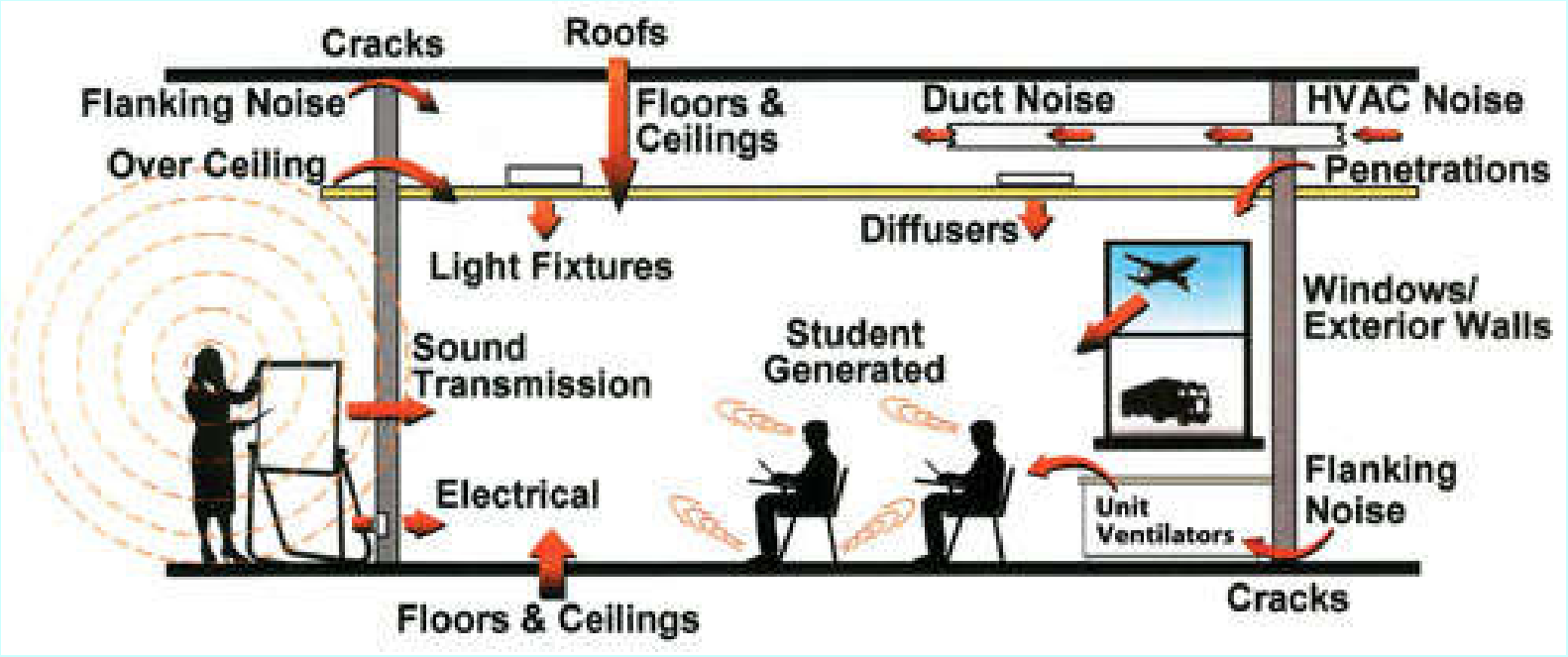
MEBS7014 Advanced HVAC applications

http://ibse.hk/MEBS7014/



Noise and Vibration Control II

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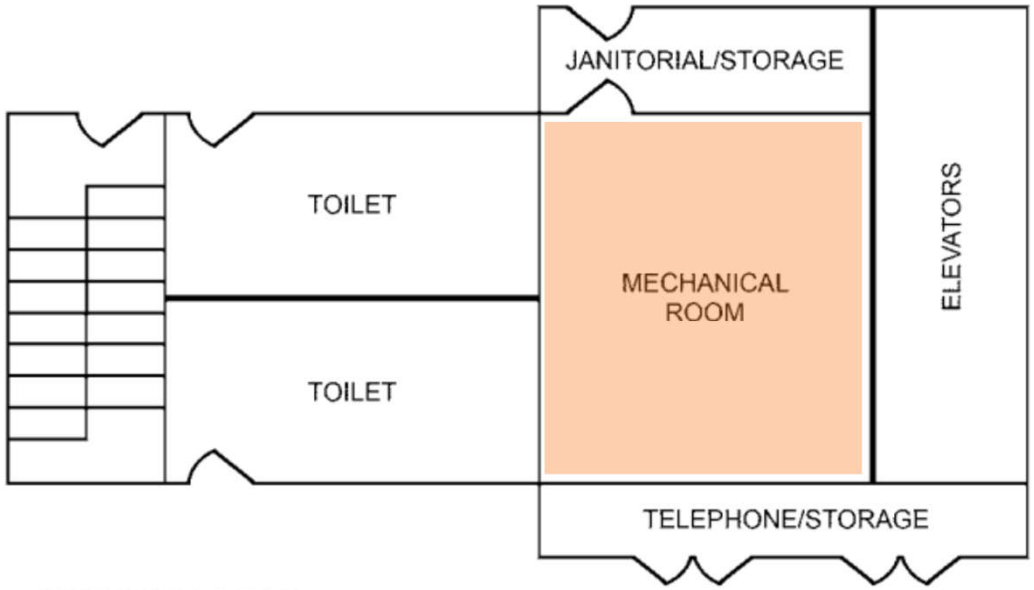
Contents

- Design guidelines
- Fan systems
- Ductwork noise
- Terminal units

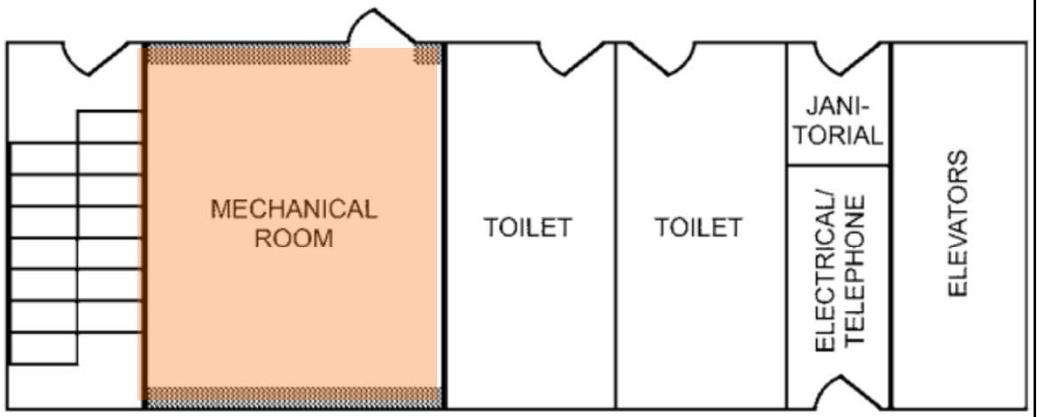
Design guidelines

- HVAC acoustical design considerations:
  - HVAC system type & equipment selection
    - Consider acoustical properties & implications
  - Mechanical room sizing & duct shafts
    - Allow sufficient clearance & limit the air velocity
  - Space planning (locate the noisy equipment as far as possible from the noise/vibration sensitive areas)
    - Such as chiller rooms, fan/AHU rooms, cooling towers, & rooftop package units
  - Walls & slabs for mechanical rooms + penetration
  - Outdoor equipment areas & construction

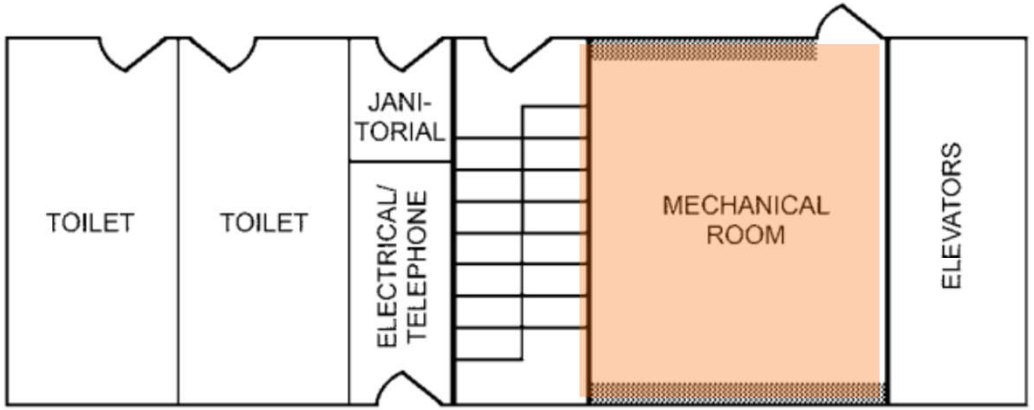
Comparison of various mechanical equipment room locations



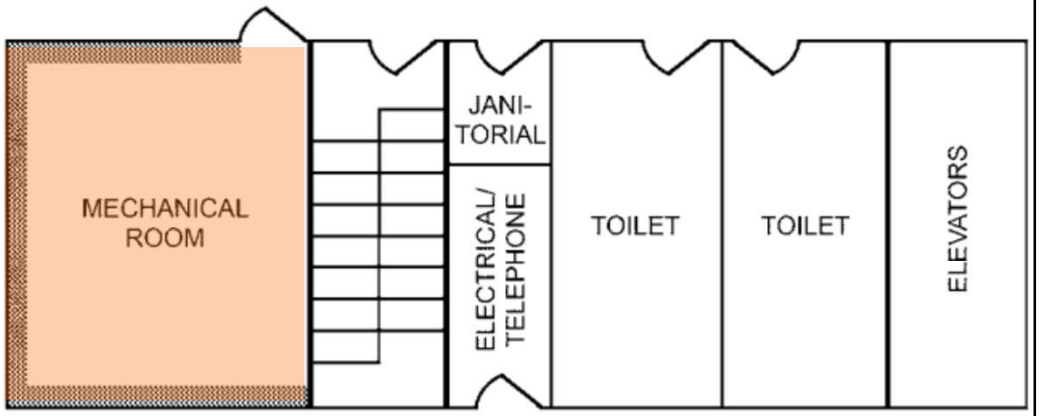
A. BEST CORE LAYOUT
No mechanical room walls exposed to tenant space. No supply and return air openings need be next to tenant space. Ceiling over toilets can be used for supply air ducts or return air path.



B. BETTER CORE LAYOUT
Exposes 2 mechanical room walls to tenant space. Ceiling over toilets can be used for supply ducts or return air path.



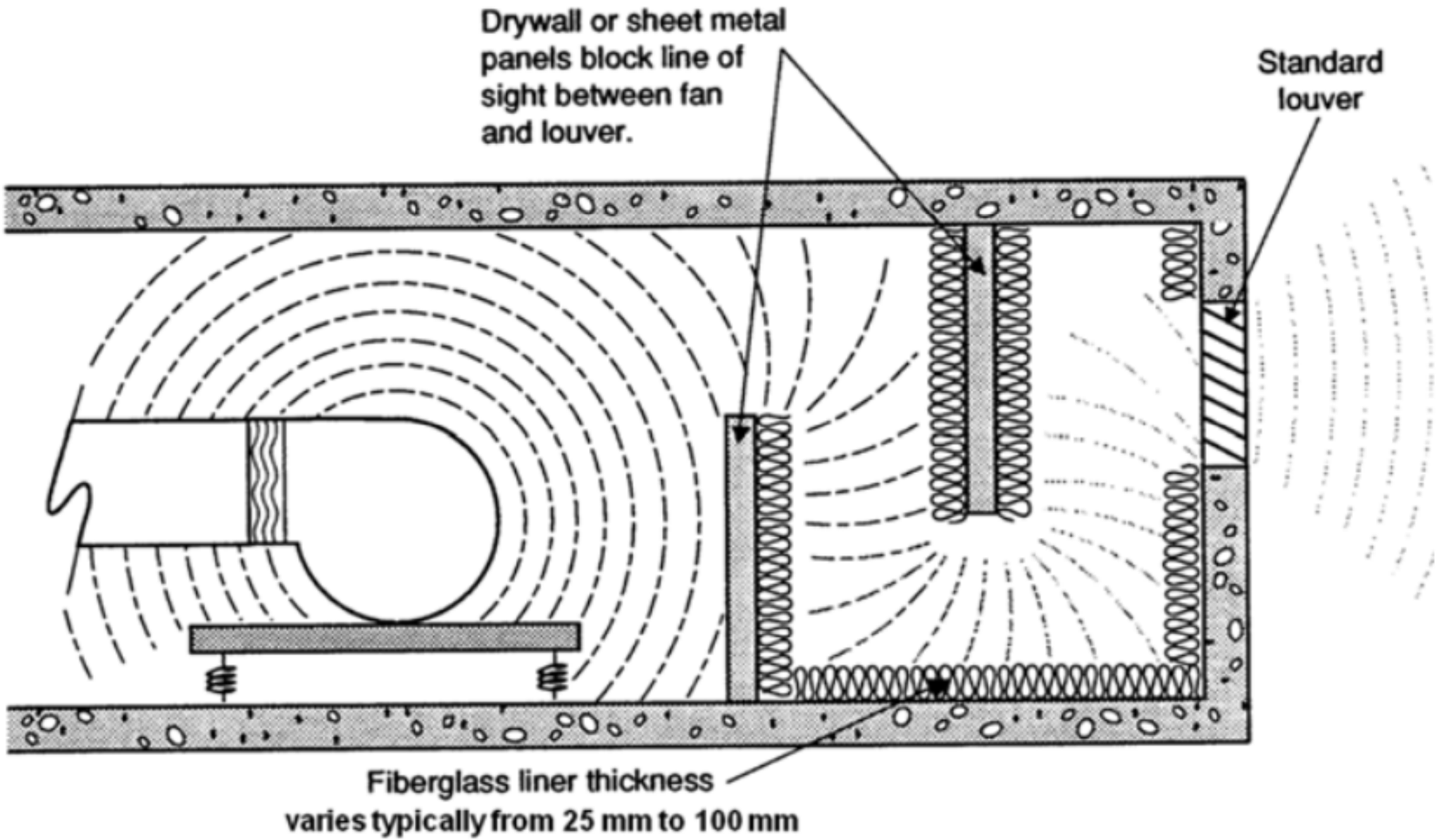
C. FAIR CORE LAYOUT
Exposes 2 mechanical room walls to tenant space. Impenetrable mechanical room partition to elevators and stairs results in supply and return air wall openings next to tenant space.



