO 10848-2:2017.

22.15 Suspended ceilings: absorption is not isolation

An acoustical lay-in ceiling is commonly selected for sound absorption, appearance and service access. Its noise reduction coefficient or absorption coefficients do not establish sound isolation between rooms. Absorption reduces reverberant energy within a room under the tested mounting. Interroom attenuation depends on panel transmission, grid, perimeter, plenum, partition head, penetrations and services.[75]

A highly absorptive tile may be porous and have limited barrier performance; a dense tile may provide better plenum attenuation but less absorption. Manufacturers may offer composite or backed panels, yet the exact suspension and plenum depth remain important; ASTM E1414/E1414M-21a ranks ceiling systems under prescribed laboratory conditions and warns that field performance can differ significantly when plenum depth, ducts, beams and other conditions change.[76]

Secure-room design should generally avoid relying on a shared lay-in ceiling as the primary boundary; a deck-to-deck wall or independent ceiling may be required by the design basis; where access above the ceiling remains necessary, hatches and removable panels become controlled openings. The ceiling's role should be stated: absorption, architectural finish, fire-resistive membrane, airborne barrier, isolated lining or some combination. Each role has different evidence.

75 MB-0147. ASTM International, ASTM C423, ASTM E795-23.
76 MB-0211. ASTM International, ASTM E1414.

Figure 22-5. A ceiling with a shared plenum is an interroom path, not merely an absorptive finish

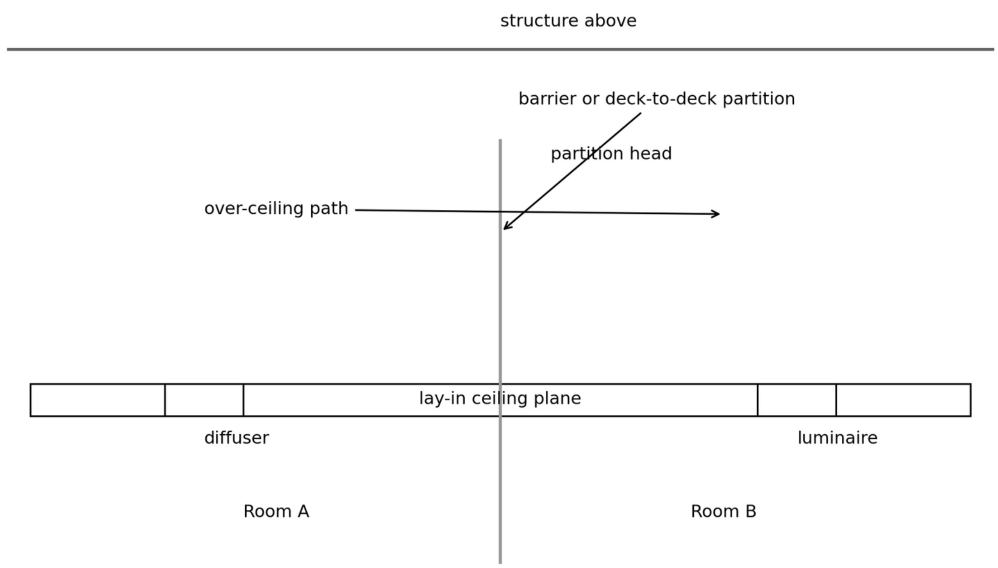

Figure 22-5. A ceiling with a shared plenum is an interroom path rather than merely an absorptive finish. Author's original diagram.

Worked example 22.13. Reverberation effect of added ceiling absorption

Engineering question. What first-order reverberation-time change follows when a 90 m² ceiling changes from average absorption coefficient 0.15 to 0.75 in a 300 m³ room, with other absorption 35 m² sabins?

Initial absorption is $A_1 = 35 + 90(0.15) = 48.5\,m^2$. Final absorption is $A_2 = 35 + 90(0.75) = 102.5\,m^2$. Using Sabine's relation,

$$T_{60,1} = 0.161\frac{300}{48.5} = 0.996\,s\,, T_{60,2} = 0.161\frac{300}{102.5} = 0.471\,s\,.$$

The calculation assumes diffuse fields and frequency-appropriate absorption. It demonstrates an interior decay benefit. It says nothing about ceiling-plenum isolation or speech transmission into another room.[77]

77 MB-0149. ASTM International, ASTM C423, ISO 3382-2:2008.

22.16 Common plenums, ceiling attenuation and partitions

A partition terminating at the ceiling plane leaves a path over its head. Sound passes through the source-room ceiling, across the plenum and through the receiving-room ceiling; ducts, luminaires, cable trays and beams alter the field and can provide additional paths; ASTM E1414/E1414M-21a provides a standardised laboratory ranking but emphasises that its measured attenuation is not a fundamental material property and that field conditions may differ.[78]

A partition extending through the ceiling to the structural deck can close the plenum path, but only if the head is sealed and services are controlled; a plenum barrier can help where deck-to-deck construction is impracticable, yet it must intersect the ceiling, walls, services and structure continuously. Thin barriers can flap or be punctured; fire and seismic requirements can conflict with rigid closure.

The result should be modelled in linear power terms; source-room ceiling transmission, plenum propagation, barrier insertion, receiving-room ceiling transmission and direct partition transmission may operate in parallel; a single ceiling attenuation class cannot be added arithmetically to wall STC. The complete path needs frequency-resolved measurement or a validated model.

Worked example 22.14. Combining direct wall and plenum paths

Engineering question. What combined band attenuation follows from two parallel paths of 58 dB and 46 dB?

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78 MB-0211. ASTM International, ASTM E1414.

Convert each attenuation to a power ratio:

$$\tau_1 = 10^{-58/10} = 1.58 \times 10^{-6}, \tau_2 = 10^{-46/10} = 2.51 \times 10^{-5}.$$

For equal reference coupling, the combined ratio is $\tau_c = 2.67 \times 10^{-5}$, giving

$$R_c = -10 \log_{10}(\tau_c) = 45.7\, dB.$$

The stronger 58 dB path adds little because the 46 dB plenum path dominates; actual area, source coupling and receiving absorption must be included in a project model; the example explains why upgrading the wall alone can fail.

22.17 Grid mechanics, panel fit and service devices

A suspended ceiling grid is a structural network. Main runners, cross tees, hangers, perimeter angles and locking details support panels and service devices. ASTM C635/C635M-22 classifies grid structural performance, while ASTM C636/C636M-19(2025) addresses installation. Those documents do not rate room isolation, though they recognise that additional detailing may be required for sound attenuation and fire-resistive assemblies.[79]

Panel fit influences leakage and rattle. A panel that rocks, is cut short or is held open by cables creates a path; hold-down clips can improve contact but affect access and seismic movement; gaskets can reduce leakage but must remain compatible with the grid and fire listing. Tegular edges, concealed grids and metal pan systems behave differently from square lay-in mineral fibre.

Luminaires, diffusers, speakers, sprinklers and access panels replace ceiling area with devices of different mass and leakage; a tested composite ceiling

79 MB-0165. ASTM International, ASTM C635, ASTM C636.

must match device type and location. Field substitutions can be decisive. A luminaire with an open return slot or a loudspeaker back-can omission may defeat the intended barrier; the ceiling coordination drawing should therefore be an acoustic document, not merely a reflected-ceiling plan.

Table 22-4. Ceiling and plenum configurations, useful evidence and principal limitations.

Configuration	Useful evidence	Principal limitation
Lay-in absorptive ceiling below deck-to-deck wall	C423 absorption and room decay measurements	Absorption does not establish interroom isolation
Partition terminating at ceiling with common plenum	E1414 laboratory comparison and field room-pair data	Plenum depth, devices, ducts and field geometry can dominate
Plenum barrier at partition line	Barrier construction record and before/after field test	Services and perimeter interfaces can bypass the barrier
Independent gypsum ceiling	E90 specimen data, hanger dynamics and field measurement	Perimeter, devices, restraints and services can short-circuit isolation
Fire-resistive suspended membrane	Fire listing plus acoustic evidence for exact configuration	Acoustic substitutions may invalidate fire basis and vice versa
Clouds or baffles under open structure	C423 absorption and occupied-room decay	No continuous ceiling plane exists for interroom attenuation

22.18 Independent and isolated ceilings

An independent ceiling can add a substantial second leaf beneath a floor or roof. It may be supported on independent framing or resilient hangers and can contain multiple gypsum layers, damping, cavity absorption and services. Its value depends on separation, mass, stiffness, cavity depth, hanger dynamics, perimeter isolation and avoidance of bridges. The system must also carry its dead load, access loads and supported equipment.[80]

A resilient hanger behaves as a spring-damper system; isolation begins only above its resonance. A hanger selected for high load can be too stiff at low frequency; a soft hanger can deflect excessively or become unstable;

80 MB-0167. ASTM International, ASTM C635, ASTM C636.

services, sway braces, perimeter tracks and access hatches can bypass it; seismic restraints may be required and should remain slack or otherwise configured as designed during normal operation, while still providing life safety under earthquake motion.[81]

The ceiling leaf itself has modes and coincidence behaviour; additional layers increase mass but also dead load; staggered joints and damping can improve robustness; a large access panel is an operable opening and should be treated like a small door. Recessed lights and speakers need independent support and sealed enclosures where required.

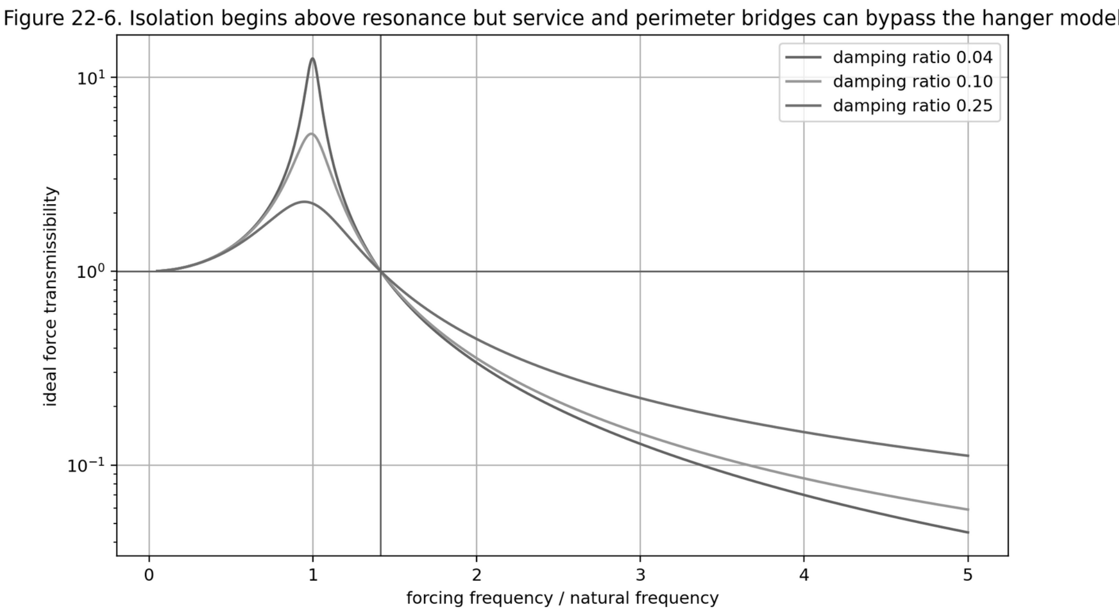

Figure 22-6. Ideal hanger transmissibility improves above resonance, but perimeter contacts, services and restraints can bypass the model. Author's original calculation plot.

Worked example 22.15. Hanger natural frequency

Engineering question. What natural frequency results when one hanger supports 900 N and has static deflection 18 mm?

81 MB-0306. ASTM International, ASTM E580.

For an ideal vertical spring under gravity, $f_n = (2\pi)^{-1}\sqrt{g/\delta}$, where $g = 9.81\,m/s^2$ and $\delta = 0.018\,m$:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{9.81}{0.018}} = 3.72\,Hz.$$

The load cancels because stiffness equals load divided by deflection; if deflection varies by 15 per cent, frequency varies by about 7.5 per cent; the result assumes linear static-dynamic equivalence and vertical motion; rubber, springs, geometry and preload may produce different dynamic stiffness. The calculation does not include service bridges or ceiling modes.

22.19 Hanger layout, supports and restraint conflicts

Hanger spacing controls load distribution, local ceiling deflection and dynamic coupling. Concentrated devices require independent support. If a heavy luminaire shares the isolated ceiling frame, it changes mass and local modes; if it is supported directly from structure, its trim and conduit can bridge the ceiling; the coordination detail must state which support is acoustically and structurally intended.

Perimeter conditions are equally important. A ceiling that is rigidly fixed to every wall can transmit vibration into the room boundary; a floating perimeter needs a controlled gap and flexible seal, but fire, smoke and seismic requirements may demand restraint; the solution should be designed explicitly rather than improvised by the installer. ASTM E580/E580M-24a places seismic decisions under the authority having jurisdiction and includes prescriptive restraint conditions; it does not establish acoustic isolation.[82]

82 MB-0303. ASTM International, ASTM E580.

Sway braces and snubbers can remain disengaged under ordinary vibration while limiting extreme movement; their clearances should be inspected and recorded; a brace that bears continuously becomes a rigid bridge; a restraint installed after acoustic commissioning can change the result. The lifecycle register should therefore include ceiling restraints and their normal operating clearance.

22.20 Roof decks, rain, hail and exterior source states

Roofs receive sources not normally applied to interior floors; rain and hail generate distributed impacts whose spectra depend on drop size, velocity, membrane, insulation, deck and interior lining; aircraft and traffic produce oblique airborne incidence; rooftop plant and foot traffic add structure-borne forces. Thermal movement and wind alter joints and curbs. A secure-room roof must be assessed against the authorised source states and accessible exterior locations.

Metal decks can be light and efficient radiators; insulation and membrane add damping and distribute impact but do not necessarily produce high airborne isolation; concrete roofs provide mass but transmit plant vibration through curbs and supports; timber roofs can exhibit low-frequency modes. An isolated ceiling below can improve the interior result if its supports and penetrations remain controlled.

Roof hatches, skylights, vents, drains, overflow scuppers and smoke-control openings are weak paths; a hatch must seal under weather, movement and repeated access. A drain connects to pipework. A roof curb transfers force and creates flashing and air-seal interfaces; the roof plan should therefore include an acoustic penetration schedule and a maintenance-state test plan.

22.21 Roof curbs, mechanical plant and structural interfaces

A rooftop unit may be isolated at the curb, at internal equipment mounts or both; the curb must carry gravity, wind and seismic loads while controlling vibration; flexible connectors in ducts and pipes can reduce force transmission but require alignment and maintenance. A short-circuited connector, hard conduit or condensate line can bypass the isolation.

The deck beneath the curb can be locally flexible. A stiff curb on a light deck may excite a large radiating area; adding mass locally may shift modes without reducing force; a structural frame that carries equipment to columns can reduce deck excitation but can transmit vibration into the building core; the appropriate route depends on source spectrum and receiving locations.[83]

83 MB-0060. ASHRAE, ASHRAE Handbook - HVAC Applications.

Figure 22-7. Roof assemblies couple exterior loading, rooftop plant, deck flanking and wall-head movement

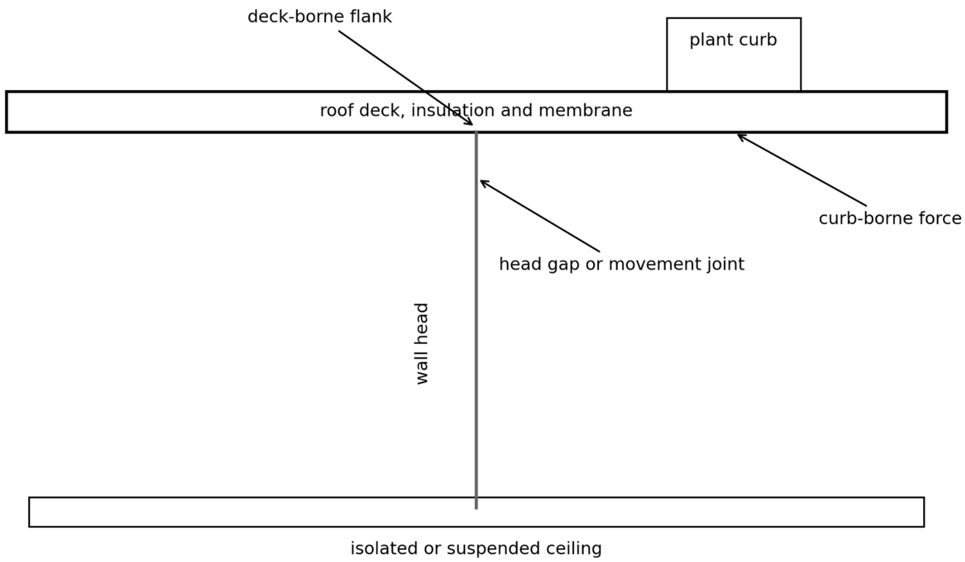

Figure 22-7. Roof assemblies couple exterior loading, rooftop plant, deck flanking and wall-head movement. Author's original diagram.

Worked example 22.16. Isolation efficiency of a rooftop spring mount

Engineering question. What ideal isolation is suggested for plant forcing at 30 Hz on mounts with 5 Hz natural frequency and damping ratio 0.08?

The frequency ratio is $r=30/5=6$. Using the force-transmissibility equation from Worked Example 22.8 gives $T_F=0.0396$, approximately $-28.0\,dB$ in force amplitude. The value is dimensionless. At this high ratio, real performance may be limited by mount misalignment, rocking, flexible-connector stiffness, restraint contact and deck mobility. The result does not predict room sound or certify the curb assembly.

22.22 Wall heads, slab edges and façade intersections

The wall head closes the room against a moving floor or roof; structural deflection, shrinkage, creep and seismic movement must be accommodated; a rigidly packed joint can crack or transfer force; an open joint transmits air; fire-resistive joint systems have tested movement and fire functions that cannot be replaced by generic acoustic sealant. The design must coordinate backing, sealant, track, deflection allowance, fire stopping and inspection.

At the slab edge, the floor meets the façade; curtain-wall anchors, spandrels, safing insulation, smoke seals and perimeter fire barriers create a complex path; sound can travel through the slab, façade mullion, spandrel cavity or underfloor/ceiling plenums; a high-performing floor and wall can therefore be bypassed at the edge.[84] Field intensity and vibration scans should follow the junction line.

Core walls, stairs and shafts provide other continuous paths. A floor may be discontinuous at a joint but connected through reinforcement, beams or finishes. A ceiling can bridge around a column. The junction model should include geometry and material continuity rather than treating the room as six independent rated faces.[85]

22.23 Seismic movement, building joints and acoustic continuity

Seismic design introduces deliberate clearances, separation joints, braces and restraints; these details protect life and prevent component interaction, but they can conflict with the desire for continuous acoustic closure; a suspended ceiling may require perimeter separation and bracing. A partition head may require vertical movement; a raised floor can cross a seismic joint only through a purpose-designed transition. The acoustic design cannot simply fill the required gap with rigid material.

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84 MB-0841. International Organization for Standardization, ISO 12354-1:2017, ISO 10848-4:2017.
85 MB-0840. International Organization for Standardization, ISO 12354-1:2017, ISO 10848-1:2017.

A movement joint is a dynamic assembly.[86] Its performance depends on minimum and maximum width, direction of movement, backing, seal geometry, adhesion, cover plates and fire or smoke functions; the acoustic path changes as the joint opens and closes; a field test at the mean position may not represent the extreme service state. The commissioning record should therefore state measured joint width and environmental or load condition.

Seismic restraints on isolated ceilings and floating elements can be designed to remain clear during ordinary operation and engage only under large displacement; their installation must be verified. A nominal 10 mm clearance that is consumed by misalignment becomes a permanent bridge; conversely, excessive clearance can permit impact and rattle; the relevant authority and structural engineer determine the restraint requirement; the acoustical engineer determines how normal-operation contact affects the transfer path.[87]

Worked example 22.17. Open-area effect of a movement gap

Engineering question. What opening area results if a 6 m wall head opens uniformly by 3 mm?

$$S_o = (6.0)(0.003) = 0.0180\,m^2.$$

The units are square metres. If the room boundary area is 80 m², the geometric opening fraction is 0.0225 per cent; that small fraction can dominate a high-isolation boundary if acoustically open; a real fire-resistive joint contains backing, safing and sealants, so its transmission is not that of

86 MB-0305. ASTM International, ASTM E580, ASTM E119-25a.
87 MB-0304. ASTM International, ASTM E580.

a free aperture. The calculation supports inspection of joint state, not a prediction of rated performance.

22.24 Demountable partitions and the ceiling interface

Demountable partitions are attractive where layouts change, yet their modularity creates repeated joints, ceiling interfaces and service routes; a partition that terminates at the ceiling plane depends on the ceiling-plenum system; a deck-to-deck modular partition depends on the head track, movement detail and closure around structure. Panels, glass modules, doors and base channels may have different laboratory evidence.

The interface should be designed as a system;[88] ceiling panels may need to be cut around the head; grid members may pass through or terminate; a plenum barrier may be attached to the partition. Services can cross above it. Every change to the office layout can alter the acoustic path; the as-built record should therefore include panel module, head and base details, plenum treatment, doors, glazing, services and tested configuration.

Demountability also affects inspection. A panel can be removed for examination, but repeated removal can damage gaskets or create hidden gaps; a security-sensitive room may require controlled fasteners, tamper evidence or escorted access; those controls are operational and physical-security measures, not acoustic ratings, but they influence whether the configured boundary remains stable.

22.25 Access panels, hatches and removable components

Access is essential for valves, dampers, junction boxes, controls and inspection. Every access panel or hatch is an operable boundary. Its leaf,

88 MB-0212. ASTM International, ASTM E1414, ASTM C636.

frame, latch, gasket, hinges and surrounding construction determine performance.[89] A ceiling hatch can behave like a small door, but it may be lighter, less frequently adjusted and installed above eye level where defects remain unnoticed.

The panel should be scheduled by location, clear opening, leaf construction, frame, seal, latch compression, fire rating, acoustic evidence and inspection interval; the frame must be supported without bridging an isolated ceiling or floating system; a recessed panel should not reduce cavity depth or cut resilient channels without a compensating detail. A panel in a raised floor must carry rolling and concentrated loads while controlling leakage and rattle.[90]

Temporary access during maintenance requires reinstatement evidence; a photograph before closure, torque or latch check, seal inspection and local acoustic test may be appropriate; the maintenance procedure should specify replacement of damaged gaskets and prohibition on leaving panels ajar. A room can pass commissioning and later fail because one ceiling tile or floor panel was not properly replaced.

Worked example 22.18. Panel-latch compression variation

Engineering question. How much does gasket compression vary when a four-latch panel has nominal 2.0 mm compression but one corner is 0.8 mm low?

The three correct corners have 2.0 mm and the deficient corner 1.2 mm. Mean compression is

89 MB-0320. ASTM International, ASTM E90-23, ASTM E119-25a.
90 MB-0165. ASTM International, ASTM C635, ASTM C636.

$$\acute{c}=\frac{2.0+2.0+2.0+1.2}{4}=1.8\,mm.$$

The mean hides the local defect. Range is 0.8 mm, or 40 per cent of nominal compression; acoustic leakage follows the local contact gap rather than the average; the calculation supports contact mapping at multiple points; it does not determine insertion loss without gasket and pressure data.

22.26 Airborne field measurement of horizontal boundaries

Airborne field measurement across a floor-ceiling pair uses source-room excitation, receiving-room pressure measurements, room absorption or decay data and a metric suited to the geometry. ASTM E336-25a and ISO 16283-1 define field procedures within their respective systems. The result includes direct and flanking paths present during the test. It belongs to the particular rooms, source positions, receiving positions, furnishings, openings and operating state.[91]

Horizontal boundaries can create non-diffuse fields. A source near the floor excites it differently from a source near the ceiling; a large receiving room may contain spatial gradients; recesses, ceiling clouds, raised floors and furniture alter decay; multiple source positions and microphone positions are therefore necessary, and the report should retain individual band results before averaging.

A floor-ceiling result is not always symmetric; transmission from upper to lower room can differ from lower to upper because source-room and receiving-room absorption, ceiling systems, finishes and flanking differ; reciprocity applies to linear transfer functions under defined conditions, but

91 MB-0269. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

field metrics include room normalization and spatial sampling. Direction should be recorded rather than assumed.

22.27 Impact field measurement and reportable metrics

ASTM E1007-25 defines several field measures whose reportability depends on room volume, absorption and adjacency. It permits direct-room and separated-space assessments and includes flanking. ISO 16283-2:2020 specifies field impact procedures for rooms within defined volume and frequency ranges. The choice of method and metric should be fixed before testing, not selected after viewing the most favourable number.[92]

Tapping-machine positions should sample structural variability. On a concrete slab they may include mid-panel, near beams and near boundaries; on timber they should include over joists and between joists; on a raised floor they should include panel centres, joints and locations near pedestals, subject to the method's requirements and safety. The report must identify floor finish and its condition.

The receiving room should be measured in the operational configuration specified for acceptance; a suspended ceiling left open for services produces a different result from the completed state; a large item of furniture can alter absorption and microphone access. Background events such as lifts, plant and traffic should be recorded and excluded or incorporated consistently.

92 MB-0202. ASTM International, ASTM E1007-25, ISO 16283-2:2020.

Worked example 22.19. Spatial variation and arithmetic averaging

Engineering question. What energy-average level follows four receiving positions of 42, 45, 47 and 50 dB?

The logarithmic mean is

$$L_{avg}=10\log_{10}\left(\frac{10^{4.2}+10^{4.5}+10^{4.7}+10^{5.0}}{4}\right)=46.9\,dB.$$

The arithmetic average of decibels would be 46.0 dB and is not equivalent; the range is 8 dB, indicating substantial spatial variability that should be investigated rather than hidden by the mean; uncertainty includes repeatability, source position and room-state terms. The result does not establish a single local maximum or listener exposure.

22.28 Ceiling-plenum measurement and interpretation

A ceiling-plenum laboratory test isolates a prescribed path for ranking; it does not recreate every real plenum. Ducts, beams, cable trays, fire barriers, luminaires and variable depths change propagation; the source and receiving ceilings may have different panels; a partition can stop at the ceiling, extend into the plenum or reach the deck; the report should describe the geometry rather than cite only a ceiling attenuation class.[93]

Field diagnosis can use sequential interventions. Sealing one ceiling bay, installing a temporary plenum barrier, removing a diffuser or measuring above and below the ceiling can indicate path dominance; each intervention changes the system and must be reversible and documented; a large

93 MB-0211. ASTM International, ASTM E1414.

improvement after temporary ceiling sealing supports a plenum hypothesis, but it does not prove which device or joint was originally responsible.