D. POOR CORE LAYOUT
Exposes 3 mechanical room walls to surrounding tenant space. Impenetrable partition between mechanical room and exit stairs results in supply and return air wall openings next to tenant space.

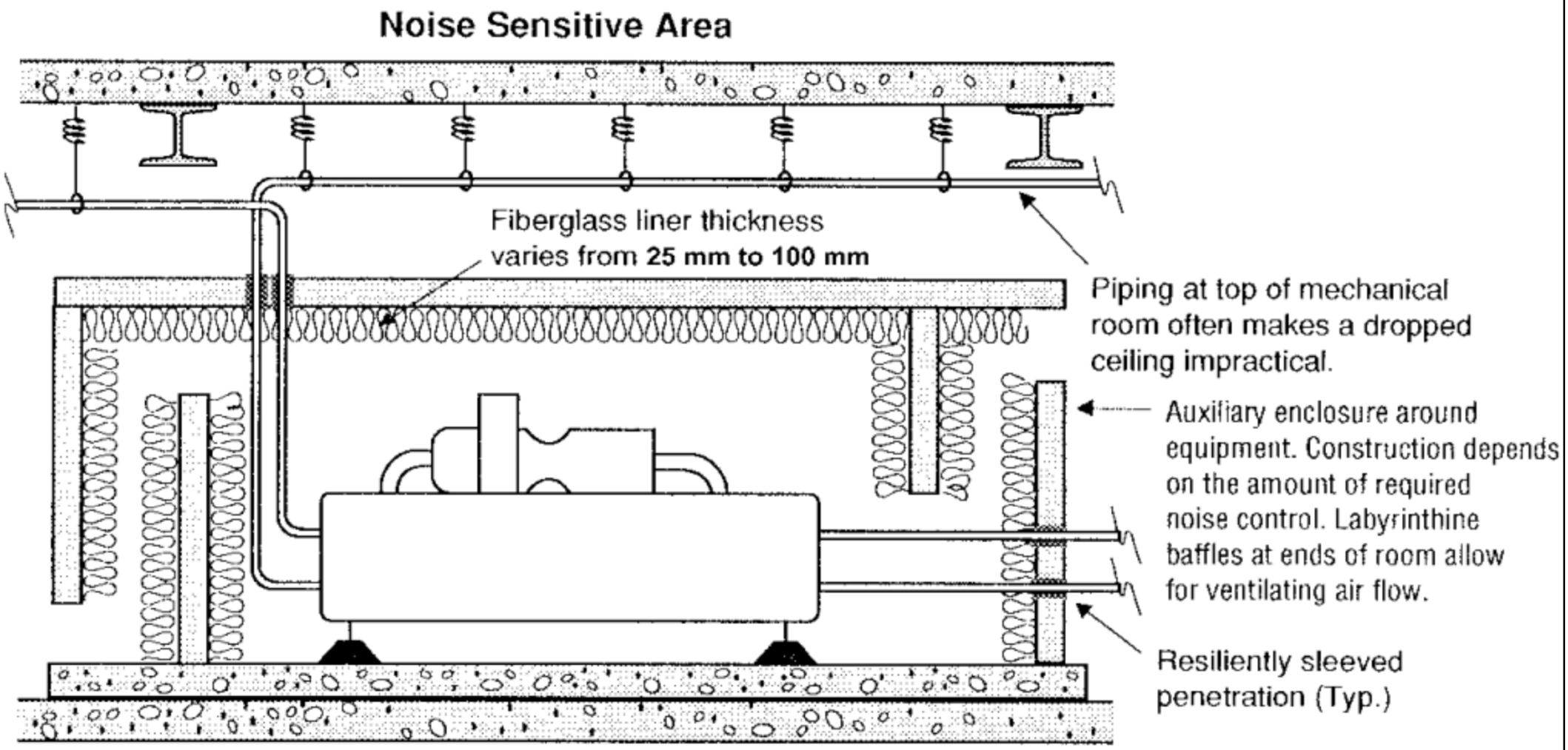
(Source: *ASHRAE Handbook Fundamentals 2017*, Chp. 21)

Labyrinth air path used for sound attenuation at an equipment room ventilation opening



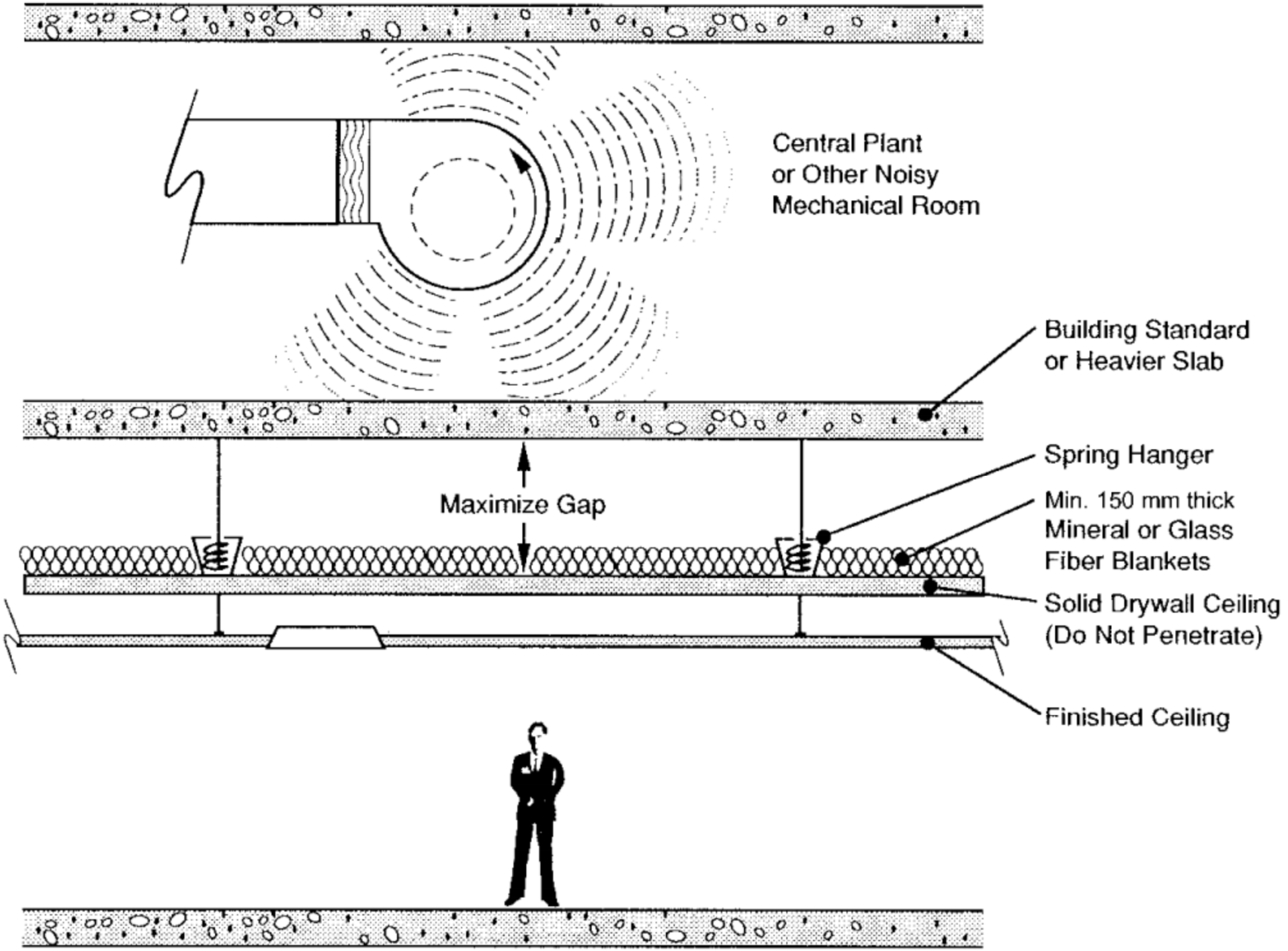
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Upward noise control for mechanical rooms



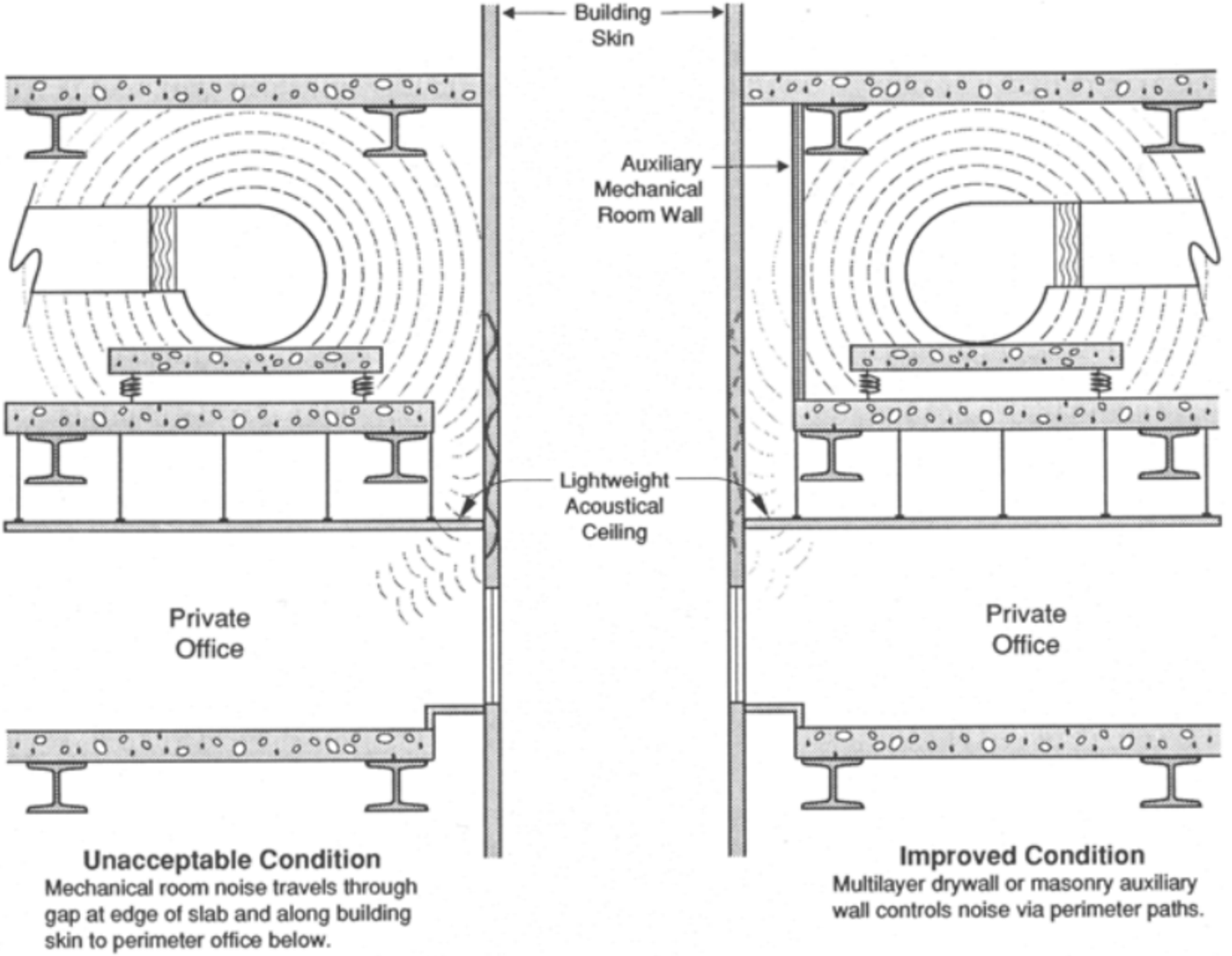
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Downward noise control using an auxiliary ceiling



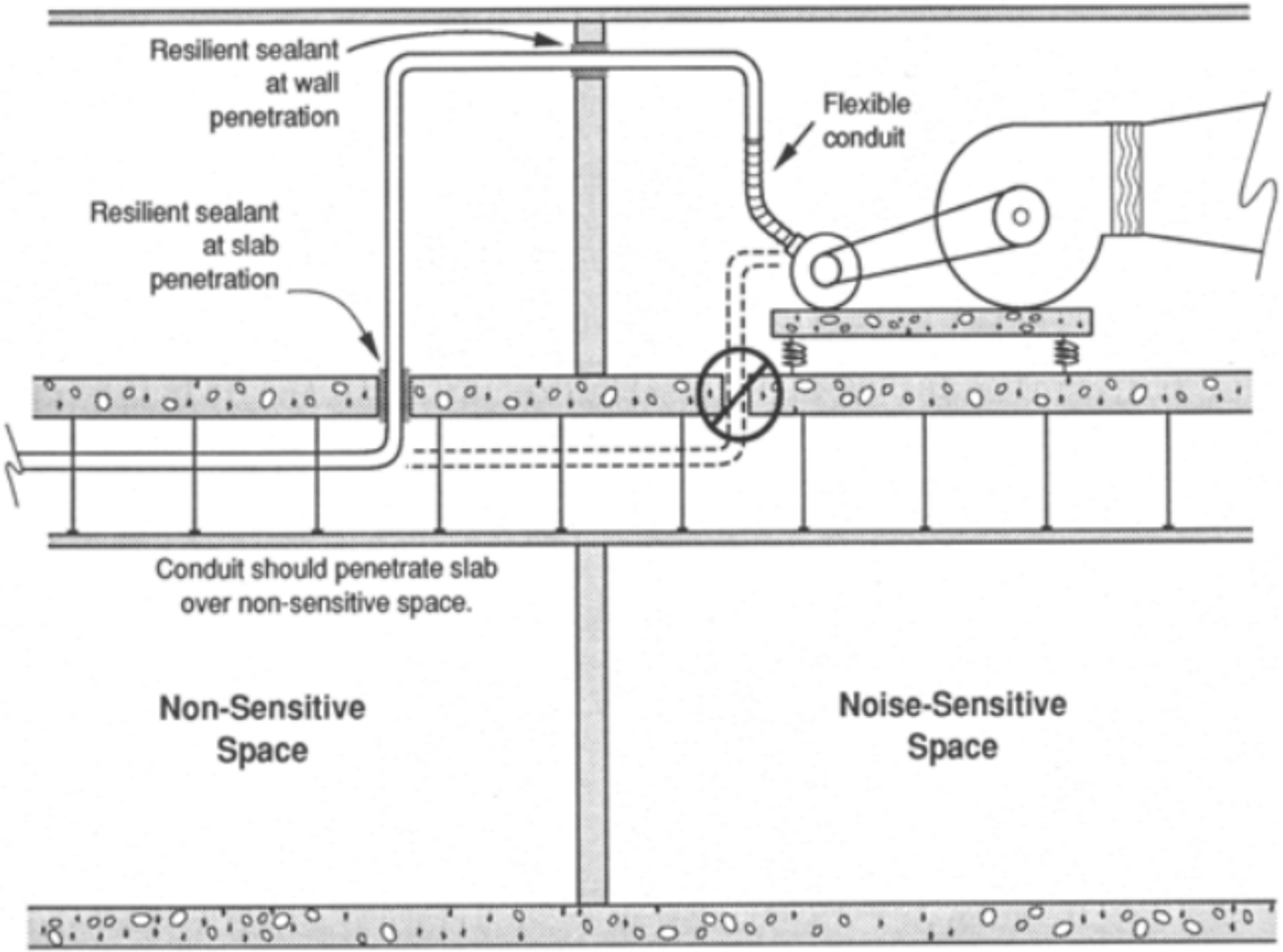
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Sound transmission at perimeter mechanical rooms



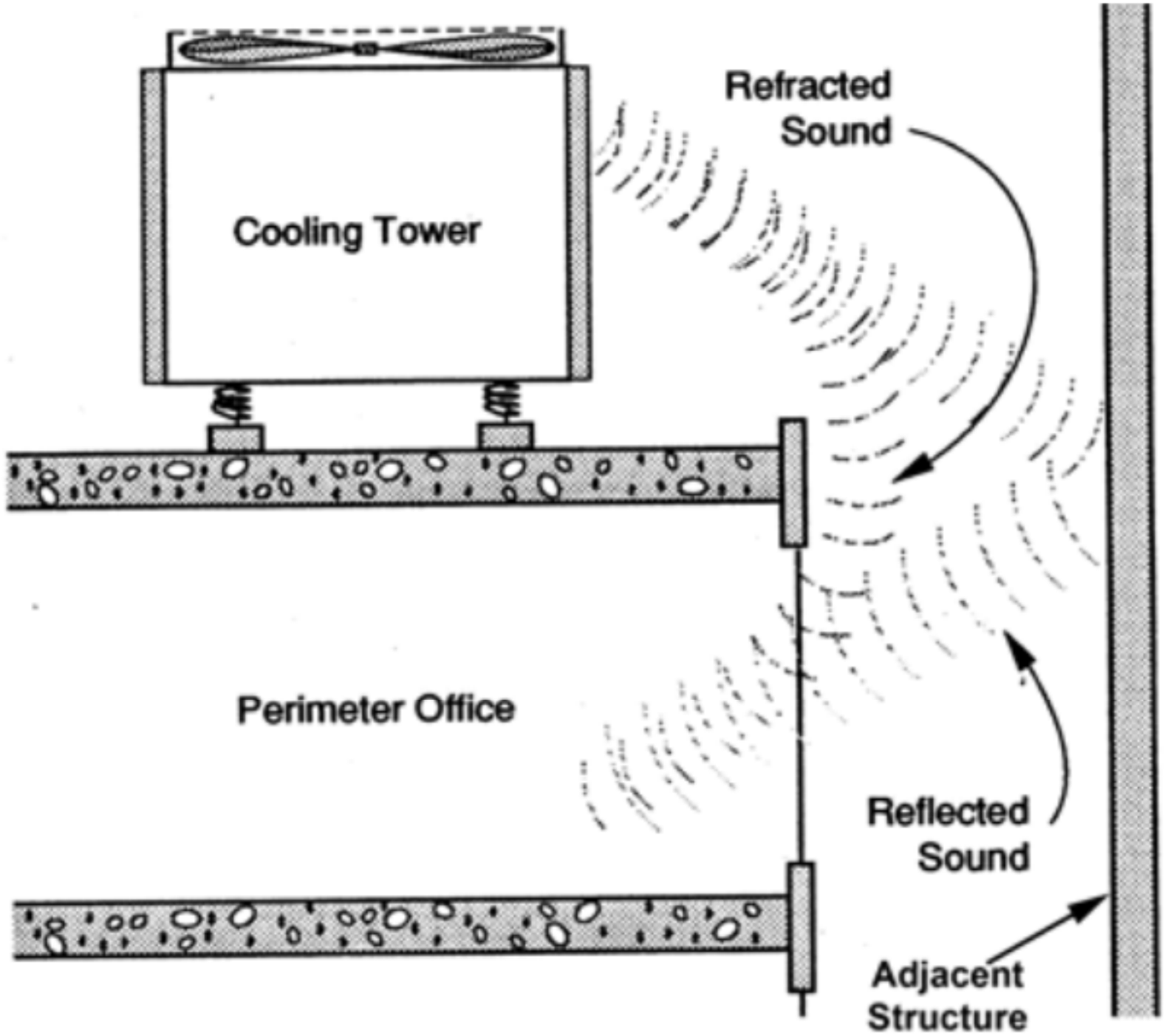
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Electrical conduit routing into a mechanical room



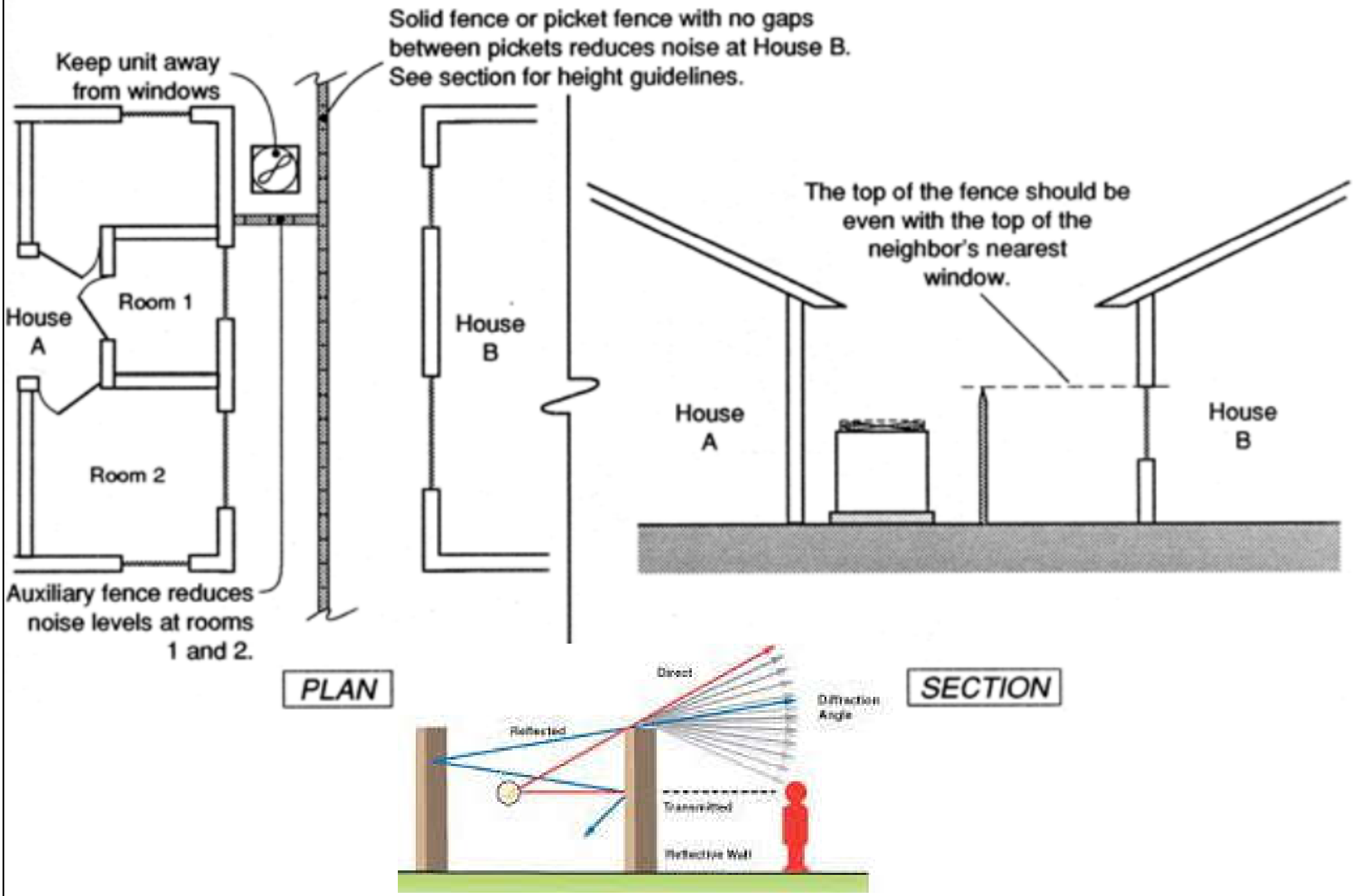
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Reflected and refracted equipment sound at a building perimeter