Sound intensity may help localise radiation through ceiling panels or devices, though non-diffuse and reactive conditions require care; microphones above the ceiling can map the plenum field; vibration sensors on grid and panels can distinguish airborne excitation from mechanical coupling. The evidence should be integrated rather than forcing one measurement to answer every question.

Worked example 22.20. Plenum-barrier insertion screen

Engineering question. If a measured plenum path contributes 44 dB attenuation and a temporary barrier reduces received energy through that path by 12 dB, what new total follows when a parallel direct path is 53 dB?

Original ratios are $\tau_p = 10^{-4.4} = 3.98 \times 10^{-5}$ and $\tau_d = 10^{-5.3} = 5.01 \times 10^{-6}$. After the barrier, $\tau_{p2} = 10^{-5.6} = 2.51 \times 10^{-6}$. Combined attenuation is

$$R_2 = -10 \log_{10}(\tau_d + \tau_{p2}) = 51.2\,dB.$$

The 12 dB path improvement yields only 6.6 dB overall because the direct path becomes significant. The ratios assume a common reference and neglect coupling changes. The example supports staged remediation and retesting.

22.29 Flanking measurement at floor, ceiling and roof junctions

Flanking transmission can be measured through transfer functions, vibration reduction indices, directional pressure methods or component methods, depending on the system. ISO 10848 provides a framework and application parts for Type A and Type B elements. Suspended ceilings, access floors and floating floors may transmit through the element and plenum simultaneously, so the measured total may not separate the mechanisms.[94]

A junction investigation should establish coordinates and directions; accelerometers on the floor, wall, ceiling grid, façade mullion and structural frame can measure mobility and transfer. Pressure microphones identify radiation. Coherence with the source helps distinguish causal response from unrelated background; a local high vibration level is not sufficient; it must be connected to receiving sound or another relevant consequence.

Prediction models under ISO 12354-1 and ISO 12354-2 use measured element and junction data. Simplified single-number methods are useful for preliminary design but can obscure low-frequency and configuration-specific weaknesses. Detailed band models require more data and still contain model uncertainty. Field validation remains necessary where the protected use is consequential.[95]

Worked example 22.21. Combining three flanking paths

Engineering question. What total attenuation follows three independent path attenuations of 52, 57 and 61 dB?

$$\tau_c = 10^{-5.2} + 10^{-5.7} + 10^{-6.1} = 9.10 \times 10^{-6},$$

so

$$R_c = -10 \log_{10}\left(9.10 \times 10^{-6}\right) = 50.4\, dB.$$

The result is lower than the strongest-looking 52 dB path because weaker contributions add energy; independence is an assumption; correlated paths

94 MB-0820. International Organization for Standardization, ISO 10848-1:2017, ISO 10848-2:2017.
95 MB-0842. International Organization for Standardization, ISO 12354-1:2017, ISO 12354-2:2017.

and shared source coupling require covariance or a more detailed model; the example shows why several apparently secondary paths can matter.

22.30 Spatial sampling and path-sensitive source positions

A floor or roof is spatially non-uniform; beams, joists, ribs, pedestals, joints, openings and supports alter mobility; a commissioning plan should place sources where the structural model predicts different response; random or evenly spaced positions may miss a local defect. Conversely, a source placed directly on an exceptional stiffener may overstate performance relative to occupied use.

The sampling plan should identify the population;[96] for quality control, the population may be repeated rooms or repeated ceiling bays; for forensic work, it may be suspected joints or service penetrations; statistical sampling assumes a defect distribution; clustered workmanship defects violate simple independent models, so risk-based and judgemental samples may be needed alongside random selection.

Microphone sampling also matters. A quiet accessible corner may be more consequential than the room average; occupied speech security concerns listener positions, not just standard acoustic positions; the acceptance report can retain standard metrics while adding an operational exposure map with clearly separated status.

96 MB-0202. ASTM International, ASTM E1007-25, ISO 16283-2:2020.

Worked example 22.22. Defect-detection probability in repeated ceiling bays

Engineering question. If 8 per cent of ceiling bays contain a significant unsealed device and 20 bays are independently inspected, what is the probability of finding at least one defect?

$$P_d = 1 - (1 - 0.08)^{20} = 0.811.$$

The result is dimensionless. Independence and uniform prevalence are strong assumptions; installation defects often cluster by crew, day or device type. To achieve 95 per cent detection under the same assumptions requires

$$n \geq \frac{\ln(0.05)}{\ln(0.92)} = 35.9,$$

or 36 bays. The calculation assists inspection design but does not replace targeted review of high-consequence locations.

22.31 Measurement uncertainty and decision rules

Horizontal-boundary measurements combine source repeatability, microphone calibration, spatial variation, receiving-room absorption, background correction, time variation, source position, instrument synchronization and configuration uncertainty; impact tests add tapping-machine condition and floor-surface state; plenum tests add strong dependence on geometry. A single expanded uncertainty should not conceal components that are actually model discrepancies or configuration unknowns.

Decision rules should be specified before testing. A result near a threshold can be accepted, rejected or treated as conditional depending on the guard band and allocation of false-acceptance and false-rejection risk. In a high-consequence room, unmeasured configurations may dominate the risk more than the numerical measurement uncertainty. The report should therefore distinguish metrological uncertainty from state and model uncertainty.[97]

When comparing before and after remediation, correlation matters; using the same instruments, rooms and positions can reduce some uncertainty, while changes in background or furnishings add others; a statistically significant improvement is not automatically sufficient if the final result remains below requirement or another path becomes dominant.

Worked example 22.23. Guarded acceptance of an impact result

Engineering question. Does an AIIC result of 51.2 with expanded uncertainty 2.0 dB satisfy a requirement of 50 under a rule requiring result minus expanded uncertainty to meet the limit?

$$51.2 - 2.0 = 49.2 < 50\,.$$

The guarded result does not pass. The arithmetic uses decibel-valued classification and the specified decision rule, not physical energy subtraction; if the rule were not agreed in advance, applying it after the test would be procedurally defective; the calculation does not address whether AIIC is the appropriate metric for the protected use.

22.32 Construction surveillance for floors and ceilings

Construction surveillance should begin before concealment. For floating floors, inspect substrate cleanliness, resilient-layer identity, seam treatment, perimeter strips, load-spreading details, penetrations and reinforcement

97 MB-0203. ASTM International, ASTM E1007-25, ISO 16283-2:2020.

before the upper plate is placed; for raised floors, inspect pedestals, stringers, perimeter closures, service barriers and cable penetrations; for suspended ceilings, inspect hangers, isolation devices, perimeter gaps, plenum barriers, device back-cans and partition heads.

The record should combine drawings, approved submittals, material lot information, photographs, measurements and nonconformance dispositions; a photograph must include scale and location; a checklist without images can miss spatial detail; images without an approved reference cannot prove compliance. The penetration register should identify every crossing by unique number and retain later modifications.

Hold points should be enforceable. If a screed is poured before edge isolation is inspected, the evidence is lost; if ceiling tiles are installed before plenum barriers and services are inspected, later access may be possible but expensive and incomplete; the schedule should allocate inspection time and prevent other trades from treating the acoustic layer as expendable.

Table 22-5. Design, concealed-work and commissioning hold points for horizontal boundaries.

Stage	Hold point	Minimum evidence	Release condition
Design	Path and source-state review	Floor/ceiling/roof schedule, junction model, authorised source matrix	Every relevant direct, impact, plenum and service path has a disposition
Submittal	Assembly and product evidence	Complete test reports, materials, mountings, structural and fire information	Evidence matches the proposed configuration or differences are resolved
Pre-concealment	Floating, raised-floor and plenum inspection	Perimeter strips, pedestals, barriers, services, hangers and photographs	No uncontrolled bridge or open path remains
First-of-type	Representative mock-up or room	Full devices, penetrations, finishes, source and receiving conditions	Defects are corrected before repetitive construction

Stage	Hold point	Minimum evidence	Release condition
Commissioning	Standard and operational tests	Band data, uncertainty, room state, vibration and listener-access records	Decision rule is applied to the specified configuration
Lifecycle	Change and recommissioning review	Updated penetration register, maintenance record and comparative tests	New baseline is recorded after material change

22.33 Commissioning sequence and state control

Commissioning should proceed from component to system; first verify configuration: drawings, finishes, ceilings, doors, services, penetrations, masking and plant state; next perform local inspections and diagnostic tests; then conduct standard airborne and impact measurements. Finally assess operational sources and occupied speech exposure where required. A failed component test should be corrected before whole-room acceptance to avoid ambiguous results.

State control is essential. Ceiling tiles must be installed, access panels latched, raised-floor panels seated and services operating in the specified mode; doors and HVAC can alter pressure and background. Rooftop plant may cycle. A room tested during daytime construction noise may appear better than it is at night; the report should include a state matrix and photographs.

Commissioning should also establish a baseline for lifecycle comparison; record representative impact spectra, room-pair airborne curves, plenum or underfloor observations, vibration transfer functions and critical joint photographs; later change can then be assessed against a documented state rather than memory.

22.34 Forensic diagnosis of horizontal-path failures

A complaint should be translated into source, time, location and consequence; “noise from above” may be impact, airborne, structure-borne plant, duct transmission or a rattle; “speech from the next room” may travel over a ceiling, under a raised floor, through a façade edge or by a service route. The investigation should not begin by assuming the most visible element is defective.

The diagnostic sequence combines document review, source reproduction, spectral measurement, vibration, local pressure mapping and reversible interventions;[98] a temporary mass layer can test plate radiation; a temporary perimeter seal can test leakage; isolating one service or removing one ceiling device can discriminate paths; each intervention must be documented and reversed unless adopted as repair.

Destructive opening is justified only when less invasive evidence has narrowed the hypothesis and when structural, fire, security and evidence-custody controls are in place; a borescope can inspect a plenum or cavity but may miss a remote bridge. Infrared imaging can indicate air paths under pressure but does not measure sound insulation; every technique has a bounded proposition.

98 MB-0406. Carl Hopkins, Sound Insulation.

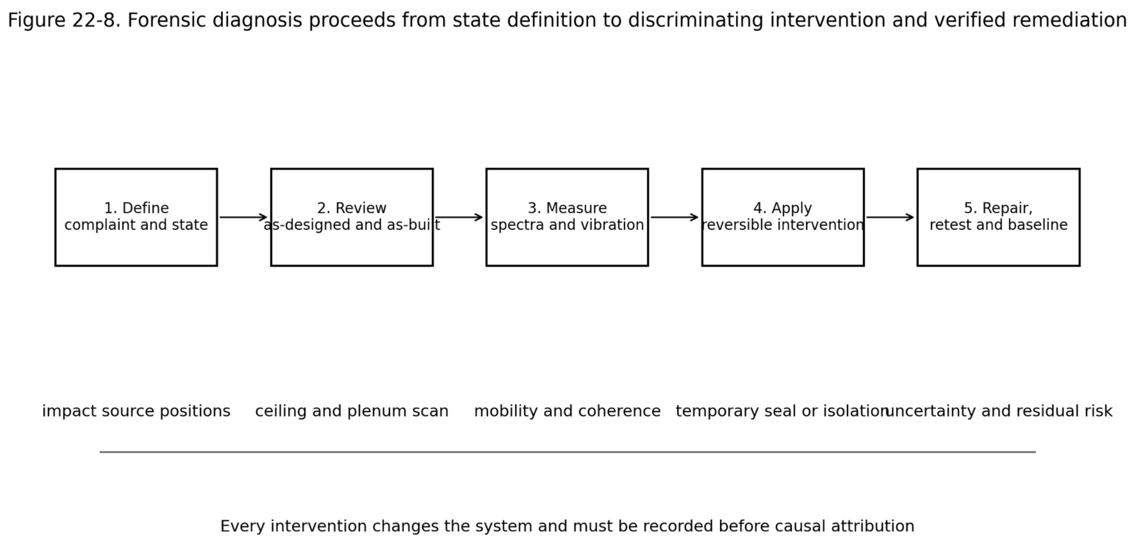

Figure 22-8. Forensic diagnosis proceeds from state definition through discriminating intervention to verified remediation and a new lifecycle baseline. Author's original diagram.

22.35 Remediation hierarchy

Remediation should target the dominant mechanism. If an underfloor cable opening governs, rebuilding the ceiling is irrational; if impact transmission is controlled by a bridged floating floor, adding ceiling absorption will not correct it; if a common plenum governs airborne speech, increasing wall mass below the ceiling may provide little benefit.

A useful hierarchy is closure, decoupling, mass, damping, absorption and operational control, selected by evidence rather than habit; closure addresses openings and seals; decoupling addresses resilient layers, hangers and structural breaks; mass reduces acceleration or airborne transmission in suitable regimes. Damping controls resonant response. Absorption controls cavities and room decay; operational controls manage sources and access; these mechanisms can interact and should not be treated as interchangeable products.

Repairs must preserve other functions. A rigid grout used to close a movement joint can cause cracking; a heavy ceiling layer can overload the grid; a sealant can violate a fire listing; a barrier can block plenum airflow or drainage. The remedial design requires multidisciplinary review and a post-repair test matched to the diagnosed path.

Worked example 22.24. Before-and-after improvement with uncertainty

Engineering question. Is a measured improvement from 43.5 to 48.0 dB distinguishable when each result has 1.2 dB standard uncertainty and the measurements are independent?

Difference is $\Delta = 4.5\,dB$. Standard uncertainty of the difference is

$$u_{\Delta} = \sqrt{1.2^2 + 1.2^2} = 1.70\,dB.$$

A nominal expanded uncertainty with $k = 2$ is 3.4 dB, so the 4.5 dB improvement exceeds that interval. Correlation from common instruments may reduce some terms, while changed room state may add others. Statistical distinction does not prove that the final 48 dB satisfies the mission requirement or that the diagnosed mechanism is unique.

22.36 Integrated design case: concrete floor with a secure room below

Consider a secure conference room below an occupied office floor; the structural slab is 200 mm reinforced concrete; the upper floor receives stone finish on a floating screed; the room below has an isolated two-layer gypsum ceiling. A raised floor in the upper office carries power and data.

The initial design specifies laboratory IIC and STC values but does not show perimeter isolation, threshold support or underfloor barriers.

The evidence map identifies four path families; direct airborne transmission through the slab is strong; impact enters through the finish and floating screed; a threshold at the upper office door bridges the screed to the slab. The raised-floor plenum connects to a corridor and crosses the room wall. Ceiling hangers below are isolated, but two large luminaires are supported from the ceiling frame and hard-connected by conduit.

The design is revised before construction. The floating-floor perimeter is detailed continuously, with an independently supported threshold; the raised-floor cavity receives a sealed barrier at the protected perimeter, with controlled service sleeves; luminaires are independently supported and use flexible electrical connections while their enclosures are sealed to the ceiling leaf. Hold points precede screed placement and panel closure.

Commissioning uses standard impact measurement, low-frequency operational footfall, airborne room-pair testing, plenum inspection and vibration transfer; the direct slab is not the governing path; a local high-frequency weakness at one floor box is corrected; the competent authority receives separate laboratory, field, occupied and acceptance records rather than one headline rating.

22.37 Integrated retrofit case: timber floor in a historic building

A historic boardroom occupies the floor below a timber office; the structure contains joists pocketed into masonry walls, old floorboards, plaster ceilings and unknown voids. Conservation constraints limit removal. Baseline testing shows low-frequency footfall and speech-modulated ceiling vibration; the standard impact rating is moderate, but operational walking produces strong 31.5 and 40 Hz response.

The investigation maps joist direction, floor pockets, ceiling keys and service routes; temporary mass panels placed above selected bays reduce mid-band radiation but not the lowest modes; a reversible ceiling brace is tested and rejected because it increases junction transmission. The adopted retrofit uses a dry floating floor on low-dynamic-stiffness supports, edge isolation, limited added mass, cavity absorption introduced through controlled openings and a secondary independent ceiling where historic fabric permits.

Because the structure is irregular, no catalogue STC or IIC is assigned to the historic assembly; acceptance uses before-and-after spectra, vibration transfer, operational footfall, speech exposure and conservation records; the case demonstrates why visible timber thickness and generic floor ratings are inadequate for a bespoke historic system.

22.38 Integrated failure case: common plenum and after-hours speech

A meeting room passes a daytime field level-difference test while adjacent office spaces are occupied and masking operates; after hours, a cleaner reports recognising names from a corridor-side office; investigation finds that the room partition stops at a lay-in ceiling. The plenum is shared, and return air uses open transfer paths; the daytime background concealed the received speech.

A ceiling-plenum test and temporary barrier demonstrate that the over-ceiling path governs; the wall below the ceiling already exceeds the path requirement; remediation extends a barrier to the deck, relocates the return path through a lined and attenuated route, seals luminaire openings and recommissions masking. The after-hours operational test is repeated at maximum authorised vocal effort and at the accessible listener positions.

The failure did not result from an inaccurate wall STC; it resulted from an incomplete boundary model and an untested operating state; the corrected record separates product evidence, field isolation, occupied performance and authority acceptance.

22.39 Lifecycle inspection and recommissioning

Horizontal systems change frequently. Floor coverings are replaced, raised-floor panels moved, cables added, ceiling tiles damaged, luminaires upgraded, sprinkler work performed and roof plant replaced; each activity can alter mass, closure, isolation or source force; a commissioning certificate does not remain true automatically.

The lifecycle plan should rank components by change rate and consequence; raised floors and accessible ceilings may need frequent visual inspection; floating screeds concealed beneath finishes require control of later penetrations; roof curbs and hatches need weather and seal inspection. Seismic restraints and isolation clearances need periodic checks. The penetration register and as-built drawings should be updated after every authorised change.

Recommissioning can be tiered. Routine inspections confirm configuration. Triggered tests follow significant work or an incident; periodic full tests verify critical rooms; trend measurements should use the same source positions, instrument chain and room state where possible; differences must be interpreted with uncertainty and configuration change, not merely plotted.

Worked example 22.25. Drift in a lifecycle indicator

Engineering question. A plenum-path attenuation baseline is 52.0 dB with standard uncertainty 1.0 dB. Three years later it is 49.5 dB with 1.2 dB uncertainty. Is the change distinguishable under independent assumptions?

Difference is 2.5 dB. Standard uncertainty is

$$u_{\Delta}=\sqrt{1.0^2+1.2^2}=1.56\,dB.$$

The difference is about 1.6 standard uncertainties and is not decisive under a two-standard-uncertainty screen; it is nevertheless operationally relevant if accompanied by a changed ceiling tile, cable opening or complaint; the result should trigger configuration inspection and repeat measurement rather than immediate causal attribution.

22.40 Fire-resistance assemblies and acoustic substitution control

A floor-ceiling or roof-ceiling assembly can be part of a fire-resistance-rated construction. The rating belongs to the complete tested or assessed assembly, including deck, joists, concrete, ceiling membranes, suspension, fasteners, insulation, penetrations and restraint; acoustic improvement by adding a resilient channel, changing ceiling mass, moving hangers or introducing access panels can alter the fire-resistance basis; conversely, a fire-driven substitution can alter acoustic performance. Neither discipline may assume that a change benign in one domain is benign in the other.[99]

99 MB-0168. ASTM International, ASTM C636, ASTM E119-25a.

The submittal review should identify the fire design, acoustic design and any tested overlap;[100] a listed assembly may permit limited substitutions, but those permissions must be documented by the responsible fire-protection and code professionals. The acoustical consultant should record how the change affects mass, cavity, fastener spacing, resilient coupling and openings; where a ceiling is the protective membrane for steel or timber, an acoustic access panel or recessed device can create a local fire and sound weakness simultaneously.

Penetration systems require compatible fire stopping and movement; a mineral-wool-and-sealant system might close an air path, but its backing density, depth and seal geometry are prescribed by the fire system; filling the remaining visible surface with generic acoustic mastic can obscure inspection or interfere with movement. A coordinated detail identifies the tested fire system, acoustic closure, movement range and inspection face.

Worked example 22.26. Added ceiling mass and hanger load

Engineering question. What additional load is placed on each hanger when a 160 m² isolated ceiling receives another 12.5 kg/m² board layer and is supported by 128 hangers?

Total added mass is $m=160(12.5)=2,000\,kg$. Added weight is $W=mg=19.6\,kN$. Average added load per hanger is

$$P_h=\frac{19.6}{128}=0.153\,kN=153\,N\,.$$

100 MB-0168. ASTM International, ASTM C636, ASTM E119-25a.

The units are force. Distribution is not uniform near edges, openings and devices. The calculation supports structural and isolator re-evaluation. It does not establish fire acceptance or revised acoustic performance.

22.41 Fire-resistive suspended ceilings and membrane continuity

Some suspended ceilings are architectural finishes; others are integral fire-resistive membranes; in a rated assembly, tile type, grid, hanger spacing, hold-down clips, expansion devices and supported services may be prescribed; replacing a tile with a visually similar high-attenuation product can invalidate the fire basis. Installing a heavy acoustic backing can overload the grid or obstruct required thermal movement.

Membrane continuity is acoustically valuable, but fire systems may require controlled openings and tested devices; sprinklers, luminaires, diffusers and access panels need their approved details; a secure-room project should not add unlisted back-cans or sealants around devices without review. The better approach is to select a fire-compatible assembly whose acoustic role has been measured or modelled, then inspect the exact construction.

Ceiling penetrations should be mapped both above and below the plane; a diffuser may include a plenum box and flexible connection that affect fire, airflow and sound; a luminaire may be independently supported while the trim contacts the ceiling. A sprinkler escutcheon may conceal an oversized opening; the commissioning inspection should compare device type, support, opening, closure and field condition with the approved assembly.

22.42 Moisture, temperature, creep and long-term stiffness

Horizontal systems are sensitive to environmental and time-dependent change; resilient underlays compress under sustained load; timber changes moisture content and stiffness; gypsum and mineral fibre ceilings respond to humidity. Roof insulation and membranes experience large temperature cycles. Concrete creeps and shrinks. Sealants age. These changes alter natural frequency, contact pressure, gap width and damping.

Floating-floor dynamic stiffness should therefore be considered over service life, not only at initial installation. Research has documented time-dependent changes in resilient materials and associated acoustic performance. Temperature can change elastomer stiffness; moisture can affect fibrous and wood products. The uncertainty budget should include environmental state where the expected change is material.[101]

Ceiling tiles can sag under humidity or water exposure, creating edge gaps and changed panel contact; a roof leak can wet insulation, increase mass, reduce thermal performance and damage the ceiling; a wet raised-floor panel can swell or lose strength. The lifecycle inspection should connect moisture observations with acoustic symptoms rather than treating them as separate maintenance issues.

Worked example 22.27. Resonance shift from resilient-layer stiffening

Engineering question. How does floating-floor resonance change if dynamic stiffness rises by 30 per cent while surface mass remains constant?

Because $f_0 \propto \sqrt{s'}$,

101 MB-0014. Alessandro Schiavi, Andrea Pavoni Belli and Francesco Russo, Estimation of Acoustical Performance of Floating Floors from Dynamic Stiffness of Resilient Layers.

$$\frac{f_{0,2}}{f_{0,1}} = \sqrt{1.30} = 1.140\,.$$

An initial resonance of 55 Hz shifts to 62.7 Hz. The ratio is dimensionless. The shift may move the weakness into or out of a critical speech, footfall or plant band; damping and nonlinearity also change, so the square-root relation is only a first-order screen.

22.43 Large-span floors, transfer structures and modal concentration

Large conference rooms, ballrooms, trading floors and assembly spaces can have long-span structures with low modal density in the operational band; a source at one location may excite a global mode that radiates over a wide area. Transfer girders, deep beams and trusses concentrate load paths; the floor cannot be represented accurately by a local surface-mass calculation.

A modal survey should identify frequencies, mode shapes, damping and source-location sensitivity; operational modal analysis can use ambient excitation, while controlled shakers or impact hammers provide transfer functions; the structural engineer should confirm allowable excitation and sensor locations. The acoustical analysis then relates structural response to receiving-room pressure or equipment susceptibility.

Large-span floors also complicate floating systems. A heavy floating slab adds dead load and may follow the base floor’s deflection; differential movement at walls and columns can bridge edge strips; modular raised floors may rock over local deflection; the design should coordinate structural serviceability, acoustic isolation and fit-out tolerances.

Worked example 22.28. Modal mass and acceleration screen

Engineering question. What acceleration amplitude follows a sinusoidal modal force of 180 N acting on an effective modal mass of 12,000 kg at a frequency far below resonance where inertial response dominates?

Using $a = F/m$,

$$a = \frac{180}{12,000} = 0.0150\, m/s^2.$$

This is approximately $1.53 \times 10^{-3} g$. Near resonance, dynamic amplification can be much larger and damping becomes decisive. The result is a static inertial screen and does not predict velocity, radiation or human response.

22.44 Stairs, ramps, bridges and circulation connections

Stairs and ramps connect floors structurally and acoustically; a stair flight can transmit footfall directly into landings and walls; stringers, handrails and balustrades can vibrate and radiate; a stair enclosure may bypass the nominal floor-ceiling boundary through doors, shafts and continuous masonry. Circulation routes therefore belong in the complete-envelope model.

An isolated stair requires careful structural and life-safety design; resilient bearings can reduce force transmission, but they must carry gravity and lateral loads, accommodate movement and remain inspectable; handrails and finishes can bridge the isolation; a floating floor that stops at a stair threshold can be short-circuited by nosings or screed continuity.

Bridges and connecting corridors between buildings introduce expansion joints and lightweight façades; they can transmit structure-borne plant or footfall and provide accessible listening positions; the survey should include these spaces even when they lie outside the nominal room stack.

22.45 Roof impact from rain and hail

Rain noise is generated by many impacts distributed in time and space; the excitation depends on drop size, terminal velocity, roof slope, membrane, insulation, deck and interior finish; hail adds larger, less frequent impacts; a metal roof can radiate efficiently, while a massive roof may transmit less airborne sound but still excite attached ceilings and services.

A standard airborne roof rating does not describe rain; project-specific rain-noise laboratory methods or controlled spray tests may support design, but their source spectrum, rainfall rate and mounting must be reported; field monitoring during natural rain can validate operational performance but lacks source repeatability. The appropriate approach may combine laboratory comparison, structural modelling and field observation.

For a secure room, rain can both mask and disrupt; high background can reduce speech audibility outside, yet it can also cause occupants to raise vocal effort; intermittent impacts can interfere with measurement and mask diagnostic signals. Commissioning should not rely on fortuitous weather, and operational analysis should consider quiet conditions as the conservative speech-exposure state.

22.46 Pressure differentials and airflow through floor and ceiling paths

Air-pressure differences arise from HVAC balance, stack effect, wind, door operation and smoke-control systems; a pressure difference can drive airflow through ceiling perimeters, raised-floor gaps and service openings;

airflow noise can reveal a path, alter seal contact and carry speech through ducts or plenums. An acoustic test conducted at neutral pressure may not represent the operating state.

Pressure testing can support diagnosis. ASTM air-leakage methods for fenestration are not directly floor-ceiling methods, but the general evidentiary distinction remains useful: measured airflow under a stated pressure identifies leakage, not sound insulation.[102] The project may use a controlled room-pressure test with calibrated airflow and smoke visualisation, provided the method and safety limitations are documented.

A lay-in ceiling can lift under excessive pressure. Raised-floor panels can rattle. Door bottoms can change contact. Fire and smoke dampers can reposition. The state matrix should include normal, setback, purge and emergency modes where these are authorised and relevant.

Worked example 22.29. Orifice-flow screening through a floor opening

Engineering question. What airflow is suggested through a 0.0020 m² opening at 12 Pa using an ideal discharge coefficient $C_d = 0.62$ and air density $\rho = 1.2\,kg/m^3$?

$$Q = C_d A \sqrt{\frac{2\,\Delta p}{\rho}} = 0.62(0.0020)\sqrt{\frac{24}{1.2}} = 0.00555\,m^3/s.$$

This is 5.55 litres per second; units reduce to volume per time; real cracks, porous media and distributed paths differ from a sharp-edged orifice; the calculation supports leakage investigation and pressure-state control; it is not an acoustic transmission model.

102 MB-0241. ASTM International, ASTM E283-24, ASTM E783-24.

22.47 High-density equipment rooms and secure technical spaces

Technical rooms can impose concentrated loads, cable density, cooling airflow and vibration on horizontal systems; equipment racks may require direct structural support through a raised floor; uninterruptible power systems, transformers and cooling units create tonal and broadband forces. Cable openings can be large. A conventional office raised floor is not automatically suitable.

The design should separate load support from environmental closure;[103] structural frames can pass through a raised floor without using panels as primary support, but the penetrations require seals and movement; equipment isolation may be placed at the machine, support frame or building structure; each layer changes force and service alignment. Flexible cables and hoses must retain sufficient slack and bend radius.

Secure technical spaces also require configuration control; a new cable bundle can defeat an underfloor barrier; a replacement cooling unit can change pressure and vibration; monitoring sensors can themselves create penetrations. The acceptance baseline should include equipment inventory, operating modes, loads, supports, services and measured spectra.

22.48 Specification language for horizontal systems

A specification should name the measurand, method, frequency range, configuration, reporting requirements and decision rule; “provide an STC 60 floor” is inadequate; the structural floor may have laboratory airborne evidence, while impact, flanking, ceiling and services remain unspecified. A

103 MB-0830. International Organization for Standardization, ISO 10848-2:2017, ASTM C635.

better requirement separates laboratory basis, predicted field result, field acceptance and operational assessment.

For floating floors, specify upper-plate mass, resilient-layer identity and dynamic stiffness, preload condition, edge isolation, penetrations, point loads, mock-up, inspection hold points and field verification; for raised floors, specify panel and pedestal system, perimeter closure, service barriers, grommets, rattle control and access procedures. For ceilings, state whether the role is absorption, plenum attenuation, fire membrane, isolated lining or architectural finish.

Submittals should include complete test reports rather than certificates alone; the reviewer needs specimen dimensions, mounting, source and receiving conditions, band data, devices and limitations; substitutions should identify every changed variable and provide a reasoned equivalence analysis. A similar product name or single-number rating is not sufficient.

22.49 Mock-ups and first-of-type verification

Mock-ups are valuable where many rooms repeat a complex floor-ceiling detail.[104] A first-of-type room can include the wall head, floating floor, ceiling, lights, diffusers, sprinklers, access panels and services. Inspection before concealment tests constructability. Acoustic measurement before replication can reveal systemic defects while correction remains affordable.

The mock-up must be representative. A simplified panel without services or a smaller cavity may produce misleading results; the specification should identify which deviations are permitted and how they affect evidence; the

104 MB-0299. ASTM International, ASTM E492-25, ASTM E90-23.

mock-up should be preserved or carefully documented after approval so later questions can be resolved.

A passed mock-up does not excuse field inspection; repetition introduces crew, material and schedule variation; a sampling plan should combine first-of-type verification, concealed-work hold points and periodic field tests; nonconforming rooms should trigger investigation of related construction, not isolated repair alone.

22.50 Ceiling clouds, baffles and discontinuous absorptive fields

Contemporary interiors frequently replace continuous suspended ceilings with clouds, rafts, baffles or exposed structure; these devices can provide absorption and visual interest while leaving the structural deck and services exposed; they do not close a plenum path because no continuous ceiling plane exists. Their acoustic benefit is principally room absorption, scattering and source-level control, not interroom barrier performance.

The laboratory absorption of a cloud depends on both faces, edge area, spacing, suspension height and array density. A result obtained from a particular mounting under ASTM C423 and E795 should not be converted into a closed-room isolation claim. In a secure room, clouds can reduce reverberant build-up and lower the pressure incident on boundaries, but occupants may compensate with increased or decreased vocal effort depending on communication conditions.[105]

Cloud suspension creates mechanical paths and overhead access issues; hangers can transmit vibration from the deck into the panel, producing

105 MB-0148. ASTM International, ASTM C423, ASTM E795-23.

rattle or secondary radiation; sprinklers, lights and sensors must remain coordinated; seismic interaction clearances may be required, and a large cloud can move relative to walls or other services. The inspection record should include support, clearance and panel condition.

Where a continuous secure boundary is required, it should be provided independently of decorative clouds; an isolated gypsum ceiling above the clouds can form the boundary, while the clouds provide absorption below; the cavity between them requires access and service control. A designer who treats the visible cloud as the ceiling can leave a completely open path above the partitions.

Worked example 22.30. Absorption added by suspended clouds

Engineering question. What equivalent absorption area is suggested by twelve 2.4 m² clouds with random-incidence absorption coefficient 0.85 on both exposed faces, neglecting edge effects?

Total exposed face area is $S=12(2)(2.4)=57.6\,m^2$. Equivalent absorption is

$$A=\alpha\,S=0.85(57.6)=49.0\,m^2.$$

The calculation assumes the reported coefficient is valid for the mounting, spacing and frequency band; array interaction and edge absorption can change the result; the value supports room-decay prediction and says nothing about transmission through the open overhead space.

22.51 Ventilated roof cavities, vapour control and condensation risk

Roof-ceiling systems often contain ventilated cavities, air barriers, vapour retarders and drainage paths; an acoustic barrier that blocks ventilation or traps moisture can damage the roof; conversely, ventilation openings, eaves and service cavities can transmit exterior sound or connect adjoining spaces. The design must integrate hygrothermal and acoustic functions rather than closing every visible gap indiscriminately.

A ventilated cavity has acoustic modes and flow resistance; porous insulation can reduce cavity energy, but its position and moisture state matter; an air barrier can provide valuable acoustic closure if continuous, yet penetrations and transitions at walls are critical. Vapour control may occur at another plane; the drawings should label each environmental control layer and identify which one provides acoustic air closure.

Condensation can alter materials and seals. Wet fibrous insulation gains mass and loses thermal performance; mould and corrosion can follow; timber swells, metal fasteners corrode and ceiling tiles stain or sag; a remediation proposed solely for sound may therefore create latent building-envelope failure. The responsible envelope professional should review changes to roof cavities and vapour control.

A secure room beneath an exterior roof should be assessed during representative seasonal states where practicable; wind-driven pressure can open laps or hatches; cold weather can stiffen elastomeric mounts and seals; summer plant operation can add vibration. The lifecycle baseline should record temperature, humidity and operating state for comparison.

22.52 Rolling loads, dropped objects and nonstandard impact sources

A standard tapping machine provides repeatability, but many operational sources differ substantially; rolling carts apply moving contact forces and wheel impacts at joints; chairs generate castor noise and impulsive loads; dropped tools and equipment produce high peak force. Gymnasium or training activities can involve heavy soft impacts. Maintenance above a secure room can be episodic but consequential.

Rolling noise depends on wheel material, diameter, load, speed, floor roughness, joints and local mobility; a small hard wheel crossing a raised-floor panel joint can excite both panel and pedestals; a soft wheel can reduce high-frequency force while retaining low-frequency load variation. The test protocol should replicate credible operational conditions and measure both force or source state and receiving response.

Dropped-object tests must be controlled for energy and safety. Potential energy mgh is a useful first descriptor, but impact duration and contact compliance determine force spectrum. A steel tool and a rubber ball with equal energy excite different bands. The receiving system can respond nonlinearly through rattles and loose contacts. Standard classifications should remain separate from these diagnostic or operational tests.

Worked example 22.31. Drop energy and average impact force screen

Engineering question. A 2.0 kg tool falls 0.60 m and stops over an estimated 4 mm combined deformation. What energy and average stopping force are suggested, neglecting rebound?

Potential energy is

$$E = mgh = (2.0)(9.81)(0.60) = 11.8\,J.$$

If all energy is dissipated over $d = 0.004\,m$, average stopping force above static weight is approximately

$$F_{avg} = \frac{E}{d} = 2.94\,kN\,.$$

Peak force can be several times larger and depends on contact dynamics. The calculation is a safety and source-severity screen, not a prediction of floor spectrum or damage.

22.53 Numerical modelling: finite elements, statistical energy and hybrids

Numerical modelling can connect structural details with acoustic response, but model choice must follow frequency, geometry and evidence; finite-element methods resolve low-frequency modes, local stiffness, orthotropy and junctions when mesh, damping and boundary conditions are adequate; statistical energy methods become useful when modal density is high and energy exchange can be represented statistically. Hybrid models combine deterministic low-frequency components with statistical subsystems.

A model should be validated against measured quantities that correspond to its state variables.[106] Structural mobility, natural frequency, mode shape, damping, transmission loss and receiving pressure are possible validation targets. Matching one single-number rating does not validate the mechanisms. A model can reproduce an overall class while misplacing resonances or compensating errors between paths.

Uncertainty enters through material properties, dimensions, supports, fastener slip, resilient-layer stiffness, damping, source force and room absorption; sensitivity analysis identifies which inputs justify field verification; for a raised floor, pedestal stiffness and perimeter gaps may dominate; for a concrete slab, junction data and flanking may dominate. For

106 MB-0843. International Organization for Standardization, ISO 12354-1:2017, ISO 12354-2:2017.

a timber floor, connection stiffness and low-frequency damping may be critical.

Prediction standards under ISO 12354 provide structured building-acoustic models using element and junction data. Their detailed and simplified routes have different information requirements and restrictions. The models support design comparison and risk identification. Final field evidence remains necessary where installation and secure use are decisive.[107]

Worked example 22.32. Mesh-size screen for a plate model

Engineering question. What maximum element size follows a six-elements-per-bending-wavelength rule when the minimum bending wavelength of interest is 0.48 m?

$$h_e \leq \frac{0.48}{6} = 0.080\, m.$$

An 80 mm element size is an upper screen; local joints, fasteners and curvature may require finer mesh; convergence should be demonstrated by repeating the solution with smaller elements; the calculation says nothing about material or boundary-condition accuracy.

22.54 Operational source-state matrix

A horizontal-boundary test programme should be derived from a source-state matrix; rows identify source states such as ordinary speech, amplified audio, walking, rolling carts, dropped objects, rooftop plant, rain, HVAC modes and maintenance; columns identify locations, durations, spectra, operating conditions, accessible receivers and consequences. The matrix

107 MB-0846. International Organization for Standardization, ISO 12354-1:2017, ISO 12354-2:2017.

prevents a laboratory classification from silently substituting for an untested operational state.

The matrix also supports proportionality. Not every room needs every source. A room beneath an unoccupied roof may not require office-footfall testing, while a room beneath a public corridor does; a roof under an aircraft route needs exterior airborne analysis; a technical operations centre with raised floors needs service-plenum and equipment-vibration states. The authorised use and threat model determine the set.

Source states should include failure and degraded modes where credible; a masking system may be off; one ceiling panel may be removed; a fan can operate at maximum speed. A door can be open during emergency egress, but that state may be excluded from acoustic acceptance if the room is not used for protected speech then. Assumptions should be explicit.

The operational matrix links design to commissioning and lifecycle; when a new piece of equipment is added, its source state is inserted and the affected paths are reviewed; this is more durable than a static certificate because it shows which uses were actually assessed.

22.55 Evidentiary reporting and expert limitations

A technical report should distinguish observation, measurement, calculation, inference and authority decision; “the ceiling tile was displaced” is an observation; “the 2 kHz receiving level fell 7 dB after temporary closure” is a measurement comparison; “the displaced tile probably contributed to the plenum path” is an inference. “The room is accepted for the defined use” is an authority decision. Mixing these statements invites overclaiming.

Raw data, calibration, source positions, room state, photographs, scripts and processing settings should be retained. Worked calculations should identify equations and uncertainty; proprietary laboratory reports can be referenced under appropriate controls, but the publication should not reproduce protected data without permission; public-source limitations must be stated where governmental criteria are unavailable.

Expert testimony requires particular restraint. A field failure does not prove negligence without evidence of duty, standard, causation and notice.[108] A laboratory rating does not prove that the installed assembly matched the specimen. A change after maintenance may indicate association but not causation. The report should state alternative explanations and the tests used to discriminate them.

Where evidence is incomplete, the correct conclusion may be bounded; for example: “The measured response is consistent with a common-plenum path, and the temporary barrier reduced the relevant bands, but the available inspection did not isolate the contribution of each diffuser and ceiling joint.” Such language is stronger than categorical certainty unsupported by the record.

22.56 Junction vibration reduction and path-specific prediction

A floor-wall or roof-wall junction cannot be represented adequately by the surface mass of either element. Incident bending-wave power can be reflected, transmitted into the adjoining element, converted between wave types, dissipated at the connection or redistributed through columns, beams and façades; the junction geometry, material combination,

108 MB-0321. ASTM International, ASTM E90-23, ASTM E336-25a.

continuity, restraint and frequency therefore determine whether a strong horizontal element becomes an efficient flank. ISO 10848 provides measurement routes for flanking transmission, while ISO 12354 uses element and junction data within building-level prediction; these methods preserve a crucial distinction: the junction quantity belongs to a defined connection and element set, not to concrete, timber or steel in the abstract.[109]

The vibration reduction index is commonly expressed from the direction-averaged velocity-level difference across a junction, corrected for the structural reverberation characteristics and junction length under the applicable model; it is useful because it converts measured or empirically estimated junction behaviour into a form that can be combined with direct-element transmission. Its numerical value is not a universal property of a wall-to-slab detail; changes in slab thickness, wall mass, resilient interlayers, edge beams, façade anchors, topping, finishes or connected room geometry can alter the result.

Prediction should retain direction where the construction is not reciprocal in practical operation; linear passive structures are reciprocal under the assumptions of the model, yet the measured room response can appear direction-dependent because source coupling, modal density, damping, support condition and receiving radiation differ. A lightweight wall supported on a heavy slab can receive structural energy differently from the slab when the source and receiver are reversed; the engineer should distinguish reciprocity of the underlying transfer relation from equality of two room-level test results.

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109 MB-0844. International Organization for Standardization, ISO 12354-1:2017, ISO 12354-2:2017.

A path ledger should identify each sequence explicitly. Examples include floor to separating wall to receiving ceiling; roof deck to façade mullion to room lining; floating floor bridge to structural slab to corridor wall; and stair landing to core wall to secure-room ceiling; each path receives a source coupling term, element attenuation, junction transmission, receiving radiation and uncertainty. Paths are combined in energy terms only after their correlations and shared components have been considered; summing decibel values directly or treating every route as independent can produce serious error.

Worked example 22.33. Combining a direct path with a junction flank

Engineering question. A measured direct floor-ceiling path has a band transmission loss of 58 dB. A modelled slab-to-wall-to-ceiling flank has an equivalent path loss of 51 dB. What combined loss follows if the paths are treated as uncorrelated power routes?

The direct and flanking transmission coefficients are

$$\tau_d = 10^{-58/10} = 1.58 \times 10^{-6},$$

and

$$\tau_f = 10^{-51/10} = 7.94 \times 10^{-6}.$$

The combined coefficient is

$$\tau_c = \tau_d + \tau_f = 9.52 \times 10^{-6}.$$

Therefore,

$$R_c = -10 \log_{10}(\tau_c) = 50.2\, dB.$$

The units cancel within each power ratio, and the result is expressed in decibels; the 51 dB flank controls the combined result, reducing the apparent benefit of the 58 dB direct path by 7.8 dB; the calculation assumes independent energy paths, compatible reference areas and a valid equivalent path representation. Coherent structural contributions, uncertain junction data and additional paths are omitted; it demonstrates why a very strong slab cannot compensate for a weaker connected route; it does not establish occupied speech security or formal acceptance.

22.57 Resilient-layer preload, load zoning and point-load governance

A resilient layer is characterised under a defined load, deformation, frequency, temperature and specimen geometry; its dynamic stiffness can be nonlinear; a layer that performs well beneath a uniformly loaded screed may behave differently beneath a safe, filing system, equipment rack or masonry plinth. Local compression changes stiffness and damping, can close designed clearances and can force the upper plate into contact with the base; average surface mass therefore does not establish local isolation.

Load zoning should begin with the as-designed equipment and furniture plan; the engineer maps permanent distributed load, movable concentrated load, partition lines, thresholds, raised pedestals and maintenance routes; each zone is checked against resilient-material stress, long-term compression, upper-plate bending and edge clearance. Where equipment requires a direct structural support, that support should pass through the floating system within an independently detailed sleeve or isolated curb rather than allowing an improvised post to bear against both leaves.

The dynamic stiffness used in a resonance calculation should correspond to the service preload; laboratory values may be reported at prescribed loads that do not match the project; the design record should state whether the value is nominal, measured, interpolated or conservatively bounded; temperature-sensitive elastomers and fibrous materials require environmental qualification. Creep data should be considered over the intended service life, especially where the upper slab has little reserve clearance.[110]

Point loads also alter the upper plate; a thin dry floating panel can dish between supports or rock at joints; a concrete screed can crack around concentrated bases; a raised-floor panel can transfer load through one pedestal, increasing local force transmission. Load-spreading plates can reduce stress, but may connect joints or approach the perimeter. The acoustic and structural details must therefore be reviewed together.

Construction surveillance should verify the load zoning before the finish conceals the resilient layer; photographs should show layer continuity, joints, perimeter strips, service sleeves and load-spreading components; equipment added later must trigger a configuration review; a lifecycle inspection that checks only visible floor finish misses the mechanical conditions below it.

Worked example 22.34. Local preload and resonance shift beneath equipment

Engineering question. A resilient layer has service dynamic stiffness per unit area of 18 MN/m³ under ordinary floor load. Beneath an equipment base, increased compression raises local stiffness to 31 MN/m³. The local

110 MB-0015. Alessandro Schiavi, ASTM E1332-22.

upper-plate surface mass is 120 kg/m². How does the ideal local resonance change?

Using

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{s'}{m'}},$$

the ordinary-zone resonance is

$$f_{0,1} = \frac{1}{2\pi}\sqrt{\frac{18\times10^6}{120}} = 61.6\,Hz.$$

The equipment-zone resonance is

$$f_{0,2} = \frac{1}{2\pi}\sqrt{\frac{31\times10^6}{120}} = 80.9\,Hz.$$

The dimensional term $(N/m^3)/(kg/m^2)$ reduces to $1/s^2$, and its square root gives radians per second before division by 2π. The local resonance rises by 19.3 Hz, or approximately 31 per cent. The calculation assumes linear stiffness at each preload, rigid plates and no damping or spatial coupling. It identifies a potentially vulnerable local zone and the need for measured stiffness or a separate support detail. It does not predict the complete room response.

22.58 Ceiling devices, back-cans and concealed service interaction

The acoustic role of a ceiling is often compromised by devices that are designed by separate trades; luminaires, loudspeakers, diffusers, access panels, smoke detectors, cameras, sprinklers and ceiling microphones interrupt the panel field and alter its mass, stiffness, leakage and plenum coupling. A device may be independently supported for seismic or fire reasons while its trim bears against the ceiling; flexible connections can prevent structural loading yet create an air path; a back-can can increase local attenuation but also add mass, rattle, obstruct airflow or conflict with a listed fire assembly.

Device schedules should state the opening dimensions, support, backing enclosure, cable or duct connection, perimeter treatment, maintenance method and evidence basis; the drawing should not use one generic symbol for acoustically different devices; a recessed loudspeaker with a ventilated metal can is not equivalent to a sealed heavy back-box. A lay-in luminaire replacing a ceiling tile removes the tested panel at that location; a diffuser connects the room to a duct or plenum whose attenuation must be analysed separately.

Independent support is necessary for many devices, but the support itself can bridge an isolated ceiling; rods, seismic wires, conduits and safety chains should attach to the appropriate structure without contacting both isolated and non-isolated elements; clearances must remain under normal movement; where a restraint engages only during an earthquake, its gap should be measured and recorded. An unplanned tie wire pulled tight during installation can defeat the intended hanger isolation while remaining nearly invisible below the ceiling.[111]

Fire and smoke requirements constrain every treatment; a proprietary fire-resistive ceiling may require particular devices, frames, clips and clearances; an acoustical enclosure added without listing review can trap heat, obstruct sprinkler distribution or alter membrane behaviour; conversely, a fire-rated

111 MB-0166. ASTM International, ASTM C635, ASTM C636.

penetration product may not provide adequate acoustic closure unless its tested configuration and movement capacity are compatible with the project. The submittal review should preserve both obligations rather than allowing one discipline to approve a detail in isolation.

Commissioning should include device-by-device inspection and selective source tests; a local loudspeaker or directional source can compare ceiling bays; temporary closure of a diffuser or access panel can test a suspected path, provided the intervention is safe and documented. The report should state whether the improvement follows air closure, added mass, changed damping or altered duct transmission; that causal distinction determines the durable remedy.

22.59 Integrated acceptance matrix for horizontal boundaries

Horizontal-boundary acceptance should not be reduced to one IIC, AIIC, STC or apparent room-pair result; the required evidence follows the authorised use, source states and accessible receiving locations; a secure conference room below an office may require airborne speech testing, impact assessment, structural-vibration review, plenum inspection and after-hours background measurement. A room below a roof may require rain, wind and rooftop-plant states instead of office footfall; a technical room above may require rolling load, fan, pump and equipment-rack support analysis.

The acceptance matrix should therefore have separate rows for direct airborne insulation, impact response, structural flanking, plenum transmission, service paths, roof sources, operational speech and formal authority disposition; columns identify the test method, source, frequency range, spatial sampling, configuration, uncertainty, decision rule, evidence owner and residual limitation. A blank cell is not presumed compliant; it is either not applicable with a stated rationale, deferred with an owner and date, or unresolved.

Sequence matters. Product and laboratory evidence support design and submittal review. Concealed-work records establish configuration. Pre-functional inspection confirms that panels, barriers, hangers, edge strips, penetrations and devices are complete; standard field tests establish installed quantities; operational tests examine credible source states; the authority then decides whether the total evidence supports the defined use. Each layer answers a different proposition.

A conditional acceptance should identify the condition precisely. Examples include restricting protected speech until rooftop equipment isolation is corrected, prohibiting storage that overloads a floating floor zone, requiring masking to remain within a commissioned range, or mandating retest after a ceiling access project; conditions should be technically enforceable and linked to configuration control. Vague statements such as “monitor noise” or “maintain acoustics” do not create a usable obligation.

Worked example 22.35. Consequence-weighted horizontal-boundary decision

Engineering question. A room has three residual horizontal-path risks after commissioning: a common-plenum path with estimated probability 0.08 of exposing a protected fragment during a defined meeting state and consequence score 9; a footfall path with probability 0.30 and consequence score 2 because it disrupts but does not expose speech; and a rooftop-plant path with probability 0.12 and consequence score 4. What simple expected-loss ranking follows?

Using the screening quantity

$$L_i = P_i C_i,$$

the plenum path gives

$$L_p = 0.08(9) = 0.72,$$

the footfall path gives

$$L_f = 0.30(2) = 0.60,$$

and the rooftop path gives

$$L_r = 0.12(4) = 0.48.$$

The scores are dimensionless decision aids. The plenum path ranks first despite having the lowest probability because its consequence is greatest; the method assumes that the probability and consequence scales are meaningful, comparable and independently assigned; it omits uncertainty, correlated events, risk aversion and legal constraints. It can help prioritise investigation but cannot replace a specified acceptance rule or authority decision.

22.60 Technical schedules for design, construction and acceptance

The following schedules convert the chapter's physical analysis into project controls. They are not universal specifications. Each project must identify the competent authority, use, source states, required metrics, fire and structural obligations, tolerances, inspection frequency and decision rules.

The hold-point schedule in Table 22-5 appears below the construction-surveillance discussion because the same record continues into commissioning and lifecycle control. It should be coordinated with the penetration register, door schedule, glazing schedule and HVAC path register developed elsewhere in the volume.

22.61 Chapter conclusions

Floors, ceilings, roofs and plenums are connected mechanical and acoustic systems; direct airborne insulation is only one part of their behaviour; impact forces, structural mobility, floating-floor resonance, pedestal coupling, ceiling-plenum transmission, roof curbs, wall heads, façade edges, services and maintenance states can dominate a secure room whose nominal partitions are strong.

Laboratory impact and airborne tests provide indispensable but bounded evidence; field measurements include flanking and installed conditions, yet belong only to the tested rooms and state; occupied speech-security assessment addresses information exposure; formal approval remains a competent-authority decision. Those propositions must remain separate.

A successful design begins with a path schedule and ends with a lifecycle baseline. Floating floors require continuous isolation. Raised floors require perimeter and service control; suspended ceilings require a clearly stated role. Roofs require source-specific treatment. Junctions require movement, fire, structure and acoustics to be coordinated; commissioning must test the mechanisms that the design actually uses, and later changes must be controlled before they silently rewrite the boundary.

22.62 Chapter 22 glossary

Absorption-normalised impact sound pressure level. Impact sound pressure level adjusted to a reference receiving-room absorption area under the applicable method.

Access floor. Removable panel floor supported above a structural base on pedestals or stringers, creating a service cavity or plenum.

Apparent impact insulation class. ASTM field rating derived from absorption-normalised impact levels and including installed flanking paths.

Ceiling attenuation. Laboratory quantity describing sound attenuation through a prescribed ceiling and common-plenum arrangement; it is not a material constant.