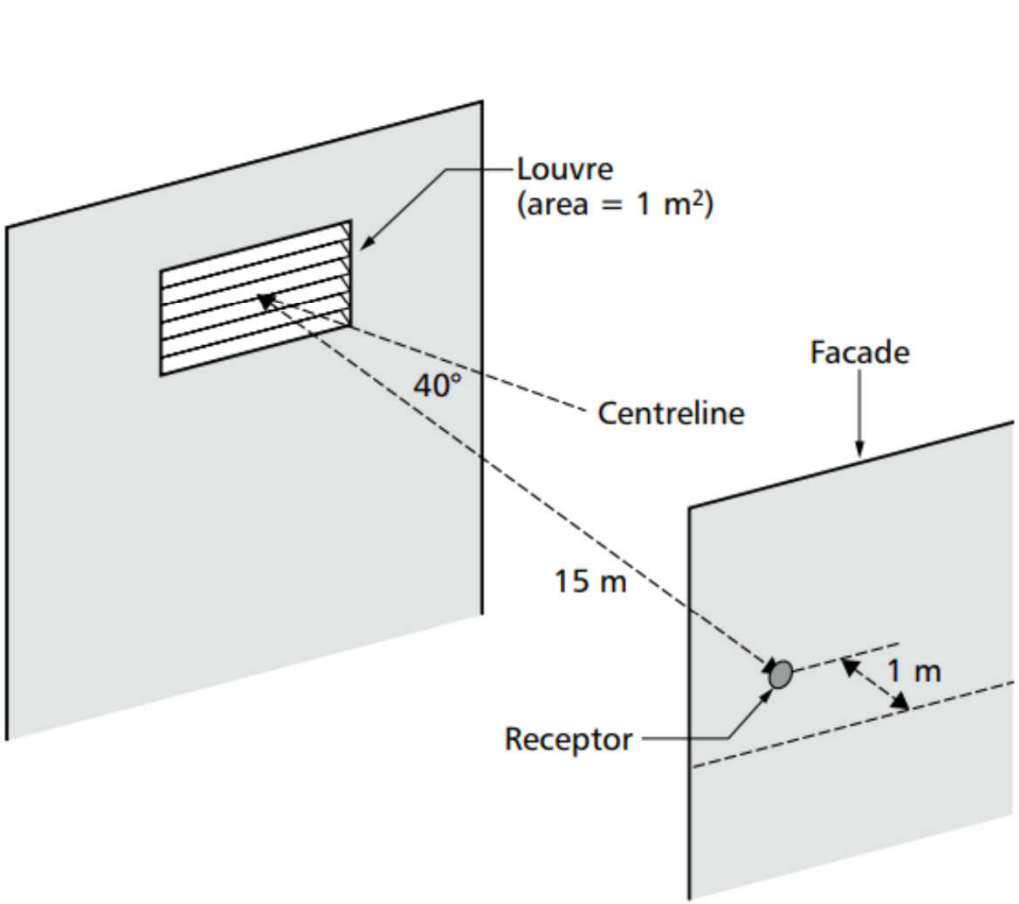
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

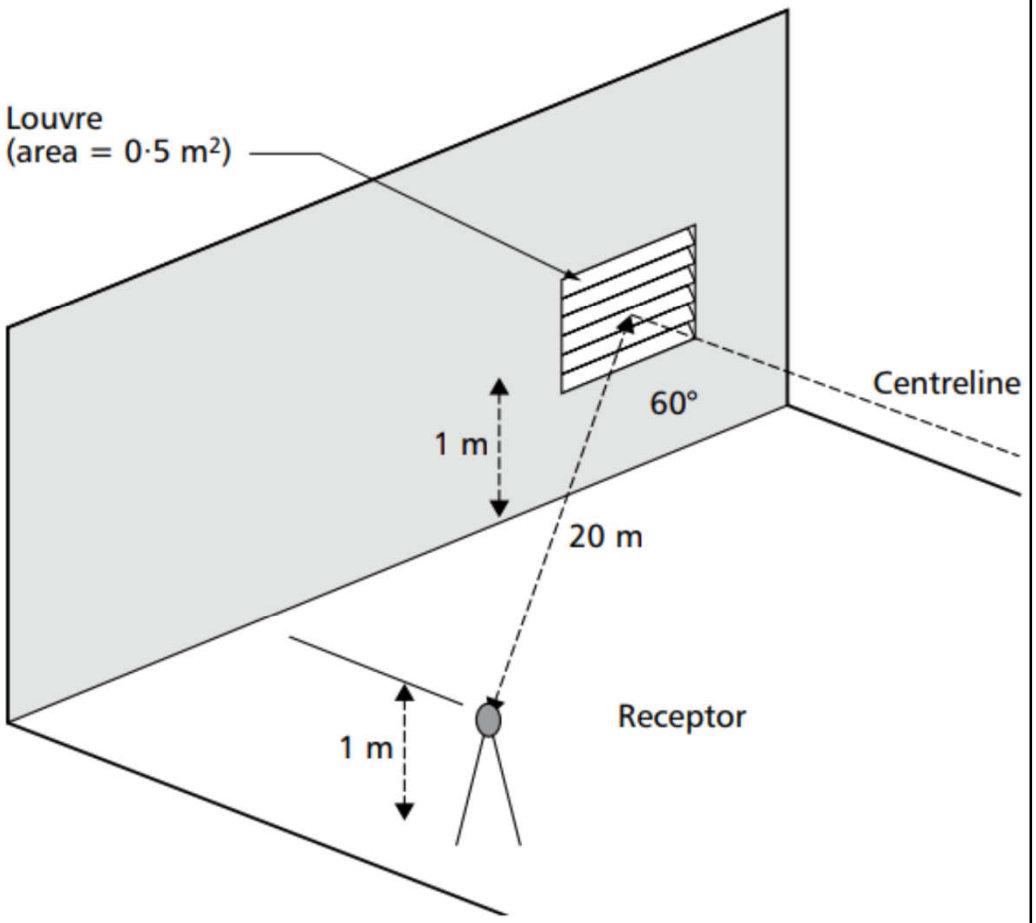
Small condensing unit noise control



(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Examples of noise from louvred opening at external receptor





(Source: CIBSE, 2016. *Noise and Vibration Control for Building Services Systems, CIBSE Guide B4: 2016*, Chartered Institution of Building Services Engineers (CIBSE), London.)

Design guidelines

- Possible causes of excessive noise in HVAC:
  - Incorrect design of the HVAC systems and their equipment area walls & slabs
  - Cost-cutting without regard for the noise and vibration implications
  - Improper installation
  - Improper start-up or commissioning
  - Ignoring the selection and/or installation guidelines published by HVAC equipment and noise/vibration control product manufacturers

Design guidelines

- Examples of problems from inadequacies in HVAC design & installation
  - Undersized fans, which could not accept the pressure loss of retrofit silencers
  - Oversized fans, which were working on an undesirable part of their characteristic
  - Vibration isolators which were bypassed by solid connections
  - Unsealed gaps around penetrations which allow airborne noise transmission

Origin and solutions of typical noise problems in HVAC systems

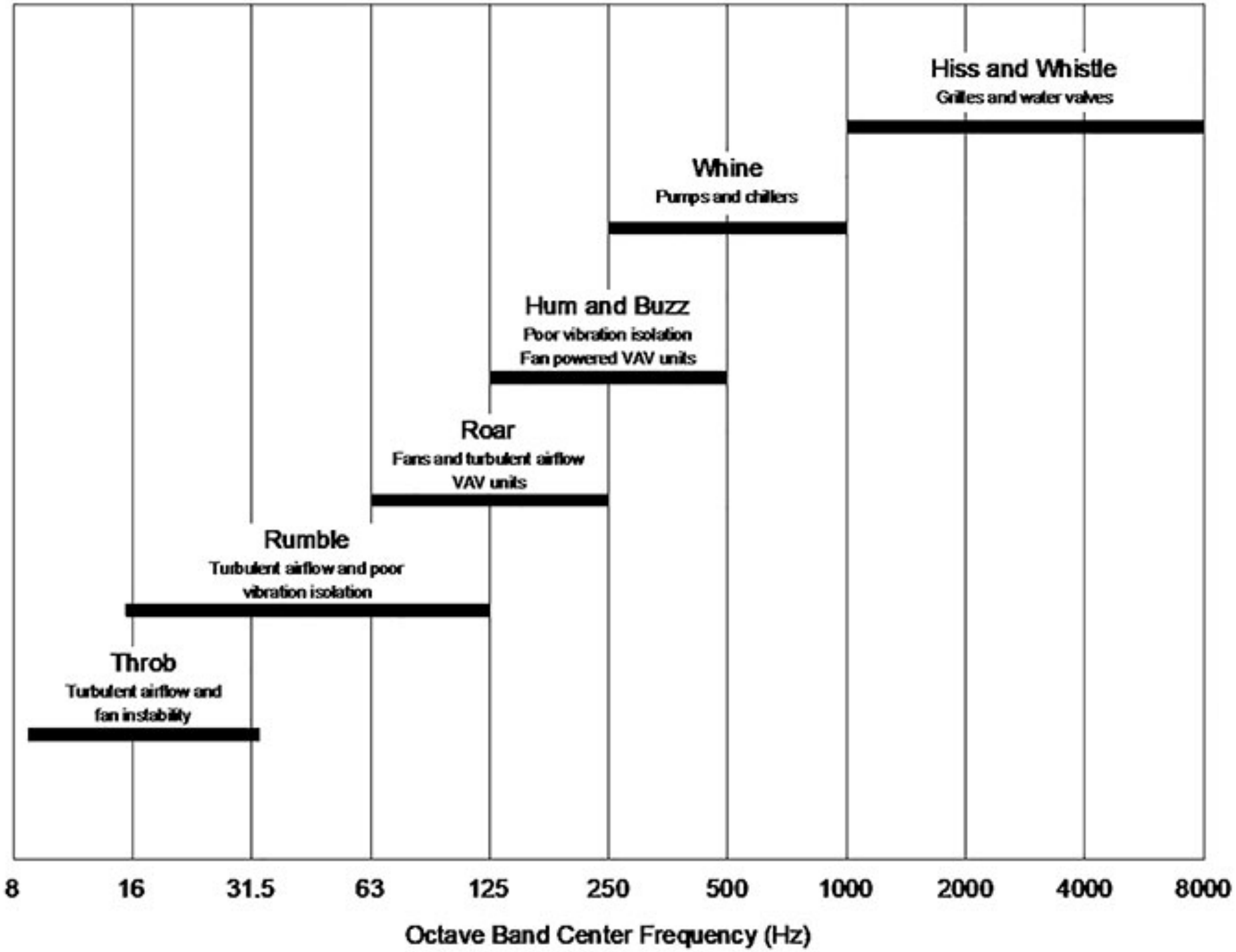
MECHANICAL NOISE	
ORIGIN	Low frequency sound waves caused by mechanical parts such as a pump, fan or compressor.
SOLUTION	Isolate the source.

AIR FLOW NOISE	
ORIGIN	Turbulent and / or high speed medium in pipes and ducts.
SOLUTION	Reduce resistance.

VIBRATIONAL NOISE	
ORIGIN	Vibrations caused by moving objects, resonating through ducts, pipes, floors and bulkheads.
SOLUTION	Reduce resistance.

(Source: http://www.heinenhopman.com/noise-control-part-4-reduce-hvac-noise-issues/)

Frequency of different types of equipment



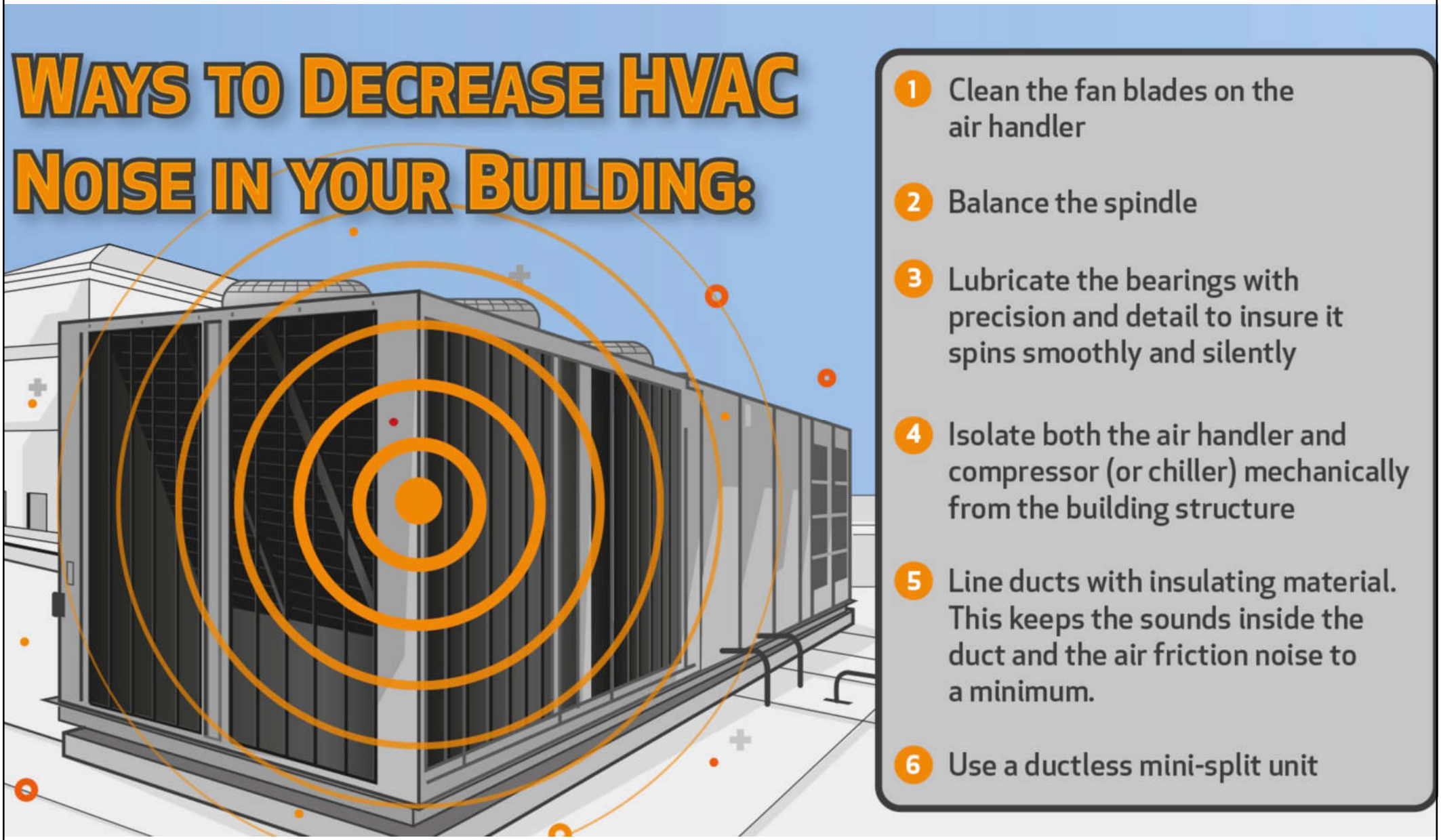
(Source: https://www.pumpsandsystems.com/isolation-noise-vibration-hvac-plumbing-piping-systems)