Dynamic stiffness per unit area. Frequency-dependent force-displacement stiffness of a resilient layer divided by loaded area, commonly expressed in newtons per cubic metre.

Floating floor. Upper floor plate supported on a resilient layer and isolated from surrounding construction to reduce impact and structure-borne transmission.

Force transmissibility. Ratio of transmitted dynamic force to applied dynamic force under a stated mechanical model.

Impact insulation class. Laboratory single-number rating derived from tapping-machine impact data under ASTM E492 and E989.

Impact sound rating. ASTM field single-number rating based on measured impact sound pressure levels without the same normalization used for AIIC.

Low-frequency impact insulation class. Supplemental ASTM laboratory rating for low-frequency impact data; it does not replace IIC.

Normalised impact sound pressure level. Impact sound pressure level adjusted to a reference absorption or reverberation condition according to the applicable standard.

Plenum barrier. Construction installed within a ceiling or floor plenum to reduce interzone sound transmission and control services at a partition line.

Raised-floor bridge. Rigid or semi-rigid connection through a raised or floating floor that transfers force or creates an air path across the intended isolation.

Resilient hanger. Ceiling or service support incorporating a spring or elastomer intended to reduce dynamic force transmission above its resonance.

Seismic restraint clearance. Designed gap that permits ordinary isolated motion while allowing a restraint to engage under larger earthquake displacement.

Soft impact source. Impact source intended to excite lower-frequency floor response than a standard tapping machine, under a defined procedure.

Tapping machine. Standardised mechanical source using repeated hammer impacts to generate comparable floor-impact measurements.

Type B element. ISO 10848 classification including elements such as suspended ceilings, access floors and floating floors where the junction has small influence under the method.

Vibration reduction index. Standardised junction quantity used in building-acoustic flanking prediction and comparison.

Chapter 23. Composite Transmission, Flanking Networks, and Complete-Envelope Analysis

23.1 The protected room is a network, not a specimen

A room used for protected conversation is bounded by more than the visible separating wall. The operative boundary includes every wall leaf, floor, roof, ceiling, door, glazing system, mullion, threshold, plenum, duct, pipe, conduit, cable route, access panel, structural junction and adjoining volume that can carry acoustic energy or vibration from the source to an accessible receiver. The network changes when a door opens, a fan changes speed, a masking system fails, an access floor panel is removed, or a quiet corridor becomes occupied; complete-envelope analysis therefore begins by defining the source state, physical configuration, receiving locations and time interval, rather than by choosing a headline wall rating.

The system model should preserve four separate propositions. Laboratory data describe the tested specimen and mounting; field data describe an installed room pair or a bounded component under the measured state; an occupied speech assessment addresses audibility or intelligibility for defined sources, backgrounds and listener access; formal acceptance remains an authority decision under an identified programme. Combining paths does not merge those propositions; it merely estimates or measures how energy reaches a receiver. [112]

A useful representation is a directed graph; source nodes contain sound power, spectrum, directivity, position and temporal state; path nodes represent boundaries, junctions, openings and service routes; receiver nodes contain microphone positions, room absorption, background, listener

112 MB-0263. ASTM International, ASTM E336-25a, ASTM E90-23.

access and the chosen measurand. Edges carry transfer functions, transmission coefficients, vibration transfer terms or empirically measured level differences. The graph is not decorative. It forces the analyst to state what each number means, where it applies and which paths remain unmeasured.

Figure 23-1. Complete-envelope analysis retains source, path, receiver, evidence and decision identities

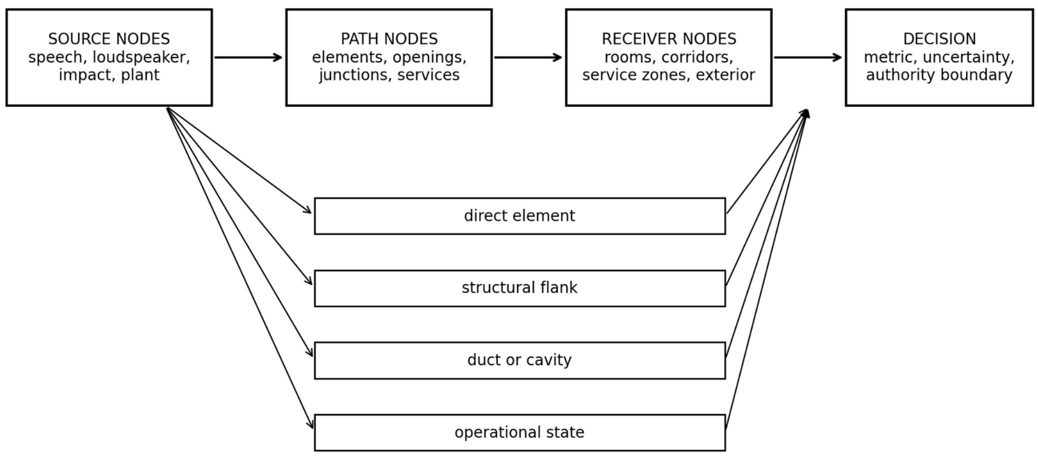

Figure 23-1. Source, path and receiver graph for complete-envelope acoustic-security analysis. Author's original diagram. Each edge represents a defined transfer quantity rather than an assumed verbal relation.

23.2 Evidence hierarchy for a composite envelope

A composite model is only as reliable as the evidence assigned to its paths; product standards establish material identity, quality or structural properties within their scope; laboratory transmission-loss tests establish frequency-dependent performance of an exact specimen; field room-pair tests establish apparent performance under installed conditions. Junction tests can characterise selected flanking combinations. Operational speech measurements add source and background state; none of those records, by itself, proves the entire room under every state. [113]

The evidence hierarchy should be explicit in the project register; a value copied from a catalogue receives a different status from a complete accredited laboratory report; a predicted junction term receives a different status from a measured vibration reduction index. A field intervention that temporarily seals a grille may support a path hypothesis, yet it does not establish the original construction behind the grille; an authority decision can accept residual uncertainty, but it does not convert an unmeasured path into a measured one.

The evidence matrix in Table 23-1 distinguishes common evidence classes. The final column is essential because it prevents a useful but limited datum from acquiring a broader meaning through repeated copying.

Table 23-1. Evidence classes and the bounded propositions they can establish

Evidence class	**Primary proposition supported**	**Minimum configuration record**	**Principal limitation**
Product certificate or material standard	Identity, composition, dimensions or quality within the product standard	Manufacturer, product, lot, edition and declared property	Does not establish completed assembly acoustic performance
Complete laboratory element report	Frequency-resolved performance of the exact specimen and mounting	Specimen geometry, materials, mounting, laboratory, method, environment and raw bands	Excludes installed flanking, later workmanship and operational state
Junction or flanking test	Transfer for the stated element pair, junction and excitation	Element types, junction length, supports, source element, receiver element and method	Applies only where the field junction is sufficiently comparable

113 MB-0264. ASTM International, ASTM E336-25a, ASTM E90-23.

Evidence class	Primary proposition supported	Minimum configuration record	Principal limitation
Field room-pair test	Apparent installed relationship for the tested rooms and state	Source and receiver geometry, positions, decay, background, configuration and uncertainty	Does not identify individual causes without diagnostic evidence
Controlled intervention	Change associated with a reversible modification	Before, intervention, restoration, source state, uncertainty and collateral effects	Supports a path hypothesis only to the specificity of the intervention
Occupied speech assessment	Audibility or intelligibility under defined source, background and listener conditions	Talker or source protocol, language, positions, access, background, metric and uncertainty	Does not establish other source states or formal accreditation
Authority disposition	Acceptance, rejection or conditional use under the identified programme	Authority, scope, conditions, evidence set, date and change-control obligations	Does not convert unmeasured technical propositions into measured facts

23.3 Linear energy ratios govern parallel paths

Decibels cannot be averaged or added directly when independent transmission paths operate in parallel. Each path must first be expressed as a linear power ratio. For a path with transmission loss R_i in decibels, the corresponding transmission coefficient is

Equation 23.1

$$\tau_i = 10^{-R_i/10}.$$

If several paths occupy areas S_i within a boundary of total area S, and if the assumptions of incoherent power addition and compatible reference quantities are reasonable, the composite coefficient is

Equation 23.2

$$\tau_c = \frac{\sum_i S_i \tau_i}{S}.$$

The composite transmission loss is

Equation 23.3

$$R_c = -10\log_{10}(\tau_c).$$

These expressions are elementary, but their evidentiary conditions are not. All component values must refer to the same frequency band, compatible incidence or room conditions, and defined states; a laboratory door value cannot be combined uncritically with a field wall value; a grille insertion loss cannot be treated as a transmission loss unless reference areas and definitions have been reconciled. Correlated coherent paths can also invalidate simple power summation at low frequency. [114]

Worked example 23.1. Wall, door and glazing composite

Engineering question. What is the ideal area-weighted transmission loss at 500 Hz for a 30.0 m² boundary comprising 24.0 m² of wall at 62 dB, a 3.0 m² door at 42 dB and 3.0 m² of glazing at 48 dB?

The variables are $S_w = 24.0\,m^2$, $S_d = 3.0\,m^2$, $S_g = 3.0\,m^2$, and $S = 30.0\,m^2$. Their transmission coefficients are

$$\tau_w = 10^{-6.2} = 6.31 \times 10^{-7},$$

$$\tau_d = 10^{-4.2} = 6.31 \times 10^{-5},$$

and

$$\tau_g = 10^{-4.8} = 1.58 \times 10^{-5}.$$

The composite coefficient is

$$\tau_c = \frac{24\left(6.31 \times 10^{-7}\right) + 3\left(6.31 \times 10^{-5}\right) + 3\left(1.58 \times 10^{-5}\right)}{30} = 8.39 \times 10^{-6}.$$

114 MB-0319. ASTM International, ASTM E90-23, ISO 12354-1:2017.

Therefore

$$R_c = -10\log_{10}\left(8.39\times10^{-6}\right) = 50.8\,dB.$$

Area units cancel, leaving a dimensionless power ratio; if each input has standard uncertainty of about 1.5 dB and shares laboratory or modelling bias, uncertainty in the composite is not obtained by treating the inputs as independent. The example also omits seals, frame paths, junction flanking and receiving-room conditions; it establishes only an idealised band result; it does not establish field isolation, speech privacy or acceptance.

23.4 Small openings can control a massive boundary

An opening behaves differently from a heavy element because its transmission coefficient can approach unity over part of the spectrum; the relevant comparison is not visible size, but transmitted power; a continuous crack representing a few ten-thousandths of wall area can carry more power than many square metres of high-performance construction. The same principle applies to door undercuts, unsealed mullion cavities, grille free area, pipe annuli and cable grommets.

For a high-performance boundary with coefficient τ_b and an opening of area S_o having coefficient τ_o, the opening contribution is $S_o\tau_o$. A useful screening ratio is

Equation 23.4

$$\Gamma_o = \frac{S_o\tau_o}{S_b\tau_b}.$$

When Γ_o greatly exceeds unity, work on the main boundary yields little benefit until the opening is controlled. The formula is a screening device.

Real openings have length, shape, lining, radiation impedance, flow and frequency dependence. [115]

Worked example 23.2. Equivalent open area of distributed cracks

Engineering question. A 40 m² concrete wall has 65 dB transmission loss at a selected band. What open area would transmit the same power if the opening coefficient is conservatively taken as unity?

The wall coefficient is

$$\tau_w = 10^{-65/10} = 3.16 \times 10^{-7}.$$

Equal power requires

$$S_o = S_w \tau_w = 40\left(3.16 \times 10^{-7}\right) = 1.26 \times 10^{-5} m^2.$$

That is 12.6 mm², approximately the area of a 3.55 mm square; the dimensional check leaves square metres; the calculation intentionally exaggerates the openness of a crack and ignores its depth and impedance, but it demonstrates why continuity inspection matters. It does not prove that a visible 3.55 mm feature is acoustically open, nor that sealing it will deliver a 65 dB field result.

23.5 The weak path is frequency-dependent

A door may dominate at mid and high frequencies, while a slab junction controls at low frequency and a plenum grille controls a narrow band; path ranking must therefore be performed band by band and for each source state. A single-number classification can conceal a change in the controlling path because its reference contour compresses the curve into one integer;

115 MB-0837. International Organization for Standardization, ISO 12354-1:2017.

the rating remains useful for procurement and broad comparison, but final design requires the residual spectrum. [116]

The path contribution in a band can be expressed as the fraction

$$\eta_i = \frac{P_i}{\sum_j P_j},$$

where P_i is the transmitted power assigned to path i under a common reference. The fraction is dimensionless and sums to unity when the path set is complete. In practice the path set is rarely complete. The analyst should therefore use terms such as “fraction of modelled transmitted power” rather than “fraction of total transmission” unless omission has been bounded.

116 MB-0282. ASTM International, ASTM E413-22, ISO 16283-2:2020.

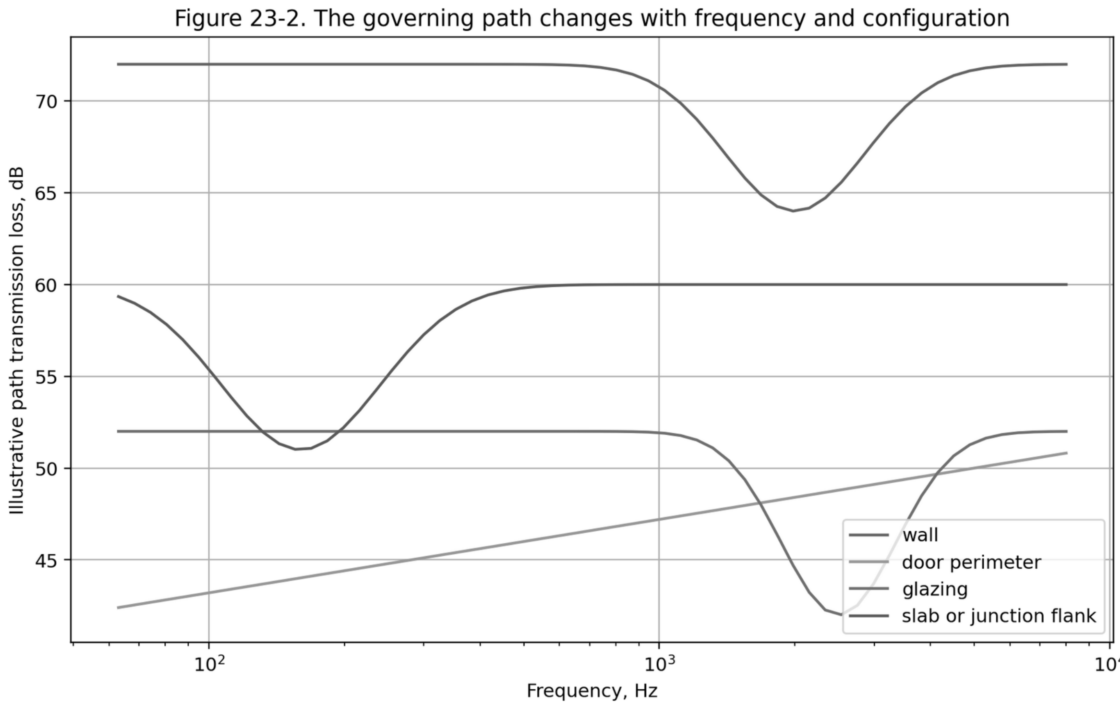

Figure 23-2. Frequency-dependent path dominance for a mixed envelope. Author's original diagram. The governing path changes with frequency, so one remedial priority cannot be assumed for the whole spectrum.

Worked example 23.3. Path contribution at one band

Engineering question. A model assigns transmitted powers of 4.0, 1.5, 0.9 and 0.6 arbitrary power units to a door, wall junction, glazing frame and duct path. What fraction is attributed to the door?

Total modelled power is

$$P_T = 4.0 + 1.5 + 0.9 + 0.6 = 7.0\,.$$

The door fraction is

$$\eta_d = \frac{4.0}{7.0} = 0.571\,,$$

or 57.1 per cent. The units cancel. If the door estimate has 20 per cent relative uncertainty and the junction estimate 40 per cent, the ranking may remain stable, but the exact percentage is less certain; the calculation applies only to the selected band and source state. It does not justify a whole-spectrum conclusion.

23.6 Direct transmission and flanking transmission are different questions

Direct transmission crosses the nominal separating element; flanking transmission reaches the receiver by another structural or airborne route; in an installed building the measured apparent result generally contains both; the distinction matters because the remedial actions differ; adding board to a direct wall does not correct a continuous slab flank. Sealing a plenum grille does not correct a precast panel joint; a room-pair test can reveal deficient overall performance without identifying the path.

ISO 12354-1 uses measured or derived element and junction data to estimate direct and flanking contributions. ISO 10848 provides measurement frameworks for selected flanking combinations or junctions. ASTM E336 measures actual room-to-room attenuation and expressly recognises direct and flanking behaviour. These methods are complementary rather than interchangeable. [117]

The evidence report should distinguish three statements:

the apparent room-pair result is below the requirement;
a path hypothesis is supported by measurement or intervention;
the causal construction defect has been directly observed or otherwise established.

Jumping from the first statement to the third is a common forensic error; a broad low-frequency deficit may be consistent with slab flanking, but also

117 MB-0266. ASTM International, ASTM E336-25a, ISO 12354-1:2017.

with duct breakout, façade coupling, source-room non-diffuseness or measurement-floor limitations.

23.7 Path taxonomy for a complete envelope

A useful taxonomy separates airborne openings, element transmission, structural flanks, service paths and operational paths; airborne openings include cracks, undercuts, grilles and connected cavities; element transmission includes wall leaves, doors and glazing; structural flanks include floors, ceilings, roofs, columns, beams, façades and continuous framing. Service paths include ducts, pipes, conduits, trays and equipment supports. Operational paths include open doors, altered dampers, removed panels, disabled masking and software-controlled audio states.

The categories overlap physically. A duct can carry airborne sound internally, radiate through its wall, and transmit vibration through hangers; a curtain wall can transmit through glass, mullions, anchors, spandrels and interior cavities; the taxonomy is therefore a search aid, not a claim that each path belongs to only one mechanism.

Table 23-2. Complete-envelope path taxonomy and minimum diagnostic evidence

Path family	**Representative routes**	**Dominant transfer quantity**	**Minimum diagnostic evidence**	**Typical remedial direction**
Direct element	Wall, door leaf, glazing lite, roof or floor panel	Transmission coefficient or element transmission loss	Element identity, dimensions, boundary condition and frequency curve	Change element, lining, mass, damping or sealing as mechanism requires
Airborne opening	Crack, undercut, grille, sleeve, service gap or connected cavity	Opening transfer, insertion loss or local level difference	Geometry, open area, tortuosity, local scan and temporary closure test	Close or attenuate the path while preserving movement, fire and service duties

Path family	Representative routes	Dominant transfer quantity	Minimum diagnostic evidence	Typical remedial direction
Structural flank	Slab, wall return, column, beam, façade anchor, frame or continuous stud	Mobility, vibration level difference, junction quantity or radiated power	Synchronous vibration, transfer functions, junction geometry and radiation check	Interrupt, isolate, damp or reroute force while preserving structural capacity
Service-air path	Supply, return, cross-talk duct, plenum or transfer-air opening	Duct insertion loss, breakout, terminal transfer or room-to-room level	Duct route, state, airflow, lining, silencer data, source and receiving scans	Add or correct silencing, length, bends, lining, terminal treatment or zoning
Service-structure path	Pipe, conduit, tray, hanger, equipment base or support frame	Force, mobility, transmissibility or structural velocity	Support geometry, operating state, coherence and controlled isolation test	Isolate supports, restore clearances, add flexible connection or reroute service
Distributed cavity	Raised floor, ceiling plenum, curtain-wall mullion, façade cavity or masonry cells	Network transfer or multiport level relation	Cavity continuity, access nodes, barriers, openings and multi-position measurement	Compartment, seal, line or reconfigure while preserving drainage and access
Operational path	Open door, removed panel, failed masking, damper mode or active loudspeaker	State-dependent source or transfer level	State log, control sequence, duty cycle and highest-consequence condition	Change procedure, interlock, monitoring, maintenance or operating authority

23.8 Junctions redistribute energy

A junction does not merely attenuate vibration. It redistributes incident power among connected elements, reflects part of it and dissipates part through material and connection loss. The result depends on wave type, angle, frequency, mobility, geometry and restraint. Heavy homogeneous elements, lightweight framed elements and mixed junctions require different models and measurement quantities. [118]

118 MB-0822. International Organization for Standardization, ISO 10848-1:2017, ISO 10848-4:2017.

The vibration reduction index K_{ij}, used in building-acoustic prediction, relates vibration level difference across a junction to element properties and junction length under the prescribed framework. It is not a universal material constant. Changing wall thickness, slab continuity, lining, connection or boundary conditions can change the value. A tabulated junction term should be treated as model input with provenance, applicability and uncertainty.

Worked example 23.4. Screening vibration level difference

Engineering question. The spatially averaged vibration velocity level on element i is 82 dB re 1 nm/s and on connected element j is 61 dB under the same excitation. What is the directional vibration level difference?

$$D_{v,ij} = L_{v,i} - L_{v,j} = 82 - 61 = 21\,dB.$$

The units are logarithmic levels relative to a common velocity reference, so subtraction yields decibels. This result is not automatically K_{ij}, because normalisation terms and method-specific conditions may apply. Repeatability, accelerometer mounting and spatial averaging must also be considered. The calculation supports directional comparison only.

23.9 Normalised flanking quantities

ISO 10848 distinguishes quantities appropriate to different element and junction types; normalised flanking level difference can describe transmission through a selected flanking combination. Junction quantities can describe vibration transfer; for Type B elements, such as access floors or uninterrupted lightweight façades, transmission through the element and its associated cavity may be inseparable in the test result; field measurements often retain unwanted paths because the building structure cannot be experimentally suppressed. [119]

A model should therefore record whether a datum is a component quantity, a junction quantity, or a combined installed quantity; double counting occurs when an analyst uses a combined measured flanking value and separately adds one of its constituent paths. Omission occurs when a laboratory junction value is used without adding field services or perimeter paths absent from the specimen.

The source register should contain the specimen dimensions, element type, junction geometry, receiving correction, frequency range and any suppression measures. Without those fields, a flanking number is difficult to transfer defensibly.

23.10 The ISO 12354 detailed model

The detailed ISO 12354-1 model estimates airborne sound insulation between adjacent rooms in one-third-octave bands, primarily from direct element data, flanking element data and junction behaviour. Its published range is ordinarily 100 Hz to 3,150 Hz, with possible extension to 50 Hz when suitable data exist. The method describes a calculation scheme and restrictions. It does not guarantee that every real path has been represented. [120]

The analyst should identify each path in the notation used by the model. A typical pair of rooms separated by element d and surrounded by flanking elements can contain the direct path Dd, two paths in which one element is direct and the other flanking, and paths between flanking elements. The

119 MB-0821. International Organization for Standardization, ISO 10848-1:2017, ISO 10848-2:2017.
120 MB-0836. International Organization for Standardization, ISO 12354-1:2017.

number of potential paths grows with connected elements. Services, doors and openings may require separate treatment because they are not adequately represented by a homogeneous element path.

The detailed model is strongest when the construction is regular, element data are traceable, junctions resemble the model families and workmanship has been controlled; its uncertainty grows when geometry is irregular, lightweight and massive systems are mixed, cavities connect around junctions, or field conditions depart from the test specimens. The model remains valuable because it exposes assumptions and permits sensitivity analysis; it should not be treated as a black-box certification engine.

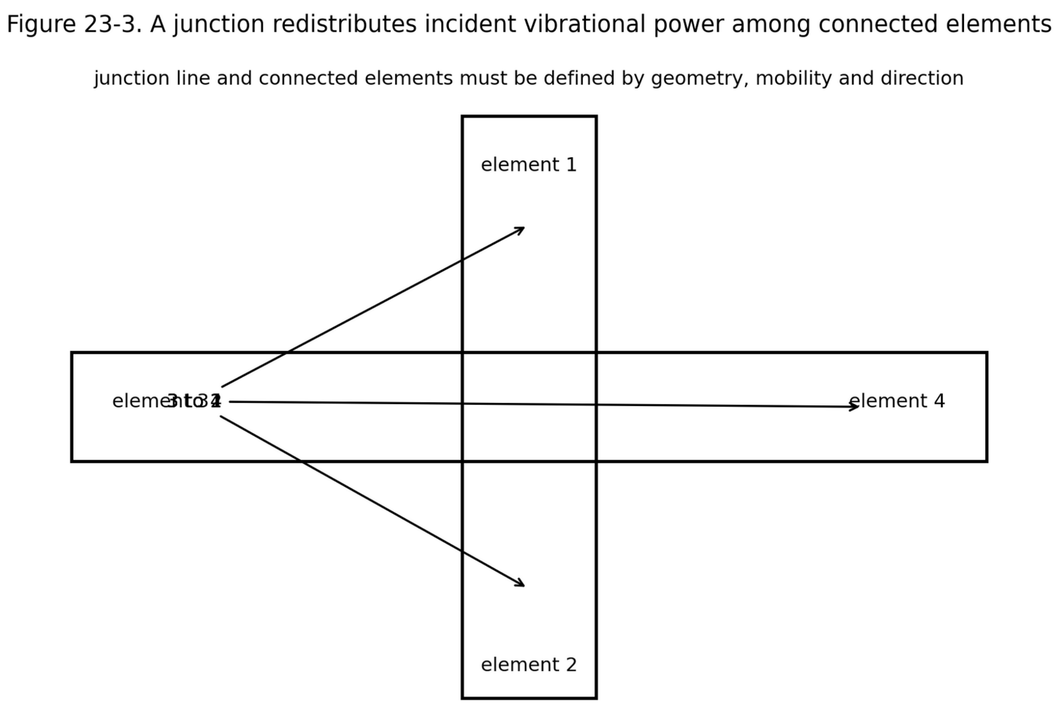

Figure 23-3. Four-element junction geometry used to organise direct and flanking transmission. Author's original diagram. Each directional route requires defined connected elements, junction geometry and reference quantity.

23.11 Detailed and simplified prediction are not equivalent

The simplified ISO 12354 model uses single-number quantities and a restricted field of application. It is efficient for early design or regular constructions, but it cannot reveal narrow-band weaknesses, low-frequency resonance or source-specific path changes. The detailed model retains frequency bands and is therefore better suited to protected speech, plant, impact and other source states with non-standard spectra. [121]

A simplified model should be labelled as such in the calculation report; the report should identify which flanking terms were defaulted, estimated or omitted; a design margin applied to the final single number does not cure a wrong path model. Conversely, a detailed frequency model does not

121 MB-0839. International Organization for Standardization, ISO 12354-1:2017, ISO 12354-2:2017.

become correct merely because it contains more numbers; its inputs and boundary conditions still require verification.