Pumping system noise analysis guide

Possible Cause	Recommended Action
Shaft misalignment	• Check and realign
Worn coupling	• Replace and realign
Worn pump/motor bearings	• Replace, check manufacturer's lubrication recommendations • Check and realign shafts
Improper foundation or installations	• Check foundation bolting or proper grouting • Check possible shifting caused by piping expansion/contraction • Realign shafts
Pipe vibration and/or strain caused by pipe expansion/contraction	• Inspect, alter, or add hangers and expansion provision to eliminate strain on pump(s)
Water velocity	• Check actual pump performance against specified, and reduce impeller diameter as required • Check for excessive throttling by balance valves or control valves
Pump operating close to or beyond end point of performance curve	• Check actual pump performance against specified, and reduce impeller diameter as required
Entrained air or low suction pressure	• Check expansion tank connection to system relative to pump suction • If pumping from cooling tower sump or reservoir, check line size • Check actual ability of pump against installation requirements • Check for vortex entraining air into suction line

(Source: ASHRAE, 2020. *ASHRAE HVAC Systems and Equipment Handbook 2020*, SI edition, Chp. 44 Centrifugal Pumps)

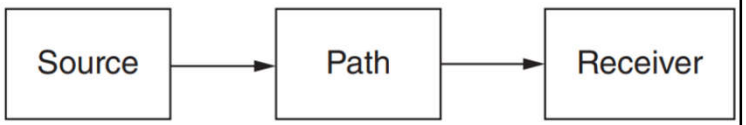
Practical ways to decrease HVAC noise in buildings



(Source: https://www.mazza-hvac.com/news/news-story/determine-hvac-noise-sources-to-improve-acoustics)

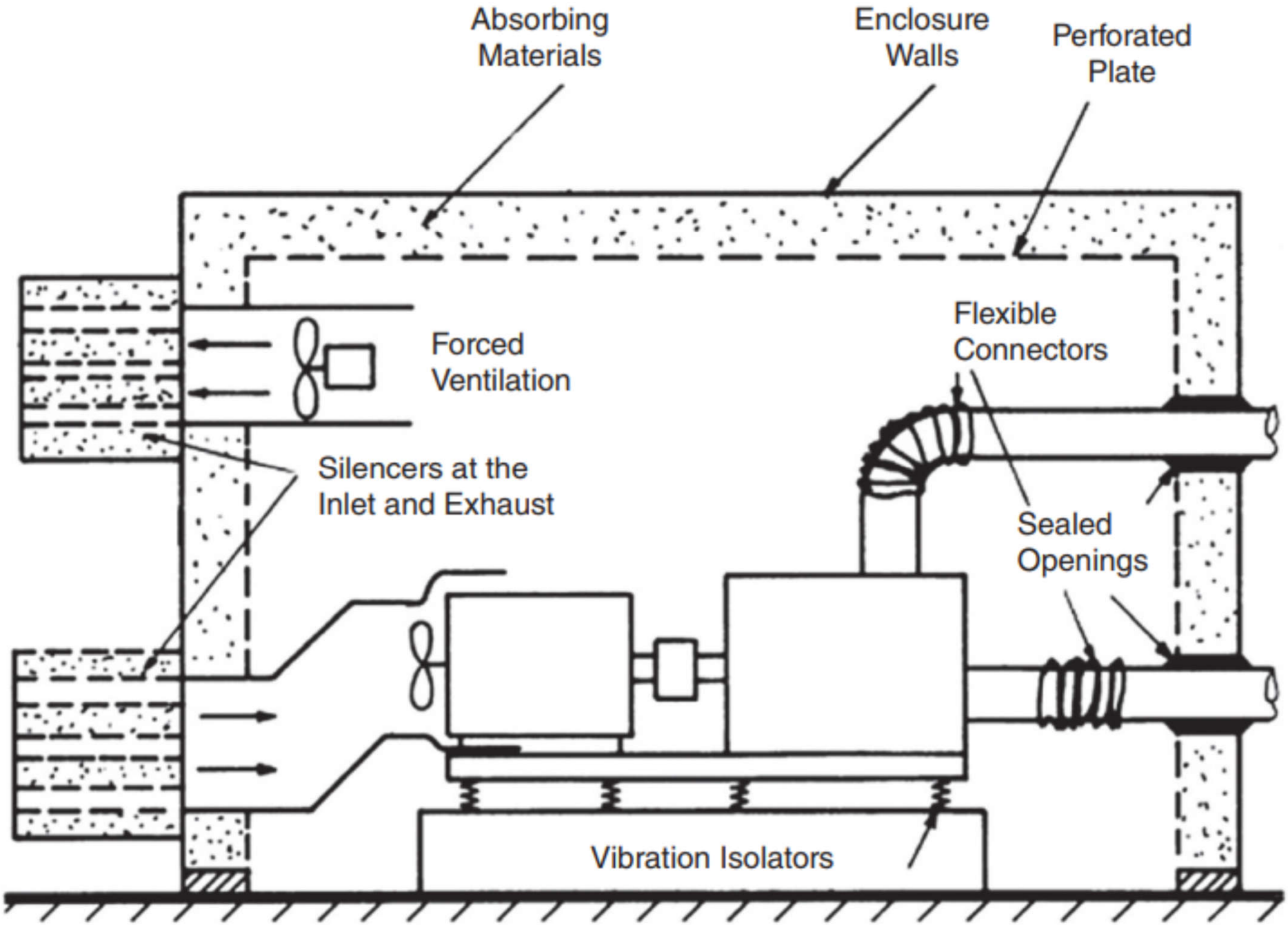
Design guidelines

- Techniques for noise & vibration control
  - Noise & vibration source identification
    - Dominant source(s) and machines
    - Transmission path identification



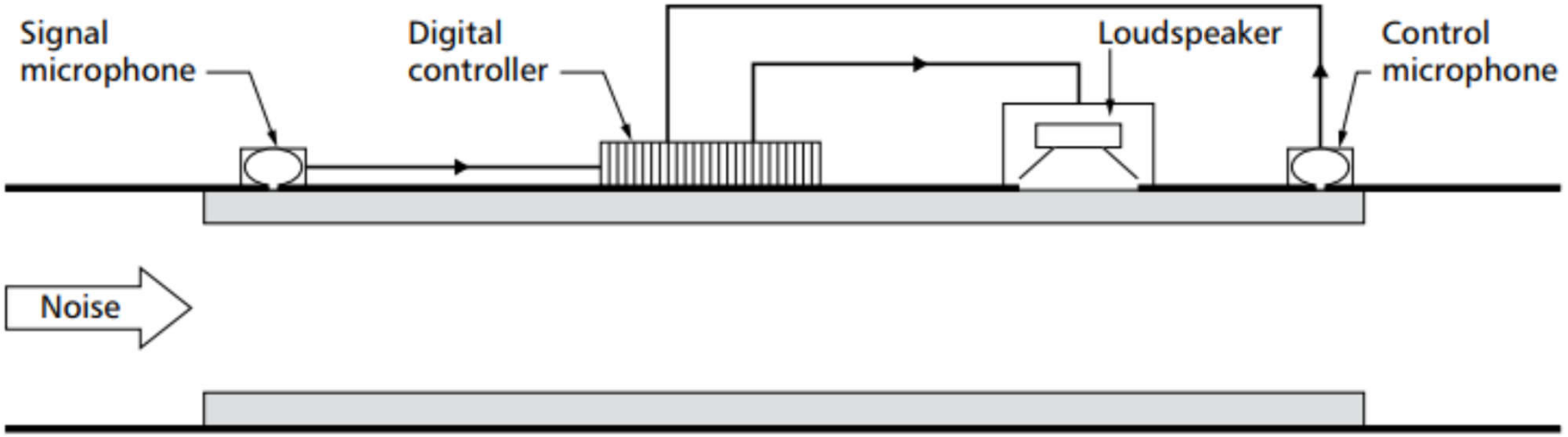
  - Noise reduction techniques
    - Use of vibration isolators (machine, inertia blocks)
    - Use of damping materials (constrained, unconstrained)
    - Use of sound absorption (porous fibrous materials, panel or membrane, suspended, spray-on, plaster)
    - Acoustical enclosures (machine enclosure)
    - Use of barriers or screens (indoor or outdoor)
    - Active control (destructive interference)

Elements of an acoustical enclosure used for machinery noise control

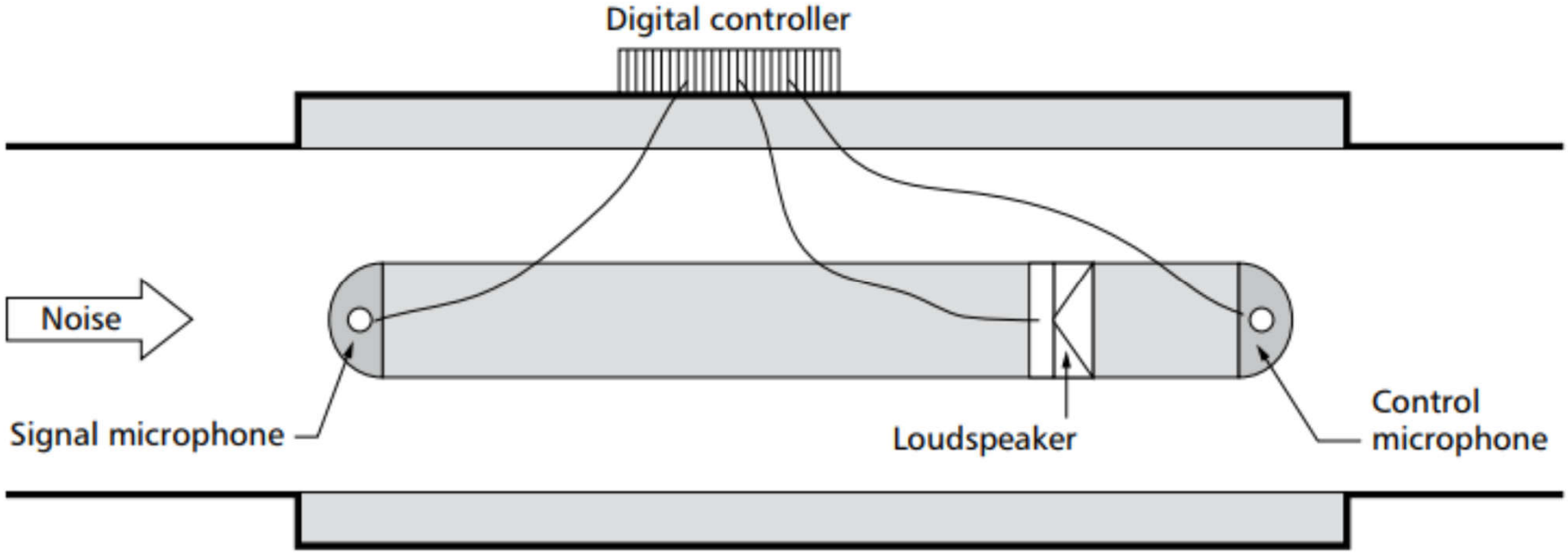


(Source: Crocker M. J. & Arenas J. P., 2021. *Engineering Acoustics: Noise and Vibration Control*, Wiley, Hoboken, NJ. https://doi.org/10.1002/9781118693902)

Active attenuators (a) mounted externally and (b) in a central pod



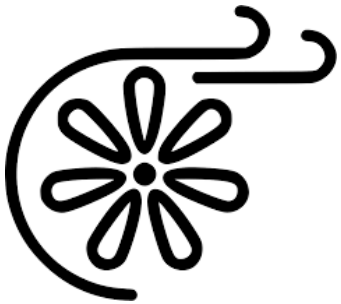
(a)



(b)