Worked example 23.5. Equal ratings, unequal residual spectra

Engineering question. Two model alternatives both yield a weighted apparent rating of 55. Alternative A has a 125 Hz result of 36 dB and Alternative B has 45 dB. A protected source is 9 dB stronger at 125 Hz than the reference spectrum. Which alternative has the lower residual level at that band?

Let the source level at 125 Hz be L_s. The receiving contribution is approximately $L_r = L_s - D$, before room and geometry corrections. Alternative B provides 9 dB more band isolation, exactly offsetting the 9 dB source excess relative to Alternative A. Its receiving level is therefore 9 dB lower than Alternative A at that band.

The calculation uses level difference as a screening quantity and assumes common geometry. It does not establish whole-room privacy, but it shows why equal single-number ratings can be operationally unequal.

23.12 Impact paths require a parallel network model

Impact sound begins as a force applied to a floor or other structure. Energy then propagates through the excited element, junctions, walls, ceilings and services before radiating in the receiving room; ISO 12354-2 and ISO 10848 provide frameworks for direct and flanking contributions, while ASTM E492 and E1007 provide laboratory and field measurement under the tapping machine; human footfall, rolling equipment and dropped objects can have different spectra and temporal behaviour. [122]

122 MB-0295. ASTM International, ASTM E492-25, ASTM E1007-25.

The network should identify the source force spectrum, point or area of application, structural element, connected junctions and radiating surfaces; a high airborne wall rating may be irrelevant if the floor and wall are structurally continuous; a floating floor can reduce the direct floor path while a perimeter bridge or service penetration retains another path. The complete model should include the altered load path created by the remediation itself.

Worked example 23.6. Combining two impact paths

Engineering question. Two independently estimated receiving-room impact levels are 44 dB and 39 dB in a band. What is their energetic sum?

Convert each level to a relative power quantity:

$$Q_1 = 10^{44/10} = 2.51 \times 10^4, Q_2 = 10^{39/10} = 7.94 \times 10^3.$$

Then

$$L_T = 10 \log_{10}(Q_1 + Q_2) = 45.2\, dB.$$

The total is 1.2 dB above the stronger path; if the paths are correlated, simple power addition may be inaccurate; the calculation also assumes compatible normalisation and reference conditions; it shows why removing a path 5 dB below the dominant path produces limited benefit.

23.13 Façades and external surfaces join the network

External surfaces can connect protected rooms to public or uncontrolled locations. ISO 12354-3 estimates façade insulation from the reduction indices of constituent elements and includes direct and flanking transmission. ASTM E1332 provides an outdoor-indoor transmission class intended for transportation-like spectra. Neither replaces band analysis for speech, tonal plant or unusual exterior sources. [123]

A façade model should include glass, opaque panels, mullions, transoms, spandrels, vents, perimeter seals, slab-edge cavities and anchors; interior partitions often terminate at the façade rather than at an independent massive return; sound can travel along mullion cavities or through a shared spandrel zone. A strong glazing unit therefore does not establish the complete exterior boundary.

External receiver geometry differs from an adjoining room; distance, façade directivity, reflections, wind and background influence exposure; a field façade test and an interior room-pair test answer different questions; the complete-envelope register should keep those results separate while showing how both inform the protected-room threat model.

23.14 Services create hybrid airborne and structure-borne paths

Ducts, pipes, conduits and cable systems can transmit energy internally, radiate through their walls, excite supports and penetrate boundaries; a single “service path” entry is therefore too coarse for serious diagnosis; the model should distinguish internal airborne propagation, breakout, break-in, wall or pipe vibration, hanger transfer, sleeve leakage and connected cavities.

A duct silencer may reduce internal propagation while adding pressure drop and regenerated noise; flexible connectors may reduce vibration at one frequency and transmit at another; fire dampers, access doors and

123 MB-0848. International Organization for Standardization, ISO 12354-3:2017, ASTM E1332-22.

transitions change both acoustic and life-safety behaviour. Later chapters treat those systems in depth; here the governing point is that each mechanism becomes a separate edge in the complete-envelope graph.

Worked example 23.7. Parallel duct and wall contributions

Engineering question. A receiving-room band level predicted through the wall path is 24 dB, while the duct path predicts 31 dB. What is the combined level and the maximum benefit if the duct path is eliminated?

The combined level is

$$L_T = 10\log_{10}\left(10^{2.4} + 10^{3.1}\right) = 31.8\,dB.$$

Eliminating the duct leaves 24 dB, an improvement of 7.8 dB; the result is dimensionally a level difference because both inputs share the same reference; the example assumes independent powers and unchanged source and room conditions. It does not prove that the duct is physically responsible; an intervention or path measurement is required.

23.15 Reference areas, room geometry and the meaning of a path contribution

A path contribution is never independent of the geometric convention used to express it; laboratory transmission loss refers power through a specimen to its area, whereas a room-pair level difference also depends upon receiving-room absorption and source-room excitation. Flanking prediction introduces junction lengths, element areas and reference absorption; these quantities cannot be interchanged merely because all final results are expressed in decibels; ISO 12354-1 and ISO 10848 preserve distinct normalisations precisely because a wall, a ceiling plenum and a line junction do not occupy the same geometric category. [124]

124 MB-0838. International Organization for Standardization, ISO 12354-1:2017, ISO 10848-1:2017.

The model register should therefore state, for every path, the source element, receiving element, shared junction, element areas, junction length, reference absorption and any normalisation embedded in the source data; a path value copied from another project can be misleading even when the nominal construction is similar. Changing room width alters junction length. Changing receiving-room volume alters decay and spatial averaging; changing the exposed area of a flank alters radiated power; the result belongs to the geometry that created it.

Where a room contains several receiving surfaces, the analyst should preserve their individual areas until the power contributions have been assembled; collapsing them prematurely into an average transmission loss can hide a small, strongly radiating surface; a ceiling tile field, a glazed strip and a door can each have different source spectra, radiation efficiencies and maintenance states. Their linear contributions may be combined, but their evidence should remain separately traceable.

Worked example 23.8. Effect of reference area on an apparent path estimate

Engineering question. A flanking surface radiates an estimated sound power corresponding to a normalised contribution of 48 dB when referred to 10 square metres. What value results if the same power is referred to an exposed area of 6 square metres?

For equal transmitted power, changing the area reference changes the level by

$$\Delta L = 10\log_{10}\left(\frac{10}{6}\right) = 2.22\,dB.$$

The contribution referred to 6 square metres is therefore 50.2 dB under the stated convention; the units inside the logarithm cancel; the calculation does not describe a physical improvement or deterioration; it shows that a reported path quantity must carry its reference area. Uncertainty in the actual exposed area should be propagated if linings, cabinets or partial-height elements obscure the radiating surface.

23.16 Source state, directionality and spatial participation

A complete-envelope model begins with a source state rather than an abstract diffuse field; ordinary speech, raised speech, maximum unamplified effort, a ceiling loudspeaker and a table loudspeaker excite the same room differently; source position changes modal participation at low frequency; orientation changes the incident energy on doors, glazing and wall intersections at mid and high frequencies. Amplified systems can deliver sustained low-frequency energy that natural speech does not maintain; a single source-room average cannot represent every operational state. [125]

The source model should contain at least a band spectrum, directivity or directional uncertainty, position distribution, operating duration and probability of occurrence; where the protected information includes brief consequential tokens, peak or short-time source levels may matter more than long-term averages. Where meetings last for hours, cumulative exposure and repeated listener opportunity matter; the path network itself may remain linear, but the consequence model is conditional upon time and source state.

125 MB-0233. ASTM International, ASTM E2638-24, IEC 60268-16:2020.

Source placement also changes the relative importance of direct and flanking paths; a talker close to a glazed façade may excite that surface more strongly than a centrally located calibrated loudspeaker; a ceiling loudspeaker near a shared plenum can place greater energy into ceiling openings and ducts. A wall-mounted display with integrated speakers can excite the mounting wall structurally; commissioning should therefore include the positions that represent intended use, not merely positions convenient for test uniformity.

Worked example 23.9. Directional source correction in path ranking

Engineering question. A talker produces 68 dB in a speech band at the reference position. The directivity correction towards a door is 3 dB, while the correction towards a side wall is minus 2 dB. The door path provides 43 dB attenuation and the side-wall path provides 39 dB. Which receiving contribution is larger?

The incident levels are 71 dB at the door and 66 dB at the side wall. The corresponding receiving estimates are

$$L_{r,d} = 71 - 43 = 28\,dB,$$

$$L_{r,w} = 66 - 39 = 27\,dB.$$

The door contribution is 1 dB larger despite its greater attenuation; if the two contributions are independent, their energetic sum is 30.5 dB; the example shows that path ranking depends upon source participation as well as isolation. The directivity corrections are illustrative and require measurement or a justified source model.

23.17 Receiving-room absorption, background and listener access

The receiving room transforms transmitted power into sound pressure; absorption area, volume, modal structure and background vary with furnishings, occupancy and building operation. A receiving corridor at midday can mask leakage that becomes audible during night security rounds; a furnished office can have shorter decay than the empty room measured before handover; a listener may stand at a wall, door crack, duct grille or façade return rather than at the microphone positions used for a room-average field test. [126]

A robust model separates transmission from receiving-state consequence; the first layer estimates sound power or a normalised level contribution; the second converts that contribution to pressure under specified absorption and geometry; the third compares the resulting spectrum with background and a defined listener or speech metric. This structure prevents a change in carpet, occupancy or ventilation noise from being mistaken for a change in the boundary itself.

Listener access should be spatially explicit. Uncontrolled spaces may include a corridor, adjacent office, ceiling void, service cupboard, exterior ledge or maintenance platform; some positions permit prolonged access and recording. Others are transient. The risk model should not assign equal weight to every point, but it should not discard a technically weak position merely because it is inconvenient; access, dwell time and concealment are institutional variables that accompany the acoustic model.

126 MB-0255. ASTM International, ASTM E336-25a, ASTM E2638-24.

Worked example 23.10. Receiving absorption and pressure-level change

Engineering question. A transmitted sound-power contribution is unchanged, but the receiving room equivalent absorption area falls from 32 to 16 square metres after furniture is removed. What pressure-level change is predicted under a diffuse-field screening model?

For constant power, mean-square pressure is inversely proportional to equivalent absorption area. Thus

$$\Delta L_p = 10\log_{10}\left(\frac{32}{16}\right) = 3.01\,dB.$$

The receiving level increases by approximately 3 dB. The area ratio is dimensionless. The result assumes a sufficiently diffuse field and does not describe local modal peaks; it demonstrates why an occupied-state or worst-reasonable-state model must accompany the transmission result.

23.18 The path matrix as a controlled engineering record

A path matrix converts the conceptual network into an auditable project record; each row identifies one source element, one junction or service route, one receiving element, the governing data, the prediction method, uncertainty, inspection evidence and current disposition. The matrix should distinguish measured, calculated, inferred and assumed values; it should also record whether a path is active in each operating state; a closed fire damper, an open transfer grille and a fan in purge mode represent different networks.

The matrix is not merely a calculation sheet; it coordinates design, construction surveillance and commissioning; a path that depends on an unverified wall head becomes an inspection hold point; a path controlled by a removable access panel becomes a maintenance item. A path with no reliable test data becomes a source-development task or a conservative uncertainty term. The matrix should survive handover so that later alterations can be assessed against the original model.

Path identifiers should remain stable throughout the project; a practical syntax might encode source room, source element, junction and receiver; for example, R101-WN-J3-CL-R102 can identify a north wall to ceiling junction path; stability permits photographs, field notes, test data and nonconformance reports to be linked without relying upon prose descriptions that change among disciplines.

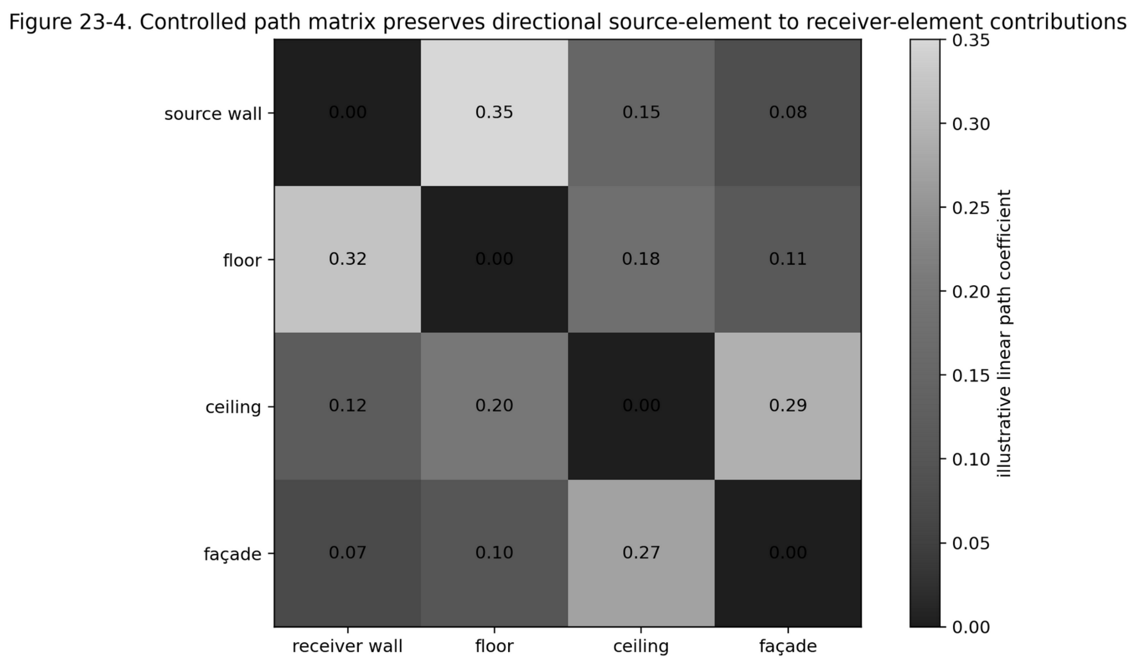

Figure 23-4. A controlled path matrix relates source elements, junctions and receiving elements while preserving direction, method, evidence and uncertainty. Author's original diagram.

23.19 Graph theory, cut sets and weakest-path interpretation

Graph theory supplies a useful abstraction when it remains subordinate to physical evidence; rooms, cavities and external zones can be represented as nodes; walls, doors, ducts, plenums, slabs and joints become edges; edge weights can represent attenuation, transmitted power, uncertainty or remedial cost; the graph reveals parallel paths and shared bottlenecks that are difficult to perceive in a drawing set. It does not, by itself, calculate the correct acoustic quantity; the weight assigned to each edge must come from an appropriate physical model or measurement.

A minimum cut set identifies the group of edges whose removal separates the protected node from an uncontrolled node; in secure-room design, this concept prevents excessive attention to one wall while another route remains open; a room may require closure of the door edge, return-air edge and raised-floor edge before the uncontrolled corridor is acoustically separated. Strengthening one edge beyond the others produces diminishing returns.

The graph can also expose common-cause vulnerabilities; several nominally separate paths may share a plenum, slab edge or façade mullion; treating them as independent in uncertainty or reliability calculations can understate risk; the path register should mark shared physical features so that covariance and intervention effects are handled correctly.

Worked example 23.11. Minimum-cut interpretation of a three-route boundary

Engineering question. A protected room connects to an uncontrolled corridor through a door path, a shared plenum path and an underfloor path. All three operate in parallel. Which interventions form a complete cut set?

Closing only the door path leaves two connections; closing the door and plenum still leaves the underfloor path; a complete cut set therefore contains at least one effective intervention on each of the three parallel routes. If the plenum and underfloor routes both pass through a common service riser, treating the riser may close two edges at once, provided the physical evidence confirms that no bypass remains.

The example is topological rather than numerical. It shows why the project should identify all parallel routes before comparing decibel improvements. The cut-set result does not establish the attenuation achieved by each intervention.

23.20 Multiroom suites and adjoining-zone propagation

A secure suite rarely contains only one source room and one receiving room; conference rooms, circulation spaces, vestibules, equipment rooms, offices, service corridors and ceiling voids form a network in which energy can pass through intermediate nodes. A direct test between the protected room and the public corridor can miss a strong path into a controlled office that later becomes uncontrolled, or a path through a service room accessible during maintenance; the adjacency model should therefore include present and foreseeable access classifications.

Intermediate rooms can attenuate or amplify consequence; two successive doors can form a sound lock when their sequencing and seals are controlled; the same vestibule can become a coupling chamber if both doors are held open; a ceiling void can distribute energy to several rooms. A stair core can provide a large reverberant shaft. Multiroom analysis should model operating states and access rules rather than assuming static architecture.

Measurements can be staged through the graph. Room-pair tests identify strong edges. Source localisation within intermediate nodes tests whether the energy is re-radiated or merely passes through; controlled closure of doors, dampers or panels can identify path dependence; the resulting graph is an evidence model, not a speculative diagram.

Figure 23-5. Multiroom graphs distinguish controlled, service and uncontrolled nodes and their state-dependent edges

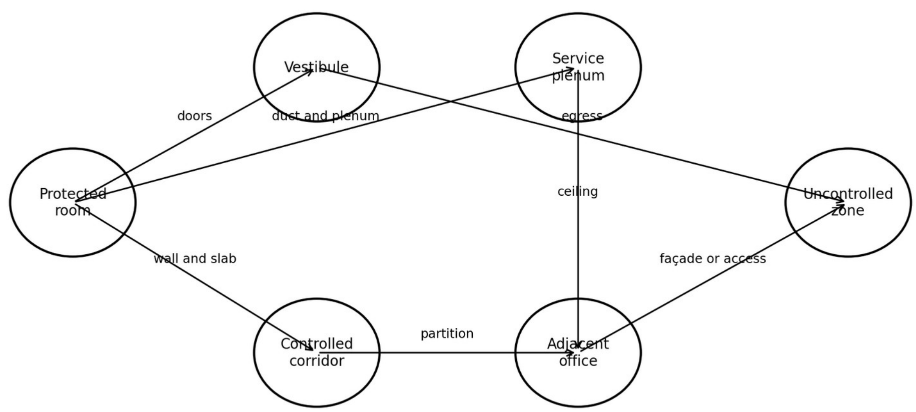

Figure 23-5. Multiroom graph models should distinguish protected, controlled, uncontrolled and service-access nodes, together with state-dependent edges. Author's original diagram.

Worked example 23.12. Two-stage transmission through an intermediate room

Engineering question. A source room level is 72 dB. The measured level difference into an intermediate room is 38 dB, and the difference from that room into a corridor under the same operational state is 31 dB. What is the simple sequential screening estimate?

The intermediate level is 34 dB. Applying the second difference gives 3 dB in the corridor; this arithmetic assumes that the intermediate field created by the first path is equivalent to the source condition used for the second test, which is rarely exact. Room absorption, source distribution and background can invalidate direct subtraction; the calculation is therefore a preliminary bound; a direct source-to-corridor test and an intermediate-room power model are preferred for acceptance.

23.21 Shared plenums, raised floors and distributed cavities

Distributed cavities are network nodes with uncertain geometry; shared ceiling plenums contain tiles, barriers, ducts, cable trays, luminaires and gaps; raised floors contain pedestals, cable bundles, floor boxes and perimeter cut panels; façade cavities may connect spandrels across several bays. These spaces can carry airborne energy and can also couple structurally through grids, pedestals or framing; ISO 10848-2 and ASTM E1414 provide measurement concepts for some Type B elements and common ceiling plenums, but actual installations can differ materially from the prescribed arrangements. [127]

A cavity should be subdivided where barriers, turns or absorption create meaningful state changes; treating an entire floor plate as one node may exaggerate coherence, while dividing every tile bay creates an unmanageable model unsupported by data. The appropriate resolution follows the diagnostic question; if a ceiling barrier is suspected, nodes on each side permit its insertion loss to be estimated; if a raised-floor plenum connects ten rooms without barriers, one distributed node may be adequate for screening.

Cavity access changes risk. A locked ceiling void and a publicly accessible raised floor do not present equal listener opportunities; yet access control

127 MB-0827. International Organization for Standardization, ISO 10848-2:2017, ASTM E1414.

can change during maintenance; the lifecycle record should identify who may enter the cavity, whether portable recording equipment could be placed there, and whether alterations require retesting.

Worked example 23.13. Distributed plenum with three outlet rooms

Engineering question. A plenum receives a band sound-power quantity normalised to unity. It distributes fractions 0.50, 0.30 and 0.20 to three receiving rooms. What are the relative level differences among the outlets?

The level associated with each fraction is 10 log10(fraction); the three relative levels are minus 3.0 dB, minus 5.2 dB and minus 7.0 dB; room 1 is 4.0 dB above Room 3. The fractions must sum to one under the simplified conservation model; real plenums include absorption, leakage, reflections and frequency-dependent outlet impedances. The example demonstrates why a single plenum attenuation value cannot identify exposure in each room.

23.22 Doors, glazing and other discrete components within the envelope

Discrete components should be represented as complete installed subsystems; a door path includes leaf transmission, seals, frame perimeter, threshold, hardware penetrations and operating state. A glazing path includes panes, interlayer, cavity, frame, gasket, perimeter, mullions and adjacent opaque panels; treating a nominal STC as the edge weight discards the very conditions most likely to control field performance; ASTM E2964 provides a field door insertion method, while ASTM E90 and ISO 10140 provide laboratory element data. Their quantities answer different questions. [128]

The component path should be divided only when doing so supports diagnosis; a door can be represented as one edge for early design; during commissioning, the leaf, head, jambs and sill may need separate local evidence. A glazing wall can be one edge when the complete tested bay matches the installation, but a curtain wall often requires separate vision glass, spandrel, mullion and perimeter paths.

Component substitutions are graph changes. Replacing glass changes mass, damping and cavity response; replacing a door closer changes latch engagement; adding an access-control cable changes frame penetration; the configuration register should update the path model rather than merely recording a product number.

Worked example 23.14. Door and wall in one boundary

Engineering question. A 24 square metre boundary contains a 2 square metre door with band transmission loss 36 dB and 22 square metres of wall with 61 dB. What is the composite transmission loss, neglecting other paths?

The transmission coefficients are

$$\tau_d = 10^{-3.6} = 2.51 \times 10^{-4}, \tau_w = 10^{-6.1} = 7.94 \times 10^{-7}.$$

The area-weighted coefficient is

$$\tau_c = \frac{2\left(2.51 \times 10^{-4}\right) + 22\left(7.94 \times 10^{-7}\right)}{24} = 2.16 \times 10^{-5}.$$

Thus

128 MB-0318. ASTM International, ASTM E90-23, ASTM E2964-26.

$$R_c = -10\log_{10}(\tau_c) = 46.7\,dB.$$

The 2 square metre door controls the boundary despite occupying only 8.3 per cent of the area; uncertainty in seal condition can outweigh uncertainty in wall performance; the result does not include flanking or receiving-room state.

23.23 Statistical energy analysis and subsystem power balance

Statistical energy analysis, or SEA, represents a complex vibrating system as coupled subsystems whose average modal energies exchange power. In building acoustics, rooms, plates and cavities can be subsystems, with coupling loss factors describing energy transfer; the method is attractive because a large structure can be reduced to a manageable power-balance model; it is most defensible where each subsystem has sufficient modal density, the field is reasonably diffuse in an energy sense and coupling can be represented statistically. [129]

For subsystem i, a basic steady-state balance can be written as

$$P_i = \omega\eta_i E_i + \sum_j \omega\eta_{ij} E_i - \sum_j \omega\eta_{ji} E_j,$$

where P_i is input power, E_i is modal energy, eta_i is internal loss factor, eta_ij is the coupling loss factor from subsystem i to j, and omega is angular frequency; each term has units of watts because angular frequency multiplied by dimensionless loss factor and energy yields joules per second.

The equation makes the network structure explicit; energy leaves a subsystem through internal dissipation and outgoing coupling, while

129 MB-1147. Robert J. M. Craik, Sound Transmission through Buildings Using Statistical Energy Analysis.

incoming coupling adds energy; reciprocity relations can constrain coupling factors, but physical symmetry should not be assumed where areas, modal densities or damping differ. The model requires band-specific parameters and should be validated against measured responses.

Worked example 23.15. Two-subsystem SEA screening balance

Engineering question. A source-room subsystem receives 0.020 W in a band. Its internal and outgoing loss factors are 0.04 and 0.01 at angular frequency 1,000 radians per second. Back coupling is neglected for a screening estimate. What is the source subsystem energy and the power transferred to the receiving subsystem?

The total loss factor is 0.05. Thus

$$E_1 = \frac{0.020}{1000(0.05)} = 4.0 \times 10^{-4}\, J\,.$$

Transferred power is

$$P_{12} = 1000(0.01)(4.0 \times 10^{-4}) = 0.0040\, W\,.$$

Twenty per cent of the input power is transferred under the simplified model; the calculation neglects receiving feedback, additional paths and uncertainty in the loss factors; it is a screening illustration, not a building prediction.

23.24 Limits of SEA in small rooms and low-frequency secure-room problems

The conditions that make SEA convenient often fail at the frequencies most important to heavy construction and amplified speech; small rooms have sparse modes at low frequency; structural elements can have deterministic resonances, local boundary conditions and strong spatial variation. Coupling can be dominated by one bolt, crack or service bridge rather than by a statistical ensemble; a subsystem average then obscures the local mechanism.

Modal overlap provides a useful screening indicator; when modal bandwidths overlap substantially, energy averaging becomes more plausible; when modes are isolated, deterministic analysis or direct measurement is preferred; the transition is gradual, and different subsystems in the same model can occupy different regimes. A concrete slab may have many modes while a small glass pane has only a few significant modes in a band.

Secure-room analysis also places unusual importance on rare weak paths; SEA predicts average energy exchange, not necessarily the local pressure at a listener's ear beside a door seal; a hybrid strategy can use SEA for distributed flanking and deterministic submodels for critical components. The report should identify the frequency bands in which each method is trusted.

Worked example 23.16. Modal overlap screening

Engineering question. A subsystem has average modal spacing 8 Hz and modal half-power bandwidth 3 Hz. What is the modal overlap factor under the simple ratio of bandwidth to spacing?

$$M = \frac{3}{8} = 0.375.$$

The result is below unity, indicating substantially separated modes under the simplified criterion. Statistical averaging may be weak. If bandwidth rises to 12 Hz at a higher frequency, overlap becomes 1.5 and statistical treatment is more plausible. The ratio is dimensionless. It does not replace inspection of mode shapes, coupling or spatial response.

23.25 Deterministic finite-element, boundary-element and wave models

Deterministic models retain geometry, boundary conditions and phase. Finite-element methods are suitable for bounded structural and acoustic domains when the mesh resolves the shortest wavelength of interest. Boundary-element methods can model radiation and exterior domains efficiently but require careful treatment of frequency, singular integrals and computational cost. Transfer-matrix and wave-based methods can represent layered panels and ducts where geometry permits analytical structure. [130]

The model's apparent precision is not evidence of validity; material modulus, damping, contact stiffness, seal impedance, support conditions and hidden geometry may be uncertain by orders greater than the numerical solver tolerance; mesh convergence addresses discretisation, not model-form error. Validation should compare predicted and measured modal frequencies, transfer functions or band quantities under documented states.

A complete-envelope deterministic model can become too large for practical use; substructuring and reduced-order models can preserve critical interfaces; for example, a detailed door-frame model can be coupled to a simpler room model through measured mobility or impedance. The coupling interface must conserve the relevant force and velocity or pressure and volume velocity quantities.

130 MB-0404. Carl Hopkins, Sound Insulation.

Worked example 23.17. Mesh-resolution screening for a structural wave

Engineering question. A bending wavelength is estimated as 0.48 m at the highest analysed frequency. Using six linear elements per wavelength as a minimum screening rule, what is the maximum element dimension?

$$h_{max} = \frac{0.48}{6} = 0.080\,m.$$

The maximum screening dimension is 80 mm; higher-order elements can change the requirement, and complex joints may need much finer local meshes; the calculation addresses spatial discretisation only; it does not validate material data, damping or boundary conditions.

23.26 Hybrid modelling across different frequency and evidence regimes

A hybrid model assigns each path to the method suited to its physics and evidence; low-frequency slab and room modes can be treated deterministically; mid-frequency distributed flanking can use ISO 12354 or SEA; doors, glazing and silencers can use measured element data. Small openings can use an impedance or conservative aperture model. The final result combines compatible linear power contributions, with uncertainty and correlation preserved.

The hybrid architecture should make method transitions explicit; a path should not change from deterministic to statistical treatment without a stated frequency or modal criterion; overlap bands can be calculated by both methods and compared; disagreement becomes a model-form uncertainty or a research task rather than being hidden by selecting the more favourable result.

Measured data can serve as coupling elements; a junction transfer function measured in a mock-up can replace an uncertain analytical joint model; a door's field insertion loss can replace a catalogue rating, provided the receiving normalisation and installed configuration are compatible. The evidence map should record which inputs are measured and which are predicted.

Figure 23-6. Hybrid modelling assigns methods by regime and joins them through controlled interfaces

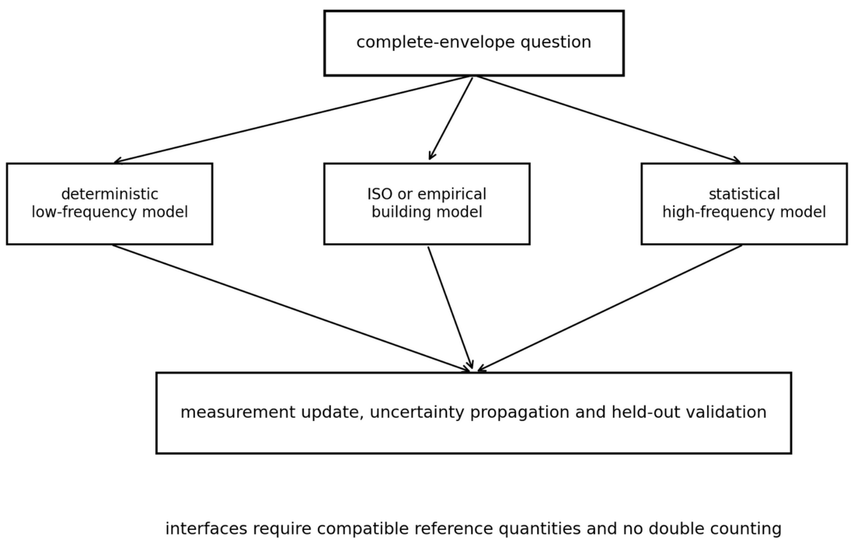

Figure 23-6. Hybrid models assign deterministic, statistical, empirical and measured treatments according to frequency, path type and evidence quality. Author's original diagram.

Table 23-3. Model families, input burden and bounded use in complete-envelope analysis

Model family	Appropriate regime	Required inputs	Strength	Principal limitation
Area-weighted energy sum	Parallel incoherent elements with compatible references	Band transmission coefficients, areas and states	Transparent weak-element screening	Cannot resolve structural junctions or coherent low-frequency interaction

Model family	Appropriate regime	Required inputs	Strength	Principal limitation
ISO 12354 detailed model	Building elements and junctions within documented method scope	Element performance, geometry, junction data and receiving conditions	Traceable path-by-path building prediction	Accuracy depends on applicability of input data and junction representation
Simplified empirical model	Early design or limited evidence	Representative ratings, geometry and empirical terms	Rapid comparison and sensitivity screening	Can conceal frequency structure and configuration-specific paths
Deterministic FEM, BEM or wave model	Low and mid frequency where geometry and material data are known	Mesh, material properties, boundaries, damping, excitation and validation data	Resolves modes, phase and local geometry	High input burden, model-form sensitivity and possible false precision
Statistical energy analysis	Sufficient modal overlap and weakly coupled subsystems	Modal densities, loss factors, coupling loss factors and source power	Efficient broadband subsystem power balance	Weak in sparse-modal, strongly coherent or highly localised conditions
Hybrid model	Mixed frequency regimes and evidence classes	Defined interfaces among deterministic, statistical, empirical and measured submodels	Uses each method where defensible	Interface consistency and double counting require explicit governance
Measurement-updated model	Existing facility with diagnostic observations	Prior model, calibrated measurements, uncertainty and held-out validation	Aligns prediction with observed system state	Calibration can hide compensating errors and is not independent validation

23.27 Measurement updating and model calibration

A model should be updated with measurements only in a manner that preserves causal meaning; adjusting several uncertain parameters until one overall level matches the field result can produce non-unique explanations; a low wall loss factor, a strong slab junction and a leaking door may yield the same total. Calibration should therefore use multiple observations that discriminate among parameters, such as vibration transfer, intensity maps, local pressure, decay and operational interventions.

Parameter updating requires bounds derived from material data, drawings and inspection; a fitted value outside a plausible range indicates model inadequacy, an omitted path or a measurement error; it should not be accepted merely because the objective function decreased. Correlations among fitted parameters should be reported.

Validation data should be separate from calibration data; if every observation is used to tune the model, agreement cannot demonstrate predictive capability; a practical sequence uses a subset of bands, source positions or path interventions for calibration and retains others for validation. The final report states the residuals and the conditions under which the model is intended to predict.

Worked example 23.18. Single-parameter calibration and non-uniqueness

Engineering question. A model predicts 31 dB in a receiving band, while measurement gives 35 dB. Increasing one path transmission coefficient by a factor g changes total power proportionally under a one-path assumption. What factor matches the measured result?

A 4 dB increase corresponds to

$$g = 10^{4/10} = 2.51 .$$

The fitted path coefficient is 2.51 times the original. The factor is dimensionless. If other paths contribute, the required factor differs, and many combinations can fit the same total; the result demonstrates why one aggregate observation cannot uniquely identify a path parameter.

23.28 Measurement uncertainty, configuration uncertainty and model-form uncertainty

A complete-envelope result is affected by at least three different classes of uncertainty; measurement uncertainty concerns the quantities obtained from instruments and calculations under a stated measurement model; configuration uncertainty concerns the physical state of the building, including concealed construction, door adjustment, duct-damper position, ceiling access, temporary seals, pressure differential, occupancy and service operation. Model-form uncertainty concerns the difference between the mathematical representation and the physical system; combining these classes into one undifferentiated allowance conceals their different remedies; better calibration can reduce some measurement uncertainty. Additional inspection can reduce some configuration uncertainty. Neither action proves that an omitted path or an invalid diffuse-field assumption has been corrected. [131]

The measurement model should therefore be written before uncertainty is assigned. Let the output quantity be

$$y = f(x, c, M) + \delta_M,$$

where x is a vector of measured or estimated physical inputs, c is a vector describing configuration state, M is the selected model structure and δ_M is model discrepancy. The expression is not intended to make discrepancy a convenient residual into which every mistake is placed. It separates what has been measured, what has been observed about the building, what has been assumed about the equations and what remains unexplained. JCGM GUM-6 emphasises that a measurement model is a structured relation

131 MB-0851. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

between output and input quantities, while the 2026 amendment to JCGM 100 addresses nonlinearity that can invalidate a simple first-order propagation. [132]

Configuration variables should be recorded as controlled states rather than assigned casual numerical uncertainty; a door closer can be in normal service, bypassed, held open or out of adjustment; a return damper can be open, closed or modulating. A suspended-ceiling tile can be present, displaced or replaced with another product; where several states are credible, each state is a separate scenario unless a probability distribution is supported by operational evidence. Averaging favourable and unfavourable configurations into one result can remove the very state that governs risk.

Model-form uncertainty deserves explicit treatment because building-acoustic models commonly combine empirical element data, idealised junction relations, statistical assumptions and estimated services; a predicted apparent sound reduction can agree with one field result for the wrong physical reason. If a door path is underestimated and a slab flank is overestimated, the errors can cancel; validation therefore requires path-sensitive observations, not only agreement of the total; residual plots by frequency, source position and diagnostic state are more informative than one overall difference.

A practical uncertainty budget can have separate columns for quantity, source, probability description, correlation, sensitivity, standard uncertainty, configuration status and model-discrepancy treatment; the result reported to an authority should identify which uncertainties are included in the

132 MB-0987. JCGM 100:2008.

expanded interval and which remain as scenario or model limitations. That distinction is particularly important when a numerical guard band is applied; a guard band calculated from instrument and repeatability terms cannot compensate for an uninspected plenum route.

Worked example 23.19. Separating measurement and configuration uncertainty

Engineering question. A receiving level for one source state is 24.0 dB. The combined standard measurement uncertainty is 0.9 dB; repeated door-contact measurements show that normal closing variation produces a standard deviation of 1.4 dB; an unverified ceiling-plenum condition could add between 0 and 4 dB but has no defensible probability distribution; how should the result be expressed?

Measurement and repeatable door-state terms can be combined, assuming independence, as

$$u_c = \sqrt{0.9^2 + 1.4^2} = 1.66\,dB.$$

For coverage factor $k=2$, expanded uncertainty is

$$U = 2u_c = 3.32\,dB.$$

The measured-state result can be reported as 24.0 dB with expanded uncertainty 3.3 dB for the defined door-operating distribution; the possible plenum contribution is not folded into that interval because no probability model is supported. It is reported as a separate unresolved scenario: receiving level may increase by as much as 4 dB if the suspected path is present; the dimensional check is consistent because all combined terms are logarithmic-level uncertainties in decibels under the stated approximation.

The calculation does not establish that the plenum condition exists or that the room is acceptable.

23.29 Covariance and correlated path inputs

Many complete-envelope inputs are correlated. The same surface-density measurement can enter several flanking paths; the same room absorption measurement can normalise direct and indirect quantities. Temperature can affect multiple viscoelastic seals and laminated panes; a common source calibration affects every receiving position; treating these inputs as independent can either understate or overstate uncertainty; JCGM 100 requires covariance terms where input quantities are correlated, and ISO 12999-1 provides a building-acoustics framework for applying uncertainty to sound-insulation quantities. [133]

For a differentiable model with inputs x_i, the first-order combined variance is

$$u_c^2(y) = \sum_i c_i^2 u^2(x_i) + 2\sum_{i<j} c_i c_j u(x_i, x_j),$$

where $c_i = \partial f / \partial x_i$ is the sensitivity coefficient and $u(x_i, x_j)$ is covariance. The sign matters. Positively correlated errors in two contributions that move the output in the same direction increase uncertainty. Correlation can reduce uncertainty when sensitivities have opposite signs, although such cancellation should not be assumed without evidence.

Correlation among physical paths is more complicated than correlation among input estimates; two receiving contributions can be coherent when driven by the same structural mode or duct field; energetic addition assumes incoherent or sufficiently averaged contributions; at low frequency,

133 MB-0850. International Organization for Standardization, ISO 12999-1:2020, JCGM 100:2008.

phase can produce reinforcement or cancellation at a point. The appropriate treatment depends on the measurand. Room-averaged band levels may justify energetic summation after spatial averaging. A local listener position near a modal maximum may require complex-pressure or transfer-function analysis.

A covariance register should identify the common cause; “correlated” is not an explanatory label; examples include a shared calibration certificate, a common material batch, one geometry measurement used in several terms, or a common environmental exposure; correlation coefficients copied from another project are rarely defensible. Where covariance is unknown but could affect the decision, scenario bounds or Monte Carlo sensitivity to plausible correlation are preferable to zero correlation by default.

Worked example 23.20. Effect of positive covariance

Engineering question. Two uncertain corrections, x_1 and x_2, each have standard uncertainty 1.0 dB and sensitivity coefficient 1.0. What is the combined standard uncertainty if their correlation coefficient is 0.70?

Covariance is

$$u(x_1, x_2) = r\,u(x_1)\,u(x_2) = 0.70(1.0)(1.0) = 0.70\,dB^2.$$

The combined variance is

$$u_c^2 = 1.0^2 + 1.0^2 + 2(0.70) = 3.40\,dB^2,$$

and

$$u_c = \sqrt{3.40} = 1.84\,dB.$$

If independence had been assumed, the result would have been 1.41 dB; positive covariance increases the uncertainty by 0.43 dB; the calculation assumes a locally linear model and a justified correlation coefficient; it does not describe coherent acoustic addition of physical pressures; it describes correlated uncertainty in two input corrections.

23.30 Monte Carlo propagation through nonlinear envelope models

Linear uncertainty propagation becomes fragile when the model contains logarithms, maxima, classifications, state switches or strongly nonlinear path combinations; a composite transmission calculation converts decibel inputs to linear coefficients, sums them and converts back; a small-open-area model can be highly skewed because open area cannot be negative and may have a long upper tail. A rating obtained by shifting a reference contour is discrete; monte Carlo propagation evaluates the full model repeatedly using sampled input distributions and can retain asymmetry, bounds and class probabilities; JCGM 101 provides the governing metrological framework, while JCGM 100 Amendment 1 addresses nonlinearity in measurement models. [134]

A Monte Carlo analysis begins with the model, not with random-number generation; every input distribution requires a basis; repeat measurements may support a normal distribution; a manufacturer tolerance with no preferred value may support a rectangular distribution; a strictly positive leakage area may be represented by a lognormal or bounded distribution. Discrete configuration states require explicit probabilities or separate scenario runs; correlations must be represented through a joint distribution, copula or conditional sampling structure.

134 MB-0994. JCGM 101:2008, JCGM 100:2008.

The number of trials is selected by convergence of the reported quantities; stable mean and standard deviation do not guarantee stable tail probability; if the decision concerns a 5 per cent failure probability, the simulation should demonstrate that the estimated tail has adequate numerical precision. Repeating the simulation with different seeds, increasing the trial count and monitoring quantiles support convergence; the random seed, software version and code checksum belong in the evidence package.

For a complete-envelope rating, each trial can produce the full band curve, the single-number classification and an occupied-state metric; the outputs should not be collapsed prematurely; the same input uncertainty may have little effect on STC but substantial effect on a low-frequency speech margin. Reporting distributions by band can reveal which mechanism drives uncertainty.

Worked example 23.21. Monte Carlo class probability

Engineering question. A field isolation estimate before classification is approximately normal with mean 45.6 dB and standard uncertainty 1.3 dB. Under a simplified assumption that integer class 45 requires the underlying quantity to be at least 45.0 dB, what is the approximate probability of meeting the class?

The standardised distance is

$$z = \frac{45.0 - 45.6}{1.3} = -0.462.$$

For a normal distribution, probability above the threshold is

$$P(Y \geq 45) = 1 - \Phi(-0.462) = \Phi(0.462) \approx 0.678.$$

The approximate pass probability is 67.8 per cent; a Monte Carlo implementation with many trials should reproduce this value under the same assumptions; real sound-insulation classification is not a simple threshold on one normally distributed scalar; it is derived from a band curve and reference-contour procedure. The example demonstrates probability reporting, not the actual classification algorithm.

23.31 Local sensitivity coefficients

Local sensitivity asks how a small change in one input changes the output near the selected operating point. For a scalar output $y=f(x_1,\ldots,x_n)$, the local coefficient is $c_i=\partial y/\partial x_i$. It is useful for uncertainty budgets, remedial prioritisation and checking numerical models. It can be calculated analytically, by automatic differentiation or by a carefully chosen finite difference. [135]

The perturbation must be large enough to overcome numerical noise and small enough to remain in the local regime; a one-decibel perturbation may be appropriate for a level input, while a one-per-cent perturbation may suit surface mass. The report should state whether the coefficient is dimensional or normalised. A normalised elasticity

$$E_i=\frac{x_i}{y}\frac{\partial y}{\partial x_i}$$

can compare inputs with different units, but it is problematic when y is a decibel level or can approach zero. For logarithmic outputs, direct finite changes in decibels are often easier to interpret.

135 MB-0988. JCGM 100:2008.

Local sensitivity can be misleading near a switch in path dominance; if the door and slab contributions are nearly equal, a small improvement in either path changes the total little because the other path remains; a larger intervention that crosses the dominance boundary can have a different marginal benefit. Similarly, a derivative at a sealed state says little about the consequence of a discrete open gap; local and global analyses should therefore be used together.

Worked example 23.22. Sensitivity of a composite level to one path

Engineering question. Two incoherent receiving contributions are 30 dB and 27 dB. What is the local sensitivity of total level to the first path level?

The linear quantities are $Q_1 = 10^3 = 1000$ and $Q_2 = 10^{2.7} = 501.2$. Total is $Q_T = 1501.2$. For energetic addition, the derivative of total level with respect to path level is the path power fraction:

$$\frac{\partial L_T}{\partial L_1} = \frac{Q_1}{Q_T} = 0.666 .$$

A small 1 dB increase in the first path raises total level by approximately 0.67 dB; the second-path sensitivity is 0.334, and the sensitivities sum to one; the result assumes incoherent addition and a small perturbation. It does not predict the benefit of a large intervention after path dominance changes.

23.32 Global sensitivity and interaction effects

Global sensitivity evaluates input influence across the full uncertainty domain rather than at one operating point. It is essential when the model is nonlinear, inputs interact or the result depends on discrete configuration states; screening methods such as the Morris elementary-effects design can identify inputs that deserve further analysis with comparatively few model evaluations; variance-based methods can decompose output variance into first-order contributions and interaction effects. [136]

For independent inputs, a first-order Sobol index for input X_i is

$$S_i = \frac{Var_{X_i}\left[E\left(Y \mid X_i\right)\right]}{Var\left(Y\right)}.$$

The total-effect index includes the input's direct effect and all interactions; a large total-effect index with a small first-order index indicates that the input matters mainly through interaction; in a secure-room model, seal compression may interact with pressure differential, door alignment and threshold level. Treating those variables one at a time can miss the combined failure region.

Input dependence requires additional care. Surface mass, stiffness and critical frequency may be physically related; door gap height and contact length may share an adjustment cause; classical variance decomposition assumes independent factors, so dependent-input methods or conditional sampling may be required; the purpose is not to produce an impressive sensitivity chart. It is to determine which evidence, design control or remediation most affects the decision.

Global sensitivity also supports model reduction. Inputs with negligible total effects over the stated domain can be fixed without materially changing the output distribution. The domain must remain visible. An input unimportant for ordinary speech may become important for amplified programme or a

136 MB-0043. Andrea Saltelli, Paola Annoni, Ivano Azzini, Francesca Campolongo, Marco Ratto and Stefano Tarantola, Variance based sensitivity analysis of model output. Design and estimator for the total sensitivity index.

quiet receiving condition; separate source-state analyses may therefore produce different rankings.

Worked example 23.23. Interaction revealed by a two-factor model

Engineering question. Let a simplified receiving-risk quantity be $Y = X_1 + X_2 + 2X_1X_2$, where X_1 and X_2 vary independently from 0 to 1. What qualitative conclusion follows from the interaction term?

The local effect of X_1 is

$$\frac{\partial Y}{\partial X_1} = 1 + 2X_2.$$

It varies from 1 to 3 depending on X_2. Neither input has one fixed effect across the domain. The cross term creates interaction, so one-factor-at-a-time changes at a single baseline cannot describe the full behaviour. In physical terms, two individually moderate defects can combine to create a disproportionately large path. The dimensionless example illustrates interaction structure; it is not an acoustic transfer equation.

23.33 Bayesian updating of path hypotheses

Path diagnosis can be framed as competing hypotheses. Let H_D denote a dominant door-perimeter path, H_P a plenum path and H_S a slab flank. Prior probabilities represent knowledge from drawings, inspection and comparable construction. New evidence, such as a temporary seal, intensity scan or vibration transfer, updates the relative probabilities through Bayes' theorem. The method disciplines inference by requiring an explicit likelihood for the observed evidence under each hypothesis. [137]

137 MB-1013. Marc C. Kennedy and Anthony O'Hagan, Bayesian Calibration of Computer Models.

For evidence E, posterior odds are

$$\frac{P\left(H_i \mid E\right)}{P\left(H_j \mid E\right)}=\frac{P\left(H_i\right)}{P\left(H_j\right)}\frac{P\left(E \mid H_i\right)}{P\left(E \mid H_j\right)}.$$

The likelihood ratio expresses how strongly the evidence discriminates. A receiving-level reduction after temporary door sealing is more probable under a door-path hypothesis than under a slab-path hypothesis, but the ratio depends on the magnitude, repeatability and possibility that the intervention changed another path; priors should not be disguised as objective facts. Sensitivity of the posterior to plausible priors should be reported when the evidence is weak.

Bayesian model calibration can also estimate uncertain parameters, but path identifiability remains a central problem; kennedy and O'Hagan distinguish parameter uncertainty from model discrepancy; in building acoustics, a fitted junction attenuation can absorb an omitted service path. The posterior may become numerically narrow while the physical explanation remains wrong; separate validation observations and model-discrepancy terms are therefore essential.

Posterior probabilities are aids to investigation, not substitutes for the authority's acceptance criteria; they can prioritise openings or tests and express bounded causal confidence; the final report should state hypotheses, priors, likelihood basis, evidence and sensitivity, rather than presenting one posterior number without the assumptions that produced it.

Worked example 23.24. Updating odds after a temporary-seal test

Engineering question. Prior probabilities are 0.40 for a door path and 0.20 for a plenum path, with the remaining probability assigned to other paths. A 7 dB improvement after temporary door sealing has probability 0.75 under the door hypothesis and 0.10 under the plenum hypothesis. What are the updated door-to-plenum odds?

Prior odds are

$$O_{D:P}=\frac{0.40}{0.20}=2.0.$$

The likelihood ratio is

$$LR=\frac{0.75}{0.10}=7.5.$$

Posterior odds are

$$O_{D:P\mid E}=2.0(7.5)=15.$$

The evidence changes the odds from 2:1 to 15:1 in favour of the door path; the result depends on the stated likelihoods and does not account for a mixed door-and-plenum cause; it supports prioritising permanent door investigation but does not prove exclusive causation.

23.34 Controlled diagnostic interventions

A controlled intervention changes one physically meaningful feature while preserving the rest of the system as far as practicable. Examples include temporary membrane sealing of a frame perimeter, closing one transfer grille, disconnecting a resilient bridge, adding mass to a suspect panel, changing one source position or placing temporary absorption in an intermediate cavity. The before-and-after difference is interpreted through a measurement model and uncertainty. [138]

Interventions should be reversible when evidence may be disputed or historic fabric is involved. They should also be safe. Closing a fire damper, disabling ventilation or modifying an egress door requires appropriate authority; a temporary acoustic treatment that violates fire, smoke, structural or operational obligations is not a valid general remedy; the intervention plan records responsible personnel, photographs, dimensions, material, time, environmental state and restoration.

A useful intervention has discriminating power. Sealing the entire room perimeter may improve the result but reveal little about location; sequentially sealing zones can identify a contribution, although each action changes the residual network; an intervention matrix should state the predicted response under each path hypothesis. Measurements are then selected to distinguish hypotheses rather than merely to collect more data.

The analysis should include repeat measurements and a null intervention; a repeated baseline estimates short-term variability; a sham or no-change interval can reveal drift in source, background or instrumentation; without those controls, a small apparent improvement may be attributed to the intervention when it arose from normal variation.

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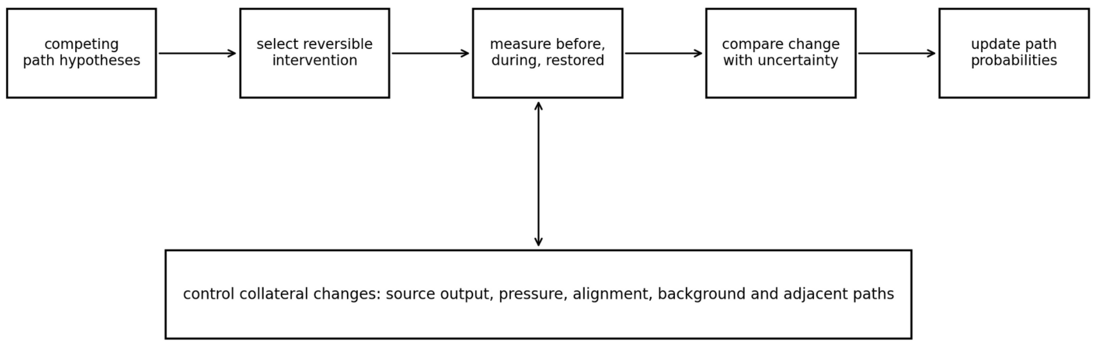
138 MB-0265. ASTM International, ASTM E336-25a, ISO 10848-1:2017.

Figure 23-7. Diagnostic intervention turns path identification into a controlled causal test



a causal claim is bounded by intervention specificity, repeatability and configuration evidence

Figure 23-7. Diagnostic intervention turns path identification into a controlled causal test while preserving collateral-state controls. Author's original diagram.

Worked example 23.25. Significance of a diagnostic intervention

Engineering question. Baseline receiving level is 29.4 dB with standard uncertainty 0.8 dB. After a reversible frame seal it is 25.9 dB with standard uncertainty 0.9 dB. Assuming independent results, is the 3.5 dB change large relative to combined standard uncertainty?