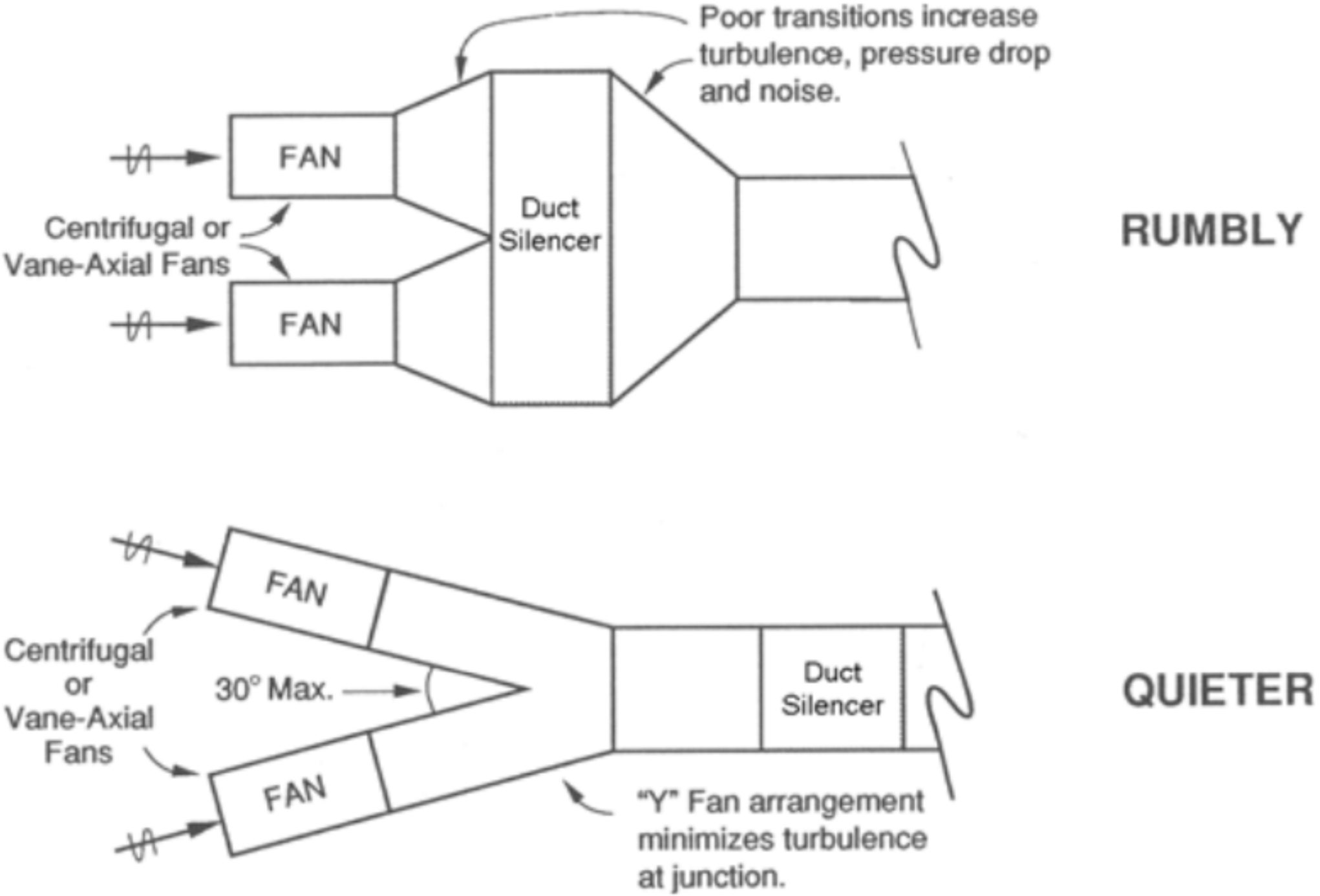
(Source: CIBSE, 2016. *Noise and Vibration Control for Building Services Systems, CIBSE Guide B4: 2016*, Chartered Institution of Building Services Engineers (CIBSE), London.)

Fan systems



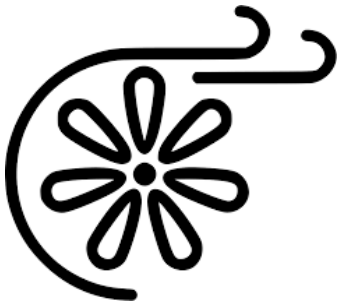
- Principles on HVAC noise & vibration control
  - Choose the operating condition of the fan so that it is at a high efficiency point on its fan performance curve; this minimises fan noise
  - Ensure good flow conditions for the air stream
    - Also reduce pressure losses, energy & operating costs
  - Isolate vibrating components, including all machinery, ducts and pipework from the structure
  - Choose an in-duct silencer, lining or other means to control airborne noise in ducts

Examples of rumbly and quieter parallel fan installations



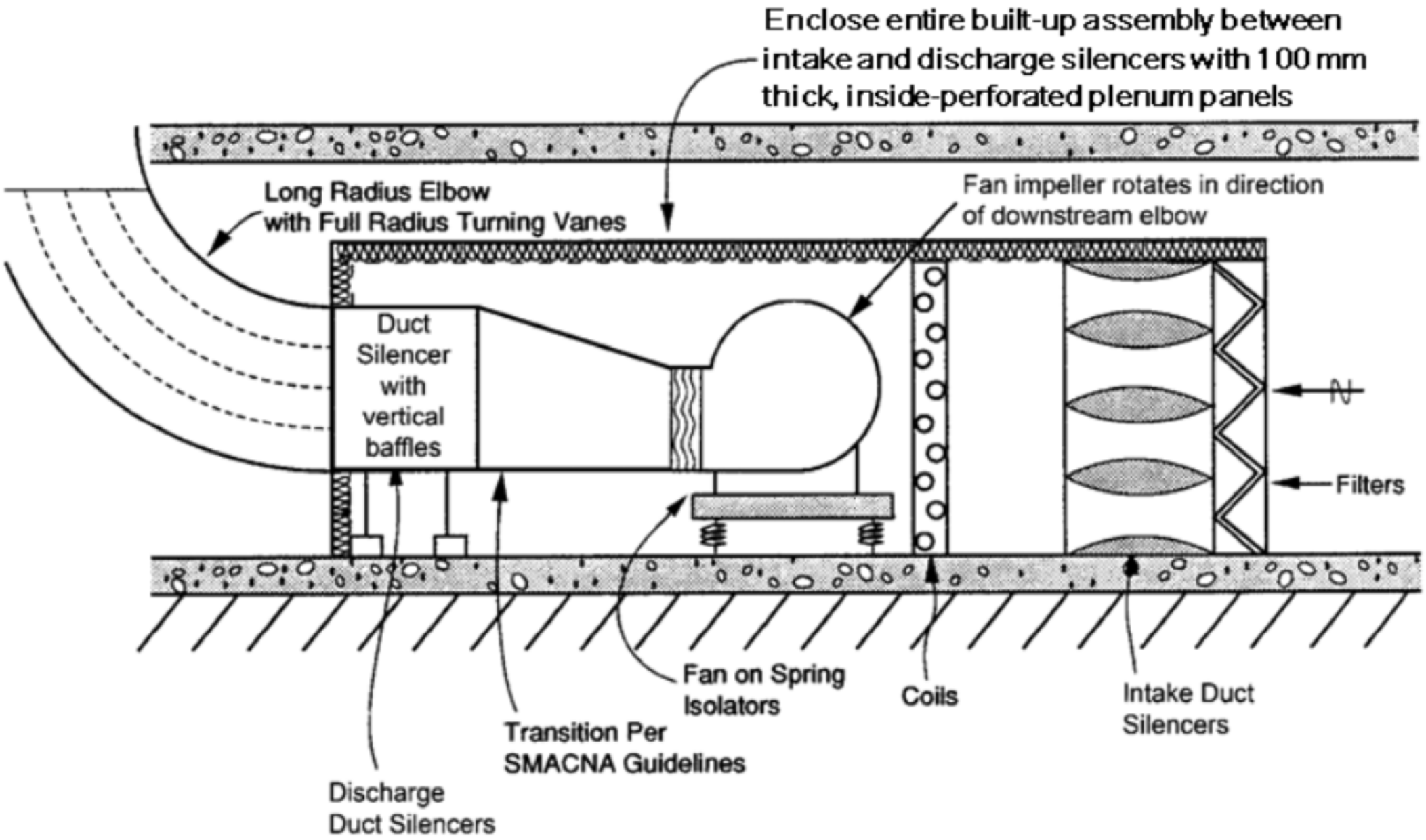
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Fan systems



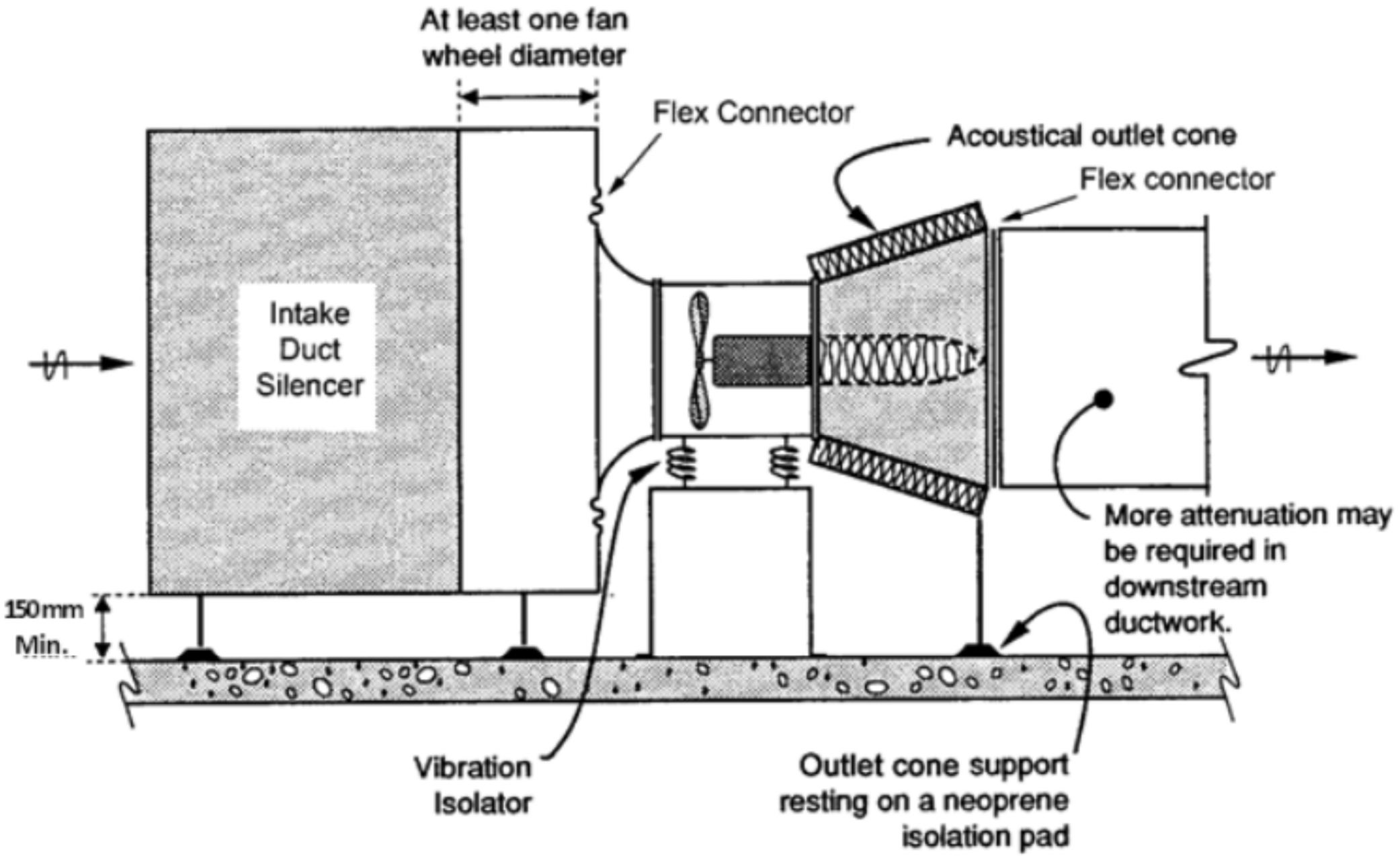
- Fans and air handling unit (AHU) rooms
  - The placement of the unit and ductwork in the room should allow smooth airflow from the return air openings to the AHU inlet
  - Smooth airflow for fan installation at the recommended velocity & pressure drop
  - Select the quietest fan equipment
  - Use of duct silencer and its arrangement
  - Vibration isolation for equipment & piping