Difference is

$$\Delta = 29.4 - 25.9 = 3.5\, dB.$$

Standard uncertainty of the difference is

$$u(\Delta) = \sqrt{0.8^2 + 0.9^2} = 1.20\, dB.$$

The standardised change is

$$\frac{3.5}{1.20} = 2.92.$$

The observed improvement is about 2.9 combined standard uncertainties, suggesting a real effect under the assumptions; correlation between measurements, source drift and changes to adjacent paths must still be considered; the result supports the frame as a material contributor but does not establish that it is the only governing path.

23.35 Value of information and test selection

A measurement programme should be judged by the decision it can change. The value of information is the expected reduction in decision loss obtained by acquiring additional evidence; a test can be technically sophisticated yet have little value if every credible outcome leads to the same remediation; conversely, a modest local intervention can be valuable when it distinguishes between two expensive and mutually exclusive repairs. Decision analysis requires the alternatives, uncertain states, consequences and current information to be stated before the test is selected. [139]

For each candidate test, the engineer should identify its possible outcomes, likelihood under each path hypothesis, cost, disruption, safety constraints and effect on the preferred decision; the calculation need not imply that every security consequence can be monetised. Consequences can be represented by an agreed ordinal or utility scale, provided its limitations are stated; the central discipline is to compare evidence acquisition with action, not to maximise data volume.

Tests can have negative value when they delay an urgent low-regret correction, expose protected operations or require destructive intervention disproportionate to the decision; repeating an already decisive room-pair

139 MB-0995. JCGM 106:2012, ISO 31000:2018.

test may add little; a local vibration survey may be more valuable if it determines whether a slab treatment is needed. Similarly, destructive opening can be justified when concealed construction determines the remedy and non-destructive evidence cannot resolve it.

A staged programme often has the highest value; low-cost inspections and reversible interventions update the path ranking; more expensive measurements are then directed at unresolved high-consequence paths. The plan includes stopping rules. If one result makes the decision sufficiently robust, further testing is not automatically required.

Worked example 23.26. Expected value of a diagnostic test

Engineering question. Two remedies are under consideration. Door repair costs 20 units and is effective only if the door path governs; slab treatment costs 80 units and is effective only if the slab path governs. Current probabilities are 0.60 door and 0.40 slab; choosing the wrong remedy adds a failure consequence of 100 units; a diagnostic test costs 8 units and correctly identifies the governing path with probability 0.90; what is the expected value of the test under this simplified loss model?

Without testing, choosing door repair has expected loss

$$L_D = 20 + 0.40(100) = 60.$$

Choosing slab treatment has

$$L_S = 80 + 0.60(100) = 140.$$

The current preferred action is door repair with expected loss 60.

With testing, the correct remedy is chosen with probability 0.90 and the wrong remedy with probability 0.10. Expected remedy cost when classification is correct is

$$0.60(20)+0.40(80)=44.$$

The expected failure consequence from a wrong classification is

$$0.10(100)=10.$$

Including test cost, expected loss is

$$L_T=8+44+10=62.$$

The test increases expected loss by 2 units under the assumptions and therefore has no positive expected value; the result changes if the test is more accurate, less costly, or if choosing the wrong door repair has different consequences from choosing the wrong slab treatment. The example demonstrates decision linkage, not a universal economic rule.

23.36 Remediation optimisation under path and budget constraints

Remediation changes a network. Improving one edge can reveal another. The optimum programme is therefore not necessarily the intervention with the largest nominal improvement to one component. It is the set of compatible actions that minimises residual exposure or decision loss subject to cost, space, fire, structural, heritage, operational and programme constraints. [140]

A basic optimisation can use binary decision variables z_k for candidate interventions. Each intervention changes one or more path transmission

140 MB-0405. Carl Hopkins, ISO 31000:2018.

coefficients. The objective may minimise a weighted sum of receiving levels across frequency and source states, or minimise cost subject to a required residual margin. Nonlinear logarithmic combination can be retained in the model. Constraints can prevent incompatible interventions, require enabling works or preserve minimum ventilation and egress.

Intervention effects are uncertain. A door adjustment may provide 2 to 8 dB depending on seal condition; an independent lining may improve the direct wall path but worsen a cavity resonance or conceal services; robust optimisation evaluates performance across uncertainty sets or distributions rather than assuming the best estimate. A low-cost package that passes only under favourable assumptions is not robust.

The sequence of work also matters. Repairing a visible gap first can reduce leakage and improve later diagnostic range; installing a lining before finding a head-of-wall defect can conceal the defect and add another cavity; the optimisation record should therefore include enabling inspection, temporary access and retesting, not only permanent materials.

Worked example 23.27. Selecting a two-intervention package

Engineering question. Three path contributions are 31 dB from a door, 29 dB from a plenum and 25 dB from a slab; door repair costs 15 units and reduces the door path by 9 dB; plenum treatment costs 18 units and reduces the plenum path by 8 dB. Slab treatment costs 50 units and reduces the slab path by 7 dB; the budget is 35 units; which feasible package gives the lowest total receiving level under incoherent addition?

Baseline linear total is

$$Q_0 = 10^{3.1} + 10^{2.9} + 10^{2.5} = 2,369,$$

so

$$L_0 = 10\log_{10}(2,369) = 33.75\,dB.$$

Door plus plenum is feasible at 33 units. New path levels are 22, 21 and 25 dB. Thus

$$Q_{DP} = 10^{2.2} + 10^{2.1} + 10^{2.5} = 600.6 \approx 601,$$

and

$$L_{DP} = 27.79\,dB.$$

Door plus slab and plenum plus slab exceed the budget; either single repair is feasible, but their totals are higher than 27.78 dB; the door-plus-plenum package is therefore best among the stated choices; the calculation assumes intervention effects are certain, paths are incoherent and no new path is created. It does not establish contractual acceptance.

23.37 Residual risk and consequence-weighted speech exposure

Residual acoustic energy is not equivalent to residual information risk. A low-frequency path may carry rhythm and voicing while a high-frequency path carries consonant cues. A repeated listener may recover names, numbers or phrases from fragments that would produce a low average intelligibility score. Complete-envelope analysis should therefore retain frequency, time, source content, listener access and consequence. [141]

A consequence-weighted model can assign importance weights $w_{b,s,r}$ to band b, source state s and receiver location r. A screening index might be

$$J = \sum_{b,s,r} w_{b,s,r} P_{b,s,r},$$

141 MB-0234. ASTM International, ASTM E2638-24, IEC 60268-16:2020.

where $P_{b,s,r}$ is a linear residual exposure quantity. The index is not a standard privacy metric and should not be presented as one. Its value lies in documenting why a particular path matters to the authorised use. Weights should be approved or at least reviewed by the responsible security and operational authorities.

Risk can also be expressed through margins; for each band and source state, the predicted or measured receiving level is compared with background, masking or another defined criterion; negative margins identify bands where information may emerge; the distribution of margins across listener positions and operating states is more useful than one best-case location.

Repeated access changes consequence. If a listener can record many meetings, rare recoverable fragments accumulate; a commissioning test over a short interval should not be extrapolated to long-term access without an explicit model; conversely, an extreme cumulative-access assumption should not be applied to a location that is physically controlled and only briefly occupied.

Worked example 23.28. Weighted residual exposure

Engineering question. Three bands have residual linear exposure quantities 1.0, 0.40 and 0.20. Their consequence weights for the protected source are 0.20, 0.50 and 0.30. What is the weighted index, and what happens if remediation halves the second-band exposure?

Baseline is

$$J = 0.20(1.0) + 0.50(0.40) + 0.30(0.20) = 0.46.$$

After remediation, the second term becomes 0.20, so

$$J' = 0.20(1.0) + 0.50(0.20) + 0.30(0.20) = 0.36.$$

The index falls by 0.10, or 21.7 per cent; the quantities and weights are dimensionless under the illustrative model; the result supports comparison only if the weights and exposure quantities are justified; it is not an ASTM, ISO, IEC or governmental acceptance metric.

23.38 Source-state matrices and temporal operation

A room does not have one source state; ordinary conversation, raised speech, maximum unamplified effort, loudspeaker programme, conferencing playback, alarm signalling, maintenance testing and emergency operation can excite different paths; HVAC, masking, door position, occupancy and neighbouring activity also vary. A source-state matrix records credible combinations and prevents acceptance from being based solely on the quietest or most favourable condition.

Rows in the matrix represent source states; columns record source spectrum, position, orientation, duration, duty cycle, audiovisual mode, room absorption, door state, HVAC state, masking state, adjoining occupancy, listener access and required evidence; states can be excluded only with an operational control that is enforceable and monitored. An instruction that occupants should never raise their voices is not equivalent to a physical control.

Temporal aggregation must preserve intermittency. A duct damper that opens for five minutes each hour can create a high-consequence interval even if the time-average energy is low; a door used fifty times per day creates repeated seal transients; a system should be assessed at steady states and relevant transitions. Logging of BMS states, door contacts and masking output can support later forensic correlation, subject to privacy and security governance.

The matrix also guides commissioning efficiency. One acoustic measurement can represent several states when the physical source and path are demonstrably equivalent. Other states require separate tests. The rationale should be recorded, avoiding both needless repetition and unjustified extrapolation.

Worked example 23.29. Duty-cycle averaging and peak-state limitation

Engineering question. A transfer grille is closed for 90 per cent of the time, producing a receiving level of 20 dB, and open for 10 per cent, producing 38 dB. What is the long-term energetic average, and why is it insufficient for a protected-conversation decision?

The linear time-weighted quantity is

$$Q = 0.90\left(10^{20/10}\right) + 0.10\left(10^{38/10}\right) = 90 + 631 = 721\,.$$

Thus

$$L_{eq} = 10\log_{10}\left(721\right) = 28.6\,dB\,.$$

The average is 28.6 dB, but protected speech occurring during the open state is exposed at 38 dB; the average masks the peak configuration; the calculation uses energy-equivalent averaging and assumes stationary levels within each state. It does not determine speech intelligibility or acceptable operation.

23.39 Receiver-access maps and adjoining-zone control

The receiving side of a path is a set of locations, not one room-average point. A corridor corner, service chase, façade ledge, ceiling access hatch or adjacent office can have different background, reverberation, access and listening opportunity. The complete-envelope graph should label nodes by control status and credible listener capability. [142]

Receiver maps combine geometry with operational governance; an uncontrolled public corridor differs from a locked service space; a service space can become accessible during maintenance; a neighbouring tenant may have long-duration access without being able to approach the separating wall closely. These distinctions affect risk but do not change the measured acoustic transfer. Engineering and access-control evidence should remain separate and then be combined in the risk statement.

Measurement positions should sample plausible maxima. Room standards prescribe spatial averaging for defined quantities, but security assessment may also require local positions where a listener can remain; a high local level beside a grille should not be diluted by averaging over inaccessible positions, nor should a transient maximum at an impossible position govern without justification. The report should identify which positions satisfy the standard method and which are supplementary threat positions.

Adjoining-zone control can sometimes be more reliable than extreme construction; extending a controlled perimeter, relocating a waiting area or restricting maintenance access may reduce listener opportunity; such controls require governance, monitoring and lifecycle review; they should

142 MB-0262. ASTM International, ASTM E336-25a, ASTM E2638-24.

not be described as acoustic improvement because the physical transfer remains.

23.40 Commissioning architecture for a complete envelope

Complete-envelope commissioning begins before construction. The basis of design identifies source states, receiver zones, metrics, path assumptions and authority roles. The submittal phase verifies element data and junction details. Construction surveillance preserves concealed evidence. Pretesting finds gross weaknesses before final finishes. Formal field measurement then evaluates the completed configuration, followed by occupied-state assessment and authority disposition. [143]

The commissioning plan should have path-specific hold points; door frames are inspected before closure; duct silencers and internal linings are verified before access is lost; raised-floor perimeter conditions are photographed before panels and equipment obstruct them. Ceiling barriers, firestops and service penetrations are mapped. The evidence is linked to coordinates and drawing references, not stored as unlabelled photographs.

Testing is staged. Instrument and source checks precede room-pair testing; baseline background and decay are measured; direct and flanking diagnostics are then selected from the model. Temporary modifications are disclosed. Final acceptance measurements are performed only after defects and temporary conditions are closed; the report distinguishes provisional diagnostic data from formal test results.

Commissioning also creates the lifecycle baseline. Door contact maps, seal force, masking spectra, HVAC states, photographs, vibration transfer and

143 MB-0256. ASTM International, ASTM E336-25a, ASTM E2638-24.

raw acoustic data permit later comparison; a future alteration can then be evaluated against a known state; without a baseline, forensic review must reconstruct the original condition from incomplete records.

Table 23-4. Diagnostic interventions and discriminating interpretations

Intervention	Target hypothesis	Expected discriminating observation	Confounding effect to control	Record required
Temporary membrane over joint or grille	Airborne leakage through the treated perimeter	Local and room-level reduction concentrated in leakage-sensitive bands	Membrane can add mass, alter radiation area or cover adjacent defects	Material, geometry, seal, before-after-restoration spectra and uncertainty
Added temporary mass to panel	Direct panel radiation or coincidence weakness	Shift or reduction associated with panel-dominated bands	Added mass may change boundary contact and adjacent trim	Mass, area, fixing method, panel state and vibration response
Temporary structural separation or resilient support	Rigid bridge or support-borne path	Reduced coherent vibration and receiving radiation during separation	Intervention may alter alignment or load distribution	Force path, preload, clearance, safety review and synchronous channels
Duct terminal closure with source maintained	Duct-air or cross-talk path	Reduction near terminal and at receiver while structural response remains	Closure can change airflow, pressure and regenerated noise	HVAC state, airflow, pressure, closure method and source stability
Controlled source relocation or rotation	Source-position or directivity participation	Predictable change in path ranking and receiver map	Room modes and source output may also change	Source coordinates, orientation, spectrum, power and repeatability
Door seal contact correction	Perimeter or threshold leakage	Local reduction at corrected contact zones and improved field door result	Latch force and operating pressure can change simultaneously	Contact map, compression, operating force, pressure and cycle state
Temporary cavity compartment	Distributed plenum or raised-floor network	Reduced multiroom transfer beyond the compartment while direct wall remains stable	Barrier may obstruct services or create new reflections	Barrier location, completeness, service state and multi-node measurements

23.41 Decision rules, guard bands and authority boundaries

A conformity statement requires a specified requirement and a decision rule. ISO/IEC 17025 and ILAC G8 require laboratories to address decision rules when statements of conformity are issued, while JCGM 106 explains the role of measurement uncertainty. The rule should be agreed before testing where possible. [144]

For a minimum isolation requirement R_{min}, a conservative rule may require

$$\hat{R} - U \geq R_{min},$$

where $\hat{R}$ is the measured result and U is expanded uncertainty. This is only one rule. Different risk allocations can use different guard bands. The laboratory should not select the rule after seeing the result. The authority responsible for the requirement determines the acceptable balance of false acceptance and false rejection.

The rule applies to the stated measurand; a field apparent rating cannot be used as a guard-banded substitute for an occupied speech test unless the requirement defines that relation; a whole-room speech result cannot certify a door product. Formal accreditation remains an authority decision that can consider other security domains and controlled criteria unavailable to the public analysis.

Configuration uncertainty and model discrepancy should not be hidden within the numerical guard band; if an unverified plenum path remains, the appropriate disposition may be incomplete evidence rather than a larger arbitrary allowance; a clear “not demonstrated” finding is more defensible than a pass produced by an invented margin.

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144 MB-0996. JCGM 106:2012, ISO/IEC 17025:2017.

Worked example 23.30. Guard-band comparison

Engineering question. A field apparent rating is 48.7 dB with expanded uncertainty 2.0 dB. The requirement is at least 47 dB, and the agreed rule requires result minus expanded uncertainty to meet the limit. What is the conformity statement?

$$48.7-2.0=46.7\,dB.$$

Because 46.7 dB is below 47 dB, the result does not meet the agreed guarded rule; the unguarded result exceeds the limit, so the report should state both the measurement and the rule rather than simply writing “failed”. The calculation does not decide formal facility accreditation and assumes the expanded uncertainty and rule are applicable to the stated quantity.

23.42 Composite case study A. Legal conference suite with door, plenum and slab paths

Status. This is a hypothetical composite case constructed from common engineering mechanisms. It is not a report of a particular facility.

A legal conference suite occupies one bay of a concrete-frame office; the separating wall is a double-stud gypsum system extending to the slab; a rated acoustic door opens to an internal corridor; the return-air system uses a shared ceiling plenum with transfer paths above adjacent rooms. The slab is continuous beneath the partition. Laboratory wall data are strong, yet short phrases are occasionally recognised in the corridor after normal office hours.

The initial room-pair field curve shows a broad mid- and high-frequency deficit relative to the wall basis, with a low-frequency shoulder that changes with source position; door-edge scanning shows elevated pressure at the latch jamb and automatic bottom. Vibration measurements show modest slab transfer below 160 Hz; a temporary membrane over the return grille produces a 5 to 7 dB improvement above 500 Hz; door adjustment produces another 3 to 5 dB improvement in the same range. Neither intervention materially changes the low-frequency shoulder.

The complete-envelope model assigns three principal paths; the plenum path is dominant above 800 Hz in the normal HVAC state; the door path is comparable from 315 to 1,250 Hz and is sensitive to closing force. The slab flank governs below 160 Hz; an attempt to upgrade the wall would produce little benefit because the wall field is not among the three leading paths.

The remedial programme installs a cross-talk silencer and lined return arrangement designed for the available pressure drop, restores door alignment and automatic-bottom timing, and treats one slab-wall junction with an isolated inner lining at the receiving side. The corridor background and HVAC state are documented because after-hours quiet conditions remain the critical receiver state. Final testing includes ordinary and raised speech, several source positions and a supplementary low-frequency structural transfer check. [145]

Worked example 23.31. Sequential path closure in the legal suite

Engineering question. Before remediation, path levels are 30 dB plenum, 28 dB door and 24 dB slab. Plenum treatment reduces its path by 9 dB, door repair by 6 dB and slab treatment by 4 dB. What are the total levels before and after all three actions?

145 MB-0259. ASTM International, ASTM E336-25a, ASTM E2638-24.

Baseline is

$$L_0 = 10\log_{10}\left(10^{3.0} + 10^{2.8} + 10^{2.4}\right) = 32.7\,dB.$$

After remediation, path levels are 21, 22 and 20 dB:

$$L_1 = 10\log_{10}\left(10^{2.1} + 10^{2.2} + 10^{2.0}\right) = 25.8\,dB.$$

The combined improvement is 6.9 dB, less than the largest individual path reduction because residual paths remain; the calculation assumes incoherent addition, stable source and compatible normalisation; it does not establish speech privacy or legal privilege protection by itself.

The authority dossier records the as-designed and as-built HVAC path, door maintenance settings, slab-junction treatment, raw measurements, uncertainty and operating restrictions; the final conclusion is limited to the configured suite and stated source and receiver states.

23.43 Composite case study B. Diplomatic meeting room with façade and mullion flanking

Status. This is a hypothetical composite case derived from publicly describable building-acoustic mechanisms. It does not reproduce controlled diplomatic criteria.

A meeting room is located against a unitised curtain wall; the internal partition meets a vertical mullion, while the floor slab intersects a spandrel zone; the glazing build-up has strong laboratory data; the opaque interior wall also has a high rating. Field measurement nevertheless shows a persistent upper-mid-frequency weakness at the façade junction, especially when the source is near the external wall.

Local scans reveal elevated response along the mullion and at one pressure-plate joint; structural excitation of the mullion produces correlated vibration on the adjacent façade bay; the path is not simply “through the glass”; it includes interior pressure loading, frame vibration, cavity propagation and re-radiation at the neighbouring bay. Temporarily adding mass to the mullion cover changes little, while sealing an internal trim joint gives a small high-frequency improvement. A temporary resilient break at a removable interior finish connection reduces vibration transfer, demonstrating a structural component.

A deterministic mullion model is calibrated against mobility and transfer-function data, while façade element transmission is retained from verified laboratory reports; the model is used for sensitivity rather than certification; it shows that the dominant uncertainty is the concealed connection between the interior partition return and the mullion, not the pane loss factor. A limited controlled opening confirms a rigid bracket spanning the intended acoustic break.

The repair replaces the bracket with a structurally reviewed isolated detail, restores seals and adds an independent interior return that terminates clear of the mullion cavity; drainage and pressure equalisation remain intact; the field test is repeated in both source directions because façade asymmetry and background differ. Public documentation states only the measured result, the mechanism and the public-source limitations; formal use remains with the competent authority. [146]

146 MB-0267. ASTM International, ASTM E336-25a, ISO 12354-3:2017.

Worked example 23.32. Correlated façade paths

Engineering question. Two façade receiving contributions are each estimated at 26 dB. If they were incoherent, the total would be 29.0 dB. At one low-frequency point their complex pressures have equal amplitude and phase correlation coefficient approximated as 0.8. What qualitative effect should be expected?

For equal mean-square pressure quantities q, the combined quantity with correlation term is

$$q_T = q + q + 2(0.8)q = 3.6q.$$

Relative to one path, the level increase is

$$10\log_{10}(3.6) = 5.6\,dB.$$

The correlated total is therefore about 31.6 dB, 2.6 dB above the incoherent total; the calculation is a simplified point-field illustration; spatial averaging, frequency resolution and phase variation can reduce correlation; it demonstrates why coherent structural paths should not always be added as independent powers.

23.44 Composite case study C. Audiovisual retrofit and a cable-penetration network

Status. This is a hypothetical composite case.

A previously commissioned executive conference room receives new displays, ceiling microphones, cameras and networked control equipment; the installation creates several wall and ceiling penetrations, adds brackets to the independent lining and introduces a cable tray through a service zone. No acoustic retest is required by the maintenance work order because the room name and principal wall types are unchanged.

After the retrofit, a complaint arises from an adjacent technical room; inspection finds that one display bracket has long anchors contacting the base structure behind an isolated lining; a cable bundle passes through an oversized sleeve with incomplete firestop backing. Above the ceiling, a new tray crosses the boundary through a cut opening closed only with a loose mineral-fibre pillow; the three defects represent structure-borne, airborne leakage and plenum paths.

The investigation separates them through controlled interventions; the display is unloaded and the bracket temporarily isolated; the sleeve is sealed with a reversible membrane outside the firestop; a temporary dense barrier is fitted around the tray opening. Each intervention changes different bands. Combined treatment produces a larger improvement than any single action, confirming a path network rather than one defect.

The permanent repair uses structurally appropriate isolated supports, a listed firestop system installed to its approved configuration, a properly detailed cable transit and an updated penetration register. The audiovisual design standard is revised to require acoustic-boundary review before any support or penetration is approved. Commissioning includes all software states because loudspeaker muting, conferencing playback and standby modes change the source. [147]

Worked example 23.33. Three retrofit defects

Engineering question. The bracket, sleeve and tray paths produce 25, 27 and 23 dB respectively. Permanent repairs reduce them by 7, 10 and 8 dB. What is the combined improvement?

147 MB-0260. ASTM International, ASTM E336-25a, ASTM E2638-24.

Before repair:

$$L_0 = 10\log_{10}\left(10^{2.5} + 10^{2.7} + 10^{2.3}\right) = 30.1\,dB.$$

After repair, path levels are 18, 17 and 15 dB:

$$L_1 = 10\log_{10}\left(10^{1.8} + 10^{1.7} + 10^{1.5}\right) = 21.6\,dB.$$

The combined improvement is 8.5 dB. The result assumes that repair effects are independent and do not change other paths. It supports a before-and-after hypothesis but requires measured confirmation.

23.45 Composite case study D. Room-within-room bridge and low-frequency structural path

Status. This is a hypothetical composite case.

A room-within-room suite uses an isolated floor, independent wall frames and an isolated ceiling; airborne field measurements above 250 Hz are strong; a persistent low-frequency response remains in an adjacent plant corridor when the room loudspeaker reproduces programme material. The response is narrow-band and spatially concentrated near one corner.

Drawings show an independent inner shell, but installation photographs are incomplete at the corner where a heavy display support was added late; mobility measurements identify a stiff transfer from the inner wall to the host column; controlled source movement changes the response, indicating coupling between a room mode and the bridge location. A borescope inspection finds a backing plate fixed through the isolation gap.

The bridge is not modelled as a small airborne opening. It is a force-transfer path. A deterministic low-frequency submodel represents the inner panel, support and column, while room pressure measurements provide excitation; the predicted resonance aligns with the field feature within uncertainty; removal of the through-fasteners and installation of an independently supported frame reduce the corner response. The room is retested at the original source position and at other positions to ensure that a mode has not merely shifted.

The case demonstrates that a sophisticated shell can be governed by one late support. It also shows why high-band room-pair results cannot be extrapolated to low-frequency amplified programme. The lifecycle rule prohibits anchoring to the host structure within marked isolation zones without acoustical and structural review. [148]

Worked example 23.34. Bridge stiffness and force transmission screening

Engineering question. A support bridge has dynamic stiffness $k_d = 8.0 \times 10^6 \, N/m$. Relative displacement across the intended isolation gap is 4 micrometres at a forcing frequency. What force amplitude is transmitted under the linear stiffness model?

$$F = k_d x = \left(8.0 \times 10^6\right)\left(4 \times 10^{-6}\right) = 32\, N\,.$$

The dimensional check gives newtons per metre times metres equals newtons; the value is a force-amplitude screening estimate; real bridge stiffness can be complex and frequency-dependent, and relative motion may include rotation; the calculation does not predict receiving sound level without structural mobility and radiation data.

148 MB-0823. International Organization for Standardization, ISO 10848-1:2017, ISO 12999-1:2020.

23.46 Composite case study E. Multiroom suite with shared services and changing access

Status. This is a hypothetical composite case.

A three-room suite contains a primary meeting room, an anteroom and a records room; the primary room does not share a wall with the public corridor, but all three rooms connect to a common return-air system and raised-floor plenum. The records room is normally controlled, yet contractors occupy it during a six-week refurbishment; the original threat model treated it as an internal buffer and did not evaluate it as a listener zone.

Network analysis shows two-stage paths from the meeting room through the anteroom and records room, plus a direct service path through the return system; under normal use, the buffer rooms and controlled access reduce consequence; during refurbishment, the access state changes. Temporary removal of raised-floor panels also lowers path impedance; the physical transmission and the listener-access graph both change.

The project introduces temporary barriers, local return isolation and escorted access; acoustic checks are performed after each construction phase because the path network changes as panels and ceilings are opened; the records room is treated as an uncontrolled receiver during contractor occupation. When work is complete, services are reinstated, penetrations inspected and the original controlled-zone status restored through administrative action.