Guidelines for a basement built-up fan system



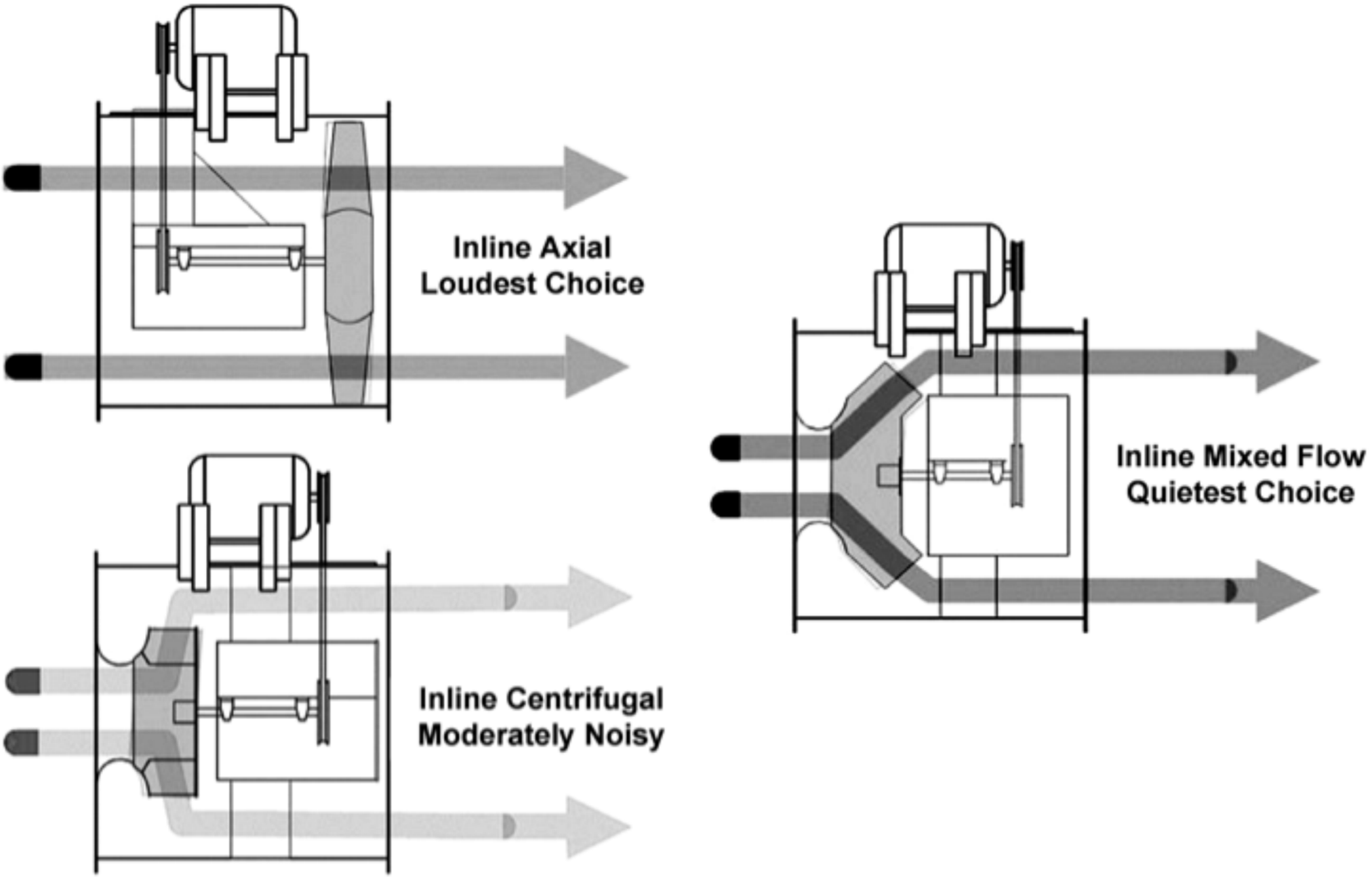
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Typical duct silencer arrangement at vane-axial fan



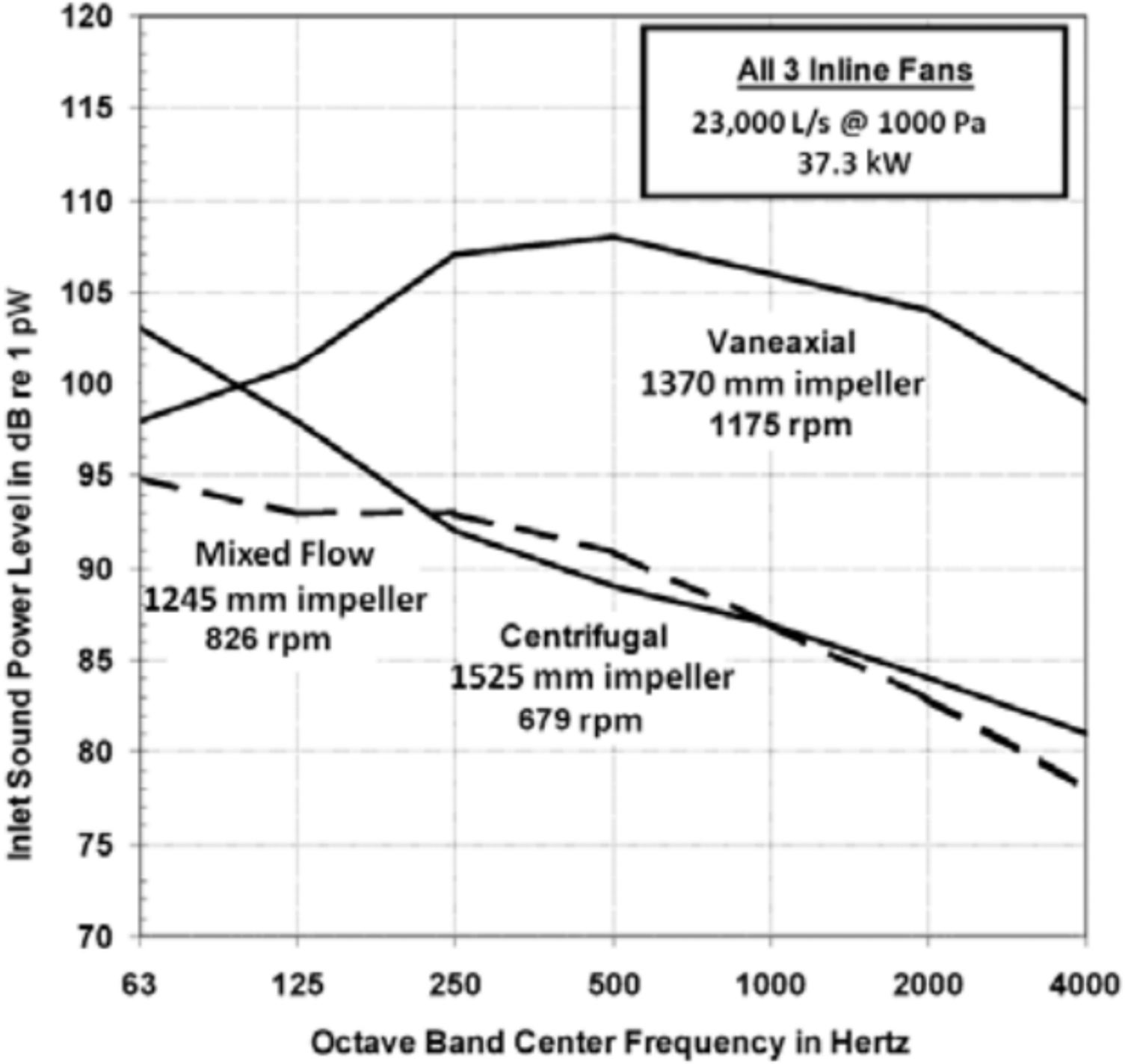
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Inline fan airflow patterns and impact on noise



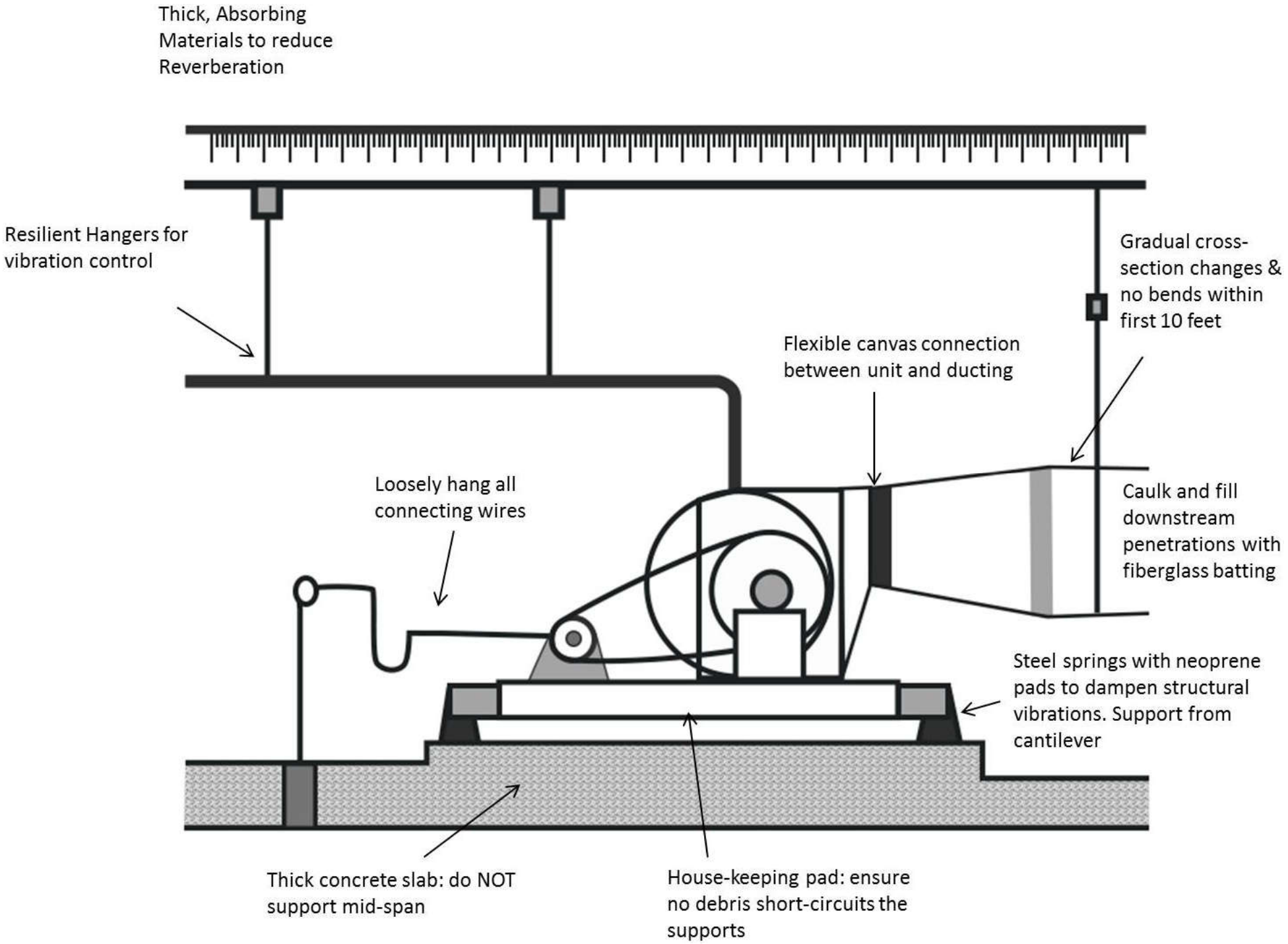
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Inline fan sound power level comparison



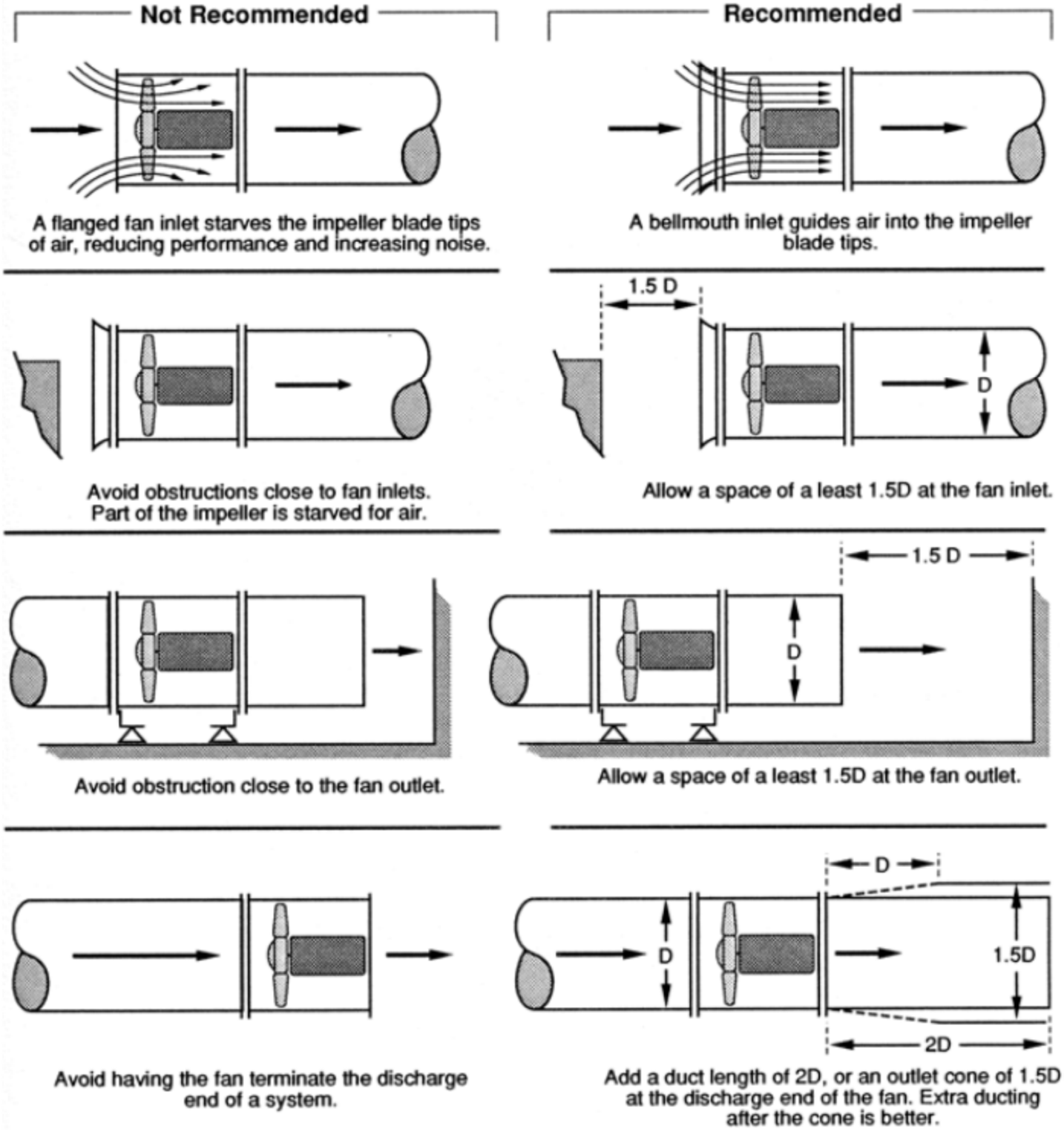
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Noise and vibration control for fan system