This case shows that room security is time-dependent. A permanent model cannot assume permanent access control. The source-state matrix and receiver-access map should include construction, maintenance and emergency states. Technical measurements and administrative controls are recorded separately and then combined in the operational risk statement. [149]

Worked example 23.35. Two-stage and direct service paths

Engineering question. A direct service path contributes 24 dB at the public corridor. A two-stage path through the records room contributes 21 dB. During refurbishment, open floor panels raise the two-stage contribution by 7 dB. What is the total before and during refurbishment?

Before refurbishment:

$$L_0 = 10\log_{10}\left(10^{2.4} + 10^{2.1}\right) = 25.8\,dB.$$

During refurbishment, the second path is 28 dB:

$$L_1 = 10\log_{10}\left(10^{2.4} + 10^{2.8}\right) = 29.5\,dB.$$

The total rises by 3.7 dB and the two-stage route becomes dominant; the calculation assumes compatible levels and incoherent addition; it does not include the increased listener opportunity, which is a separate risk factor.

23.47 Model governance, reproducibility and data lineage

A complete-envelope model can influence expensive construction, operational restrictions and security decisions. Its governance should therefore be comparable to that applied to a measurement system; the record identifies the model owner, technical reviewer, software environment, source-code or workbook version, input dataset, units, coordinate system, calculation date, approved purpose and limitations; a screenshot of a result is not a reproducible record. Another competent

149 MB-0258. ASTM International, ASTM E336-25a, ASTM E2638-24.

practitioner should be able to reconstruct the output from the retained files without relying on undocumented recollection. [150]

Data lineage begins with source identity. Laboratory reports are linked to exact specimens; drawing quantities are linked to revision and sheet; field measurements are linked to raw files, instrument serial numbers, calibration records, processing scripts and configuration photographs; estimated inputs are marked as estimates and given a basis. When one input is changed during calibration, the change log records the reason, previous value, new value and effect on outputs.

Software assurance is proportionate to consequence and complexity; a simple area-weighted spreadsheet can be checked by independent hand calculation and test cases; a finite-element or Monte Carlo workflow requires version control, benchmark problems, unit tests, mesh or sampling convergence, and independent review of critical scripts. Proprietary software does not eliminate the need for verification; the report should identify solver version, major options and any user-defined routines.

Numerical precision is not evidentiary precision. A solver may return ten decimal places from uncertain geometry and damping; output formatting should reflect uncertainty and decision need; intermediate values may be retained at higher precision for reproducibility, while published results are rounded consistently; rounding rules should be applied after, not during, the calculation unless the governing standard requires otherwise.

A model-freeze checksum can preserve the exact analysis state used for a decision. Later revisions receive new identifiers. The frozen package

150 MB-0812. ISO/IEC 17025:2017, JCGM 200:2012.

contains inputs, code, outputs, plots and a readme describing execution; this is not the final publication immutability seal for the book; it is project-level data governance for the engineering model.

Worked example 23.36. Detecting unit inconsistency in a path model

Engineering question. A software input labelled "surface mass" is entered as 180, intended to mean $180\,kg/m^2$. Another routine interprets it as $180\,lb/ft^2$. By what factor is the mass overstated?

Using $1\,lb/ft^2 = 4.882\,kg/m^2$, the interpreted mass is

$$180(4.882) = 879\,kg/m^2.$$

The overstatement factor is

$$\frac{879}{180} = 4.88.$$

The error would substantially inflate a mass-law screening result; the calculation demonstrates why values require explicit units and schema validation; it does not quantify the final model error because stiffness, resonance and other paths also contribute.

23.48 Completeness tests and path-omission checks

A complete-envelope model is never proven complete merely because it contains many paths; completeness is tested by comparing predicted totals with measurements across bands, source positions and interventions, and by checking whether the energy balance leaves systematic residuals. An unexplained residual can indicate omitted transmission, incorrect normalisation, measurement bias or invalid assumptions; the investigator should resist the temptation to distribute the residual among existing paths without physical evidence.

One useful check is the closure ratio between measured linear receiving quantity Q_m and the sum of modelled path quantities Q_p:

$$C = \frac{Q_m}{\sum_p Q_p}.$$

A ratio near one is necessary but not sufficient for model adequacy; ratios above one can indicate omitted paths or underpredicted contributions; ratios below one can indicate double counting, destructive coherence, overprediction or mismatched reference conditions; the ratio should be examined by frequency and state, not only as a broadband average.

Path suppression tests support completeness. If a suspected path is reduced and the measured total changes by less than predicted, the model may have overestimated that path or omitted a compensating path; if the measured total changes more, the intervention may have affected several paths. The intervention model should include collateral effects rather than assuming perfect isolation.

Topological review is another check. Drawings, site inspection and service registers are used to trace every physical connection between source and receiver zones; the review includes paths that do not appear in architectural plans, such as ceiling support wires, pipe hangers, raised-floor pedestals, façade brackets, cable sleeves and temporary construction openings. A graph cut-set review asks whether every source-receiver route intersects at least one verified boundary or control.

The completeness claim should be bounded. “All material paths identified above the stated detection threshold under the tested states” is defensible when supported; “all paths eliminated” is rarely defensible; the record includes detection limits, untested states and inaccessible construction.

Worked example 23.37. Closure-ratio diagnosis

Engineering question. Modelled path quantities in a band are 500, 250 and 100 linear units. Measurement gives 1,190 units. What is the closure ratio and unexplained fraction?

The model sum is

$$Q_p = 500 + 250 + 100 = 850 .$$

Closure ratio is

$$C = \frac{1,190}{850} = 1.40 .$$

The unexplained quantity is $1,190 - 850 = 340$, or 28.6 per cent of the measurement. The model underpredicts the measured quantity by 1.46 dB because $10 \log_{10}(1.40) = 1.46\, dB$. The residual could reflect an omitted path, biased inputs or incompatible normalisation. It does not identify the cause.

23.49 Cross-validation and bounded prediction claims

Calibration and validation should use different evidence. A model tuned to every available source position and band can reproduce the calibration dataset without possessing useful predictive capability. Cross-validation with held-out bands, source positions, receiver zones or configuration states tests whether the model generalises within its intended scope. [151]

151 MB-1012. Marc C. Kennedy and Anthony O’Hagan, Bayesian Calibration of Computer Models.

The held-out set should challenge the mechanisms relevant to the intended decision; if the model will predict raised speech near a façade, validation should not consist only of a centre-room broadband source; if it will support remediation of a slab flank, at least one vibration or low-frequency observation should remain outside calibration. Validation outside the model's declared domain is not required, but the domain must be explicit.

Prediction error should be reported by frequency and condition; a mean absolute error can conceal bias in one critical band; residual sign, trend and heteroscedasticity can reveal model-form problems; a model that underpredicts every low-frequency state and overpredicts every high-frequency state may have the wrong transition mechanism even if the overall average error is small.

Cross-validation also helps compare model families. A simple ISO 12354 model may outperform a highly parameterised numerical model when input knowledge is limited; model selection should favour predictive adequacy, physical interpretability and decision usefulness, not complexity; if two models perform similarly, the simpler and more transparent model may be preferable.

The final claim states what was predicted, for which configurations, with what validation evidence and uncertainty; it should not imply that success in one room establishes transferability to another; element and junction data can be reused only when their applicability is demonstrated.

Worked example 23.38. Held-out prediction error

Engineering question. A model is calibrated on four source positions. At two held-out positions it predicts receiving levels of 24.0 and 27.5 dB, while measurements are 25.2 and 25.9 dB. What are the residuals and root-mean-square prediction error?

Residuals, defined as measured minus predicted, are

$$e_1 = 25.2 - 24.0 = 1.2\,dB,$$

$$e_2 = 25.9 - 27.5 = -1.6\,dB.$$

Root-mean-square error is

$$RMSE = \sqrt{\frac{1.2^2 + (-1.6)^2}{2}} = 1.41\,dB.$$

The opposite signs show no consistent bias in this two-point sample, but the sample is too small for a strong generalisation; the calculation quantifies held-out error only; it does not prove model adequacy for untested source states or other rooms.

23.50 Limits of detection, limits of quantification and censored path estimates

A complete-envelope investigation frequently reaches the boundary of the measurement system before it reaches the boundary of the physical problem; a receiving-room spectrum may fall close to background, a vibration channel may approach self-noise, or a temporary intervention may suppress one path until another becomes indistinguishable from the residual field. The resulting datum is not zero; it is censored by the sensitivity, dynamic range, spatial sampling and operating state of the method; reporting a censored result as an exact value creates a fictitious precision and can distort path ranking. [152]

152 MB-0268. ASTM International, ASTM E336-25a, ISO 16283-1:2014.

The limit of detection is the smallest contribution that can be distinguished from the relevant blank or background under a stated decision procedure; the limit of quantification is a higher level at which the contribution can be estimated with uncertainty acceptable for the intended decision. These concepts must be adapted carefully to building acoustics because the background is not always an independent additive blank; it may include other transmission paths, room modes, ventilation noise, instrument self-noise and intermittent activity; a background correction therefore does not necessarily isolate the path of interest. It can merely remove one measured component under the assumptions of the method.

A path estimate can be right-censored or left-censored; in the present context, a very strong element can yield a lower bound on transmission loss because the receiving signal is too small to quantify; conversely, a receiving level may be reported only as less than a threshold. The path register should preserve the inequality; substituting the threshold value as though it were measured biases subsequent energy sums and sensitivity calculations. Monte Carlo propagation can represent the censored quantity by a bounded distribution or by repeated analysis at defensible limits. The chosen representation belongs in the uncertainty record.

Intervention tests require their own detection rule; if a temporary membrane changes a band by 0.7 dB while repeatability and state drift together contribute 1.4 dB standard uncertainty, the observation cannot support a strong causal attribution. If the same intervention changes the band by 8 dB and the change is spatially localised at the treated joint, the evidence is materially stronger; the conclusion depends not merely on the magnitude but on the intervention specificity, uncertainty, reversibility and possibility that the intervention changed more than one path.

Worked example 23.39. Propagating a censored high-isolation path

Engineering question. A wall path is known only to have transmission loss greater than 68 dB in a selected band because of receiving-room background. A door path is measured at 49.0 dB and a duct path at 55.0 dB. What range of total transmission loss follows if the wall is treated as lying between 68 and 80 dB?

For independent parallel paths, the total coefficient is

$$\tau_{tot} = \tau_d + \tau_v + \tau_w,$$

where subscripts d, v and w denote door, ventilation and wall. At the conservative wall bound,

$$\tau_d = 10^{-49/10} = 1.259 \times 10^{-5},$$

$$\tau_v = 10^{-55/10} = 3.162 \times 10^{-6},$$

$$\tau_{w,68} = 10^{-68/10} = 1.585 \times 10^{-7}.$$

Thus

$$R_{tot,68} = -10 \log_{10}\left(1.591 \times 10^{-5}\right) = 47.98\, dB.$$

At 80 dB, $\tau_{w,80} = 10^{-8}$, and

$$R_{tot,80} = -10 \log_{10}\left(1.576 \times 10^{-5}\right) = 48.02\, dB.$$

The censored wall changes the total by only 0.04 dB across the assumed range; dimensional consistency follows because transmission coefficients are ratios; uncertainty in the wall is therefore immaterial to this band and decision, while uncertainty in the door remains important. The calculation does not prove that the wall is satisfactory in other bands or source states.

23.51 Multiobjective optimisation, Pareto fronts and robust design

Acoustic-security design rarely has one objective. The engineer may seek low receiving speech level, low vibration transfer, acceptable reverberation, adequate ventilation, low door operating force, fire and smoke compliance, accessibility, structural capacity, moisture control, maintainability, heritage compatibility, cost and programme certainty; collapsing these obligations into one unexamined score can conceal unacceptable trade-offs. A multiobjective analysis keeps each principal objective visible and identifies designs that are dominated by another feasible design. [153]

A design is Pareto-dominated when another feasible design is at least as good in every stated objective and better in one or more; dominated designs can ordinarily be rejected without assigning subjective weights; the remaining Pareto set exposes genuine choices. For example, one door system may provide better acoustic performance but greater operating force and maintenance demand; another may be easier to operate but require a deeper sound lock. The final selection belongs to the authorised multidisciplinary process, not to an acoustic calculation alone.

153 MB-0405. Carl Hopkins, ISO 31000:2018.

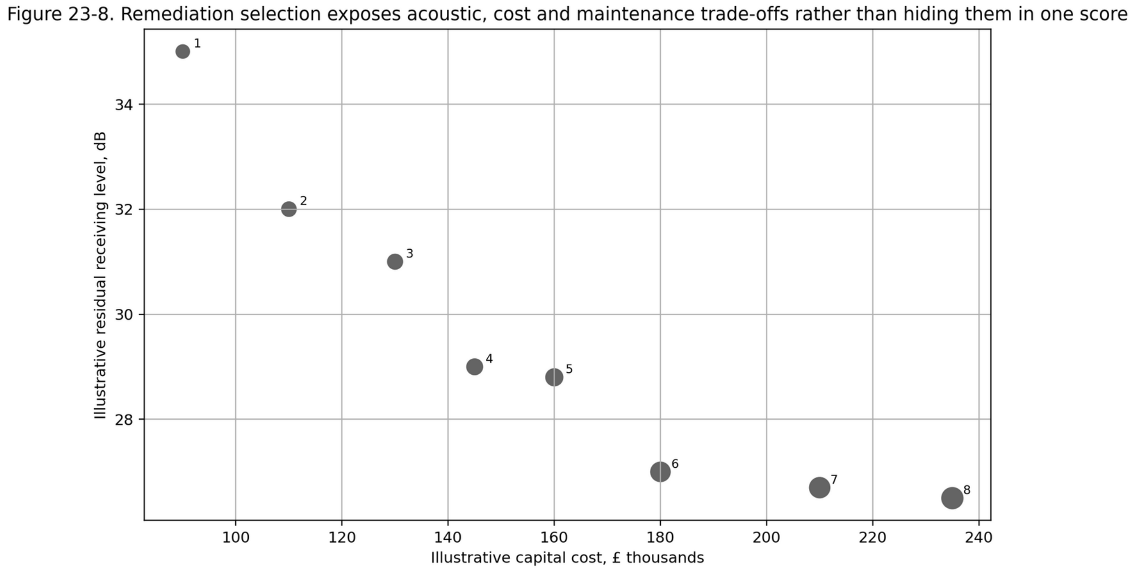

Figure 23-8. Remediation selection exposes acoustic, cost and maintenance trade-offs rather than hiding them in one score. Author's original diagram.

The objectives must be measured in physically and institutionally meaningful quantities; acoustic performance should not be represented solely by an integer STC when low-frequency speech, glazing, doors or ducts govern; lifecycle cost should include adjustment, seal replacement, retesting and disruption. Fire, egress and accessibility are constraints rather than optional preferences where law or code applies; formal accreditation is not an objective function that a public model can calculate. It remains an authority decision after the evidence is assembled.

Robust design adds uncertainty to the comparison; a nominally superior detail can be fragile if small workmanship deviations cause large loss; a slightly lower predicted result may be preferable when it has broader tolerances, inspectable seals, accessible adjustment and lower sensitivity to concealed bridging. Robustness can be evaluated by worst-case bounds, probability of meeting a threshold, expected loss or sensitivity to uncertain inputs; the selected method should match the decision consequence and available evidence.

Scenario analysis is often more transparent than assigning probability distributions where evidence is sparse; a glazing system can be evaluated under winter and summer interlayer conditions, positive and negative pressure differentials, occupied and unoccupied backgrounds, and intact or aged seals. An HVAC system can be evaluated under normal, purge, emergency and setback modes; a design that performs acceptably across credible scenarios offers stronger assurance than one optimised to a favourable nominal state.

Worked example 23.40. Pareto screening of three remedial packages

Engineering question. Three packages have estimated residual receiving level, capital cost and annual maintenance burden as follows: Package A, 27 dB, £180,000 and 120 labour-hours; package B, 29 dB, £145,000 and 65 hours; package C, 30 dB, £170,000 and 90 hours. Which packages are Pareto-dominated when lower values are preferred?

Package C is worse than Package B in all three stated objectives: it has a higher receiving level, higher cost and higher maintenance burden; it is therefore dominated and can be removed from further consideration; package A gives the lowest receiving level but costs more and requires more maintenance than B. Neither A nor B dominates the other.

The Pareto set contains A and B; selection requires the authorised team to decide whether the additional 2 dB reduction attributed to A justifies £35,000 and 55 annual labour-hours, while considering uncertainty and code constraints; the screening uses heterogeneous units and therefore does not combine them arithmetically. It does not establish speech security or approval; it exposes the remaining trade-off.

Worked example 23.41. Robust ranking under workmanship uncertainty

Engineering question. Detail X has predicted field isolation 56 dB with standard uncertainty 3.0 dB. Detail Y has predicted field isolation 54 dB with standard uncertainty 1.0 dB. Under a conservative screening rule based on the predicted value minus twice the standard uncertainty, which detail has the stronger lower assurance bound?

For X,

$$B_X = 56 - 2(3) = 50\,dB.$$

For Y,

$$B_Y = 54 - 2(1) = 52\,dB.$$

Although X has the higher nominal prediction, Y has the higher screened lower bound; the calculation is dimensionally consistent because all terms are decibel values of the same measurand; it assumes the uncertainty summaries and coverage interpretation are appropriate and ignores differences in failure consequence, distribution shape and correlation. The result supports a robustness discussion; it does not by itself dictate procurement.

23.52 Longitudinal change detection and lifecycle path control

A complete-envelope model becomes more valuable after commissioning because it supplies a structured baseline for later comparison; the baseline should preserve the path identifiers, configuration photographs, source states, receiver positions, raw spectra, vibration data, background, uncertainty and decision rule. A later result can then be compared path by path rather than merely against an old whole-room rating; lifecycle control is particularly important where doors are adjusted, seals age, filters are changed, cable routes expand, raised-floor panels are moved or ceiling barriers are disturbed. [154]

Change detection requires a stable measurand. If the baseline used one source position and the later test uses another, the difference combines room response with possible degradation; if the ventilation mode, furnishings or background changed, those states must be represented; a reference path or control measurement can help identify global instrument or source drift. The comparison should also preserve the same processing, including time windows, averaging, background correction and spatial weighting.

The alteration register should be linked to the path model; each change record identifies the affected boundary, predicted paths, inspection requirement and post-work verification; a new conduit through a wall affects direct leakage and possibly cell or cavity networks. A replacement door closer can alter seal compression; a software update to an audiovisual system can change standby noise or loudspeaker states. The register turns later work from an undocumented disturbance into a controlled experiment.

When degradation is detected, remediation should follow the same causal sequence used in the original commissioning; first confirm the measurement chain and state; then localise the changed path, review the alteration history and apply discriminating interventions; a broad rebuild before diagnosis destroys evidence and can shift the problem. The final

154 MB-0257. ASTM International, ASTM E336-25a, ASTM E2638-24.

lifecycle report should state whether the repaired room returned to baseline, met the current requirement or merely improved relative to the degraded condition.

Worked example 23.42. Significance of a longitudinal change

Engineering question. A façade-junction band level was 22.4 dB at commissioning with standard uncertainty 0.8 dB. Two years later it is 25.1 dB with standard uncertainty 0.9 dB. Assuming independent estimates, is the 2.7 dB increase larger than an approximate expanded uncertainty of the difference with $k=2$?

The standard uncertainty of the difference is

$$u_{\Delta}=\sqrt{0.8^2+0.9^2}=1.20\,dB.$$

The expanded uncertainty is

$$U_{\Delta}=2(1.20)=2.40\,dB.$$

The observed change of 2.7 dB slightly exceeds the screening interval; it warrants investigation, especially if the band is consequential and the source and receiver states are comparable; the inference is sensitive to independence, distribution and repeatability assumptions. It does not identify the cause, which could be seal ageing, a changed mullion condition, altered background or another path.

23.53 Technical schedules and controlled records

The complete-envelope analysis should produce a set of controlled records rather than one narrative conclusion; the path register identifies every path, source state, receiver node, calculation or measurement method, uncertainty, evidence status and responsible discipline; the intervention register records temporary and permanent changes. The acceptance schedule links requirements to measurands, decision rules and authority dispositions; these records permit future change control and prevent assumptions from becoming undocumented facts.

A path identifier should remain stable throughout design, construction and commissioning; for example, P-FA-03 can designate the third façade path, while revision fields record changes; stable identifiers allow a photograph, calculation, nonconformance and test result to be linked. Renaming paths casually during the project destroys traceability.

The final record should also preserve negative findings; a tested path that did not materially contribute remains useful evidence, especially if later alterations make it relevant; negative evidence is bounded by sensitivity and state; “no path detected” should be replaced by a statement such as “no contribution above the stated detection limit was identified under the documented source and configuration”.

Table 23-5. Complete-envelope acceptance and lifecycle schedule

Acceptance layer	Measurand or evidence	Configuration that must be frozen	Decision responsibility	Required retained record
Product and submittal acceptance	Product identity, complete reports, drawings and compatibility	Approved materials, dimensions, hardware, services and listed systems	Designer, owner and applicable code authority	Approved submittals, deviations, source status and review disposition
Concealed-work acceptance	Physical continuity and installed path details	Joints, frames, barriers, services, supports, firestops and clearances before closure	Construction surveillance and responsible disciplines	Coordinate photographs, inspection forms, nonconformances and closure records

Acceptance layer	Measurand or evidence	Configuration that must be frozen	Decision responsibility	Required retained record
Component commissioning	Door, glazing, silencer, masking or isolated support performance	Adjustment, airflow, pressure, controls, seals and operating state	Commissioning team and responsible designer	Instrument data, adjustment values, acceptance rule and corrective action
Room-pair acoustic acceptance	Field level difference, apparent insulation, impact or other stated metric	Source and receiver rooms, furnishings, background, HVAC and access state	Testing authority under the project requirement	Raw bands, positions, decay, background, uncertainty and conformity statement
Occupied speech-security assessment	Defined audibility, intelligibility or privacy measure	Talker or source protocol, language, listener positions, masking and operational state	Security authority informed by technical specialists	Protocol, recordings or protected data controls, result, uncertainty and limitations
Formal authorisation	Programme-specific acceptance or conditional use	Complete evidence set and stated operational restrictions	Competent governmental or institutional authority	Signed disposition, conditions, review date and change triggers
Lifecycle surveillance	Change from baseline, path-specific condition and configuration status	Comparable test state plus documented alteration history	Facility owner, security authority and maintenance governance	Baseline, trend record, alteration register, repair verification and new checksum

23.54 Chapter conclusions

Composite transmission is governed by the linear addition of energy or compatible transfer quantities, not by averaging decibel ratings; the complete envelope includes walls, doors, glazing, floors, ceilings, roofs, junctions, façades, ducts, services, cavities and operational openings. Its governing path changes with frequency, source state, receiver position and configuration.

Element data and prediction standards are indispensable but bounded; ISO 12354 provides detailed and simplified building-acoustic models when the necessary element and junction data satisfy their assumptions; ISO 10848 provides measurements for specified flanking combinations and junctions; ASTM and ISO field methods describe installed room relationships. None of these, alone, establishes occupied speech security or formal governmental acceptance. [155]

A defensible model separates measurement uncertainty, configuration uncertainty and model discrepancy; it records correlation, nonlinear propagation, sensitivity, path hypotheses and diagnostic interventions. Calibration is not validation. Agreement of one total level can conceal compensating errors; path-sensitive observations and held-back validation data are needed.

Remediation is a network optimisation problem. Treating the strongest-looking component can waste resources when another path governs; controlled interventions, value-of-information analysis and consequence-weighted residual exposure help align investigation with decisions; the result remains bounded by the stated source, receiver, access and authority conditions.

Commissioning creates both an acceptance record and a lifecycle baseline; the path register, source-state matrix, receiver-access map, raw data, uncertainty budget, photographs and as-built configuration support future alteration control; formal accreditation remains the decision of the competent authority and can depend on criteria outside the public acoustic analysis.

155 MB-0261. ASTM International, ASTM E336-25a, ASTM E2638-24.

23.55 Chapter 23 glossary

Bayesian updating. Revision of probabilities assigned to competing hypotheses after new evidence is observed, using stated prior probabilities and likelihoods.

Complete envelope. The full set of architectural, structural, service and operational paths capable of transferring sound or vibration from a protected source to a receiver.

Configuration uncertainty. Uncertainty concerning the actual physical or operating state of the system, including concealed construction and discrete equipment states.

Correlation coefficient. A dimensionless measure of linear dependence between two uncertain quantities, bounded between minus one and plus one.

Covariance. A quantity describing joint variation of two inputs and entering an uncertainty calculation when those inputs are correlated.

Cut set. A set of graph edges whose removal disconnects a specified source node from a receiver node.

Diagnostic intervention. A controlled and preferably reversible change made to distinguish among competing path hypotheses.

Direct path. Transmission through the nominal separating element or route defined as direct by the applicable measurement or prediction method.

Flanking path. Transmission through adjoining elements, junctions, services or other routes outside the nominal direct element.

Global sensitivity analysis. Evaluation of input influence across the full specified uncertainty domain, including interaction effects.

Guard band. A decision margin applied to a specification limit under a stated decision rule and risk allocation.

Hybrid model. A model combining deterministic, statistical, empirical and measured submodels in defined frequency or path regimes.

Likelihood ratio. The probability of observed evidence under one hypothesis divided by its probability under another hypothesis.

Local sensitivity coefficient. Derivative or finite-change approximation describing output change caused by a small input change near a selected operating point.

Model discrepancy. Difference between the physical system and the best representation available from the selected model structure and parameters.

Monte Carlo propagation. Numerical propagation of input distributions through a measurement or prediction model by repeated random sampling.

Normalised flanking level difference. A method-defined quantity characterising a selected flanking combination after specified receiving normalisation.

Path dominance. Condition in which one path contributes a large enough share of total transmitted energy to control the residual result in a stated band and state.

Path matrix. Controlled tabular representation linking source elements, transfer routes, junctions and receiving elements.

Residual risk. Risk remaining after design, control, measurement and remediation, stated with its assumptions and uncertainties.

Source-state matrix. Controlled record of credible source, equipment, room and operational states used in design and testing.

Statistical energy analysis. Frequency-band method representing coupled subsystems through average modal energy and power exchange.

Transmission coefficient. Linear ratio of transmitted to incident sound power for a stated element, path and condition.

Value of information. Expected reduction in decision loss attributable to obtaining additional evidence, net of the cost and consequence of the test.

Vibration reduction index. Standardised junction quantity used in building-acoustic flanking prediction under the applicable method.