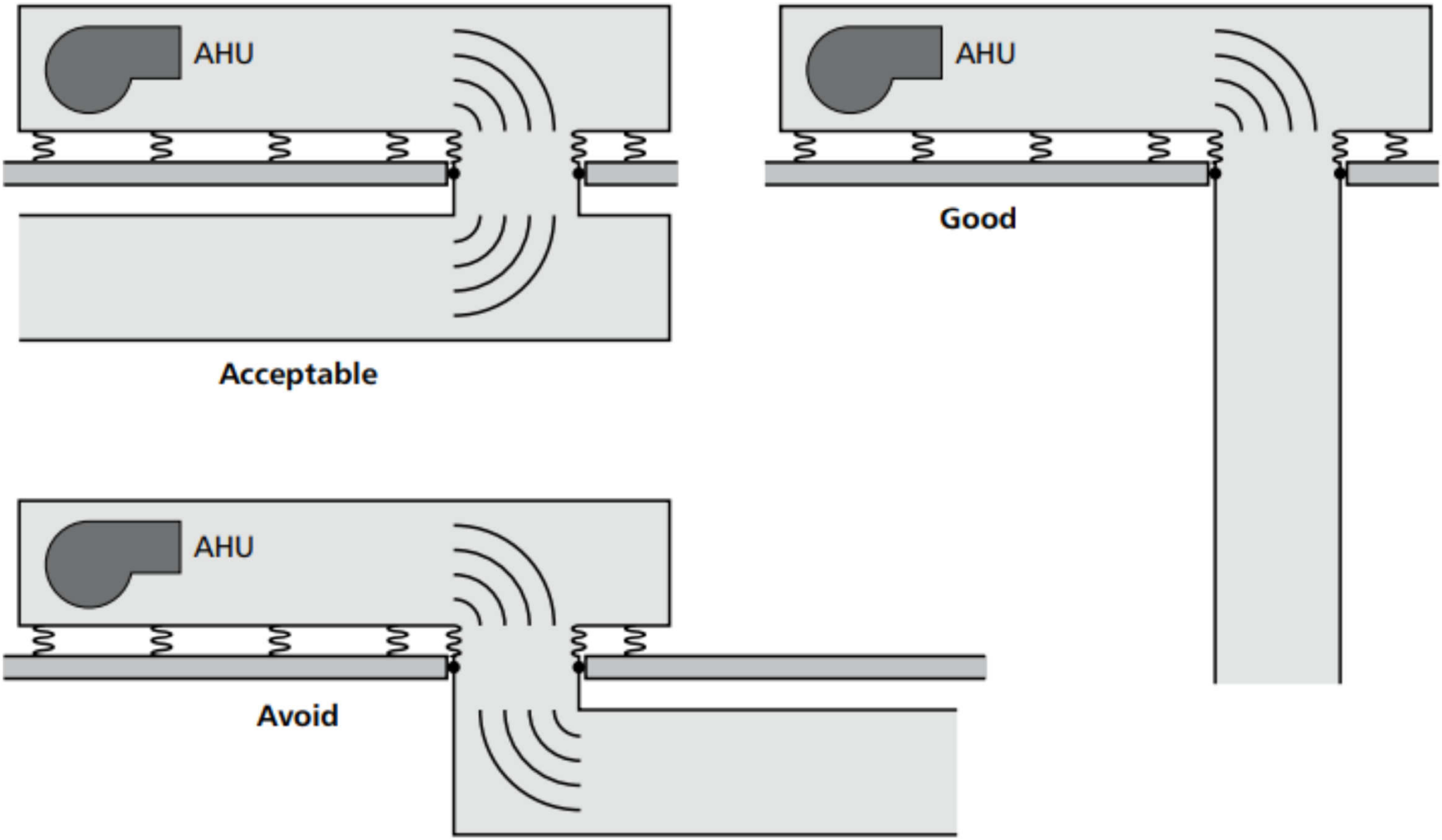
(Source: https://commercial-acoustics.com/treating-mechanical-noise/)

Guidelines for unducted axial flow fan installations



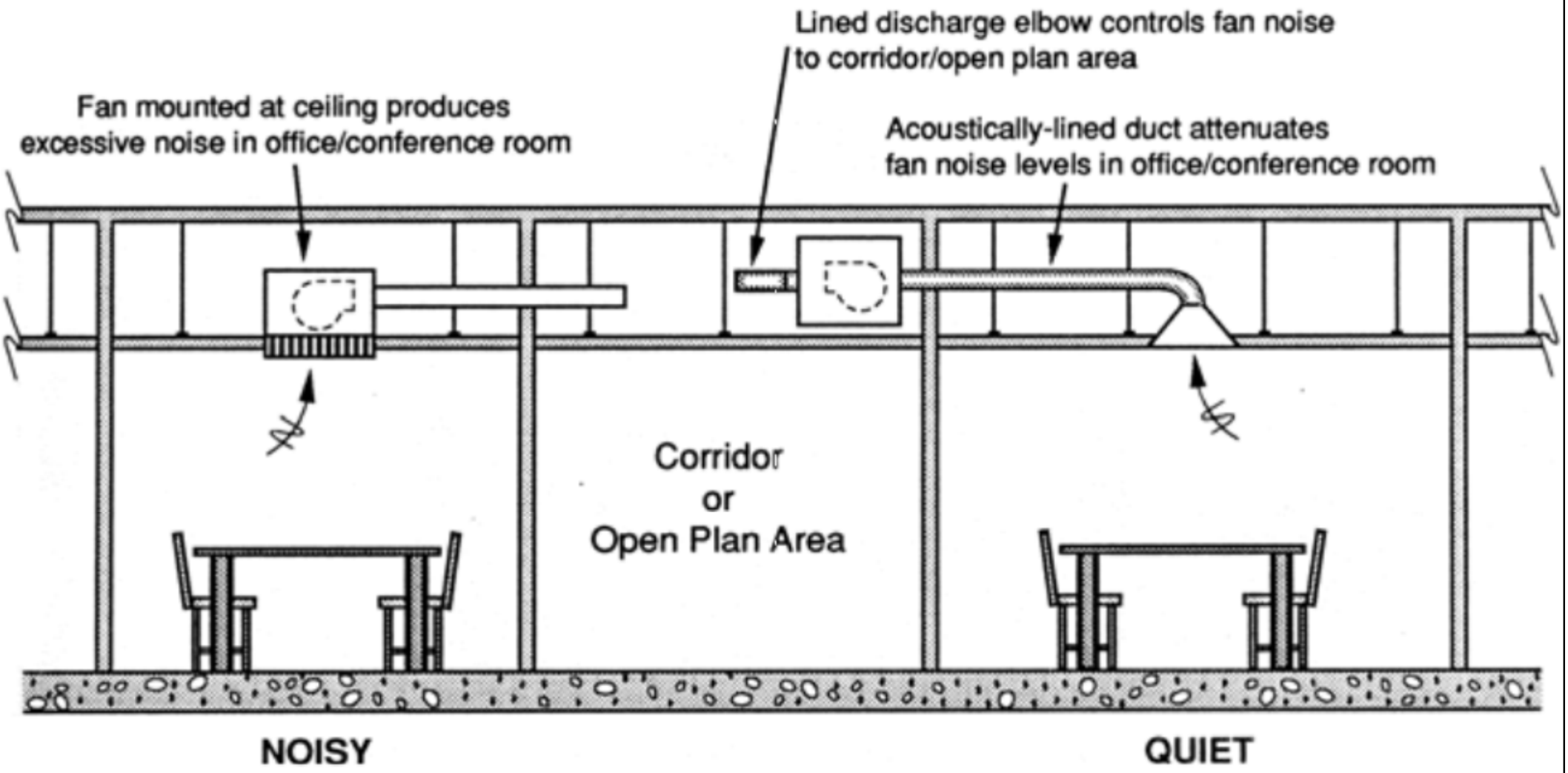
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Recommended arrangement of air handling units



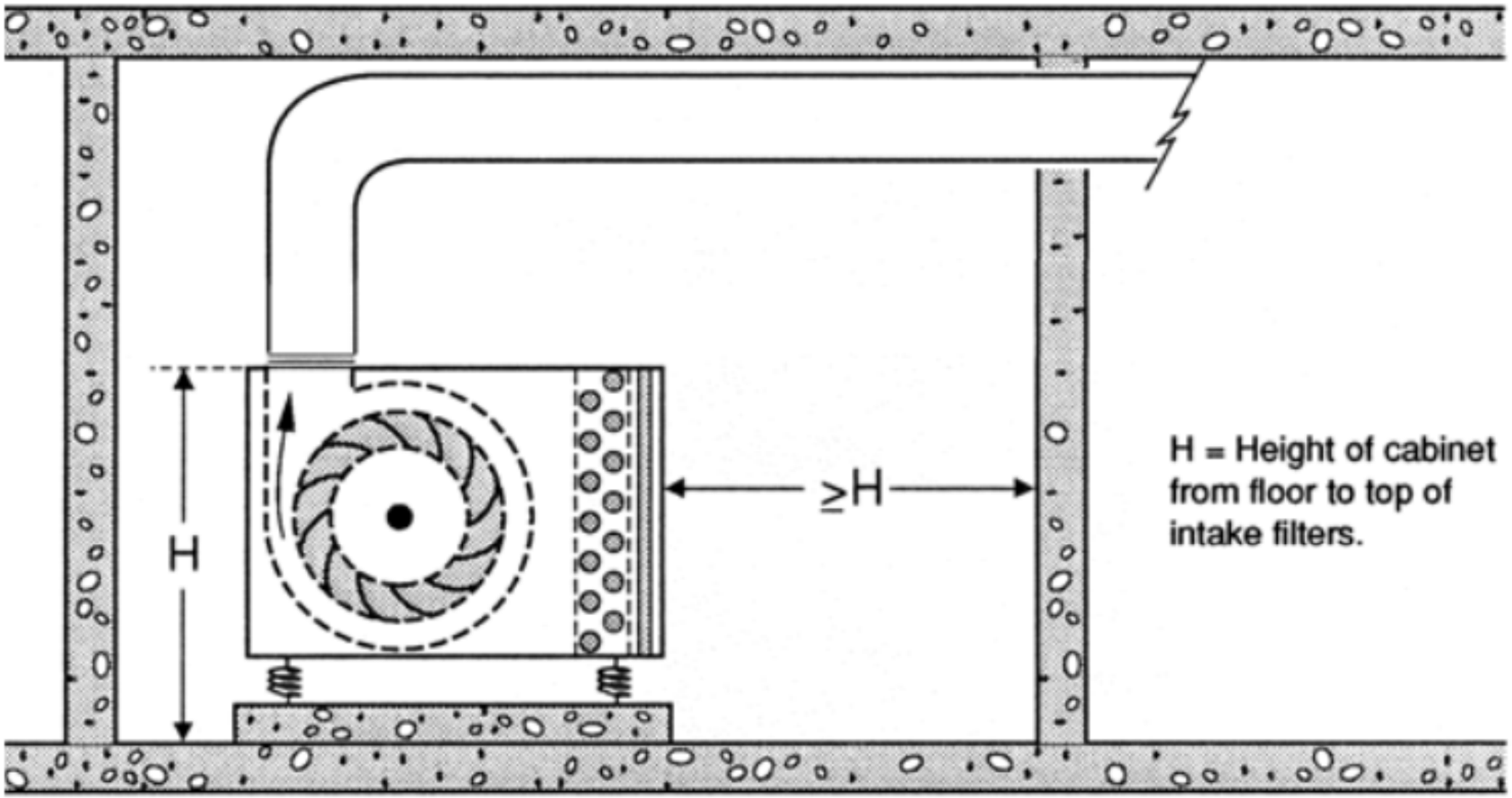
(Source: CIBSE, 2016. *Noise and Vibration Control for Building Services Systems, CIBSE Guide B4: 2016*, Chartered Institution of Building Services Engineers (CIBSE), London.)

Noisy and quiet installations of ceiling-mounted exhaust fans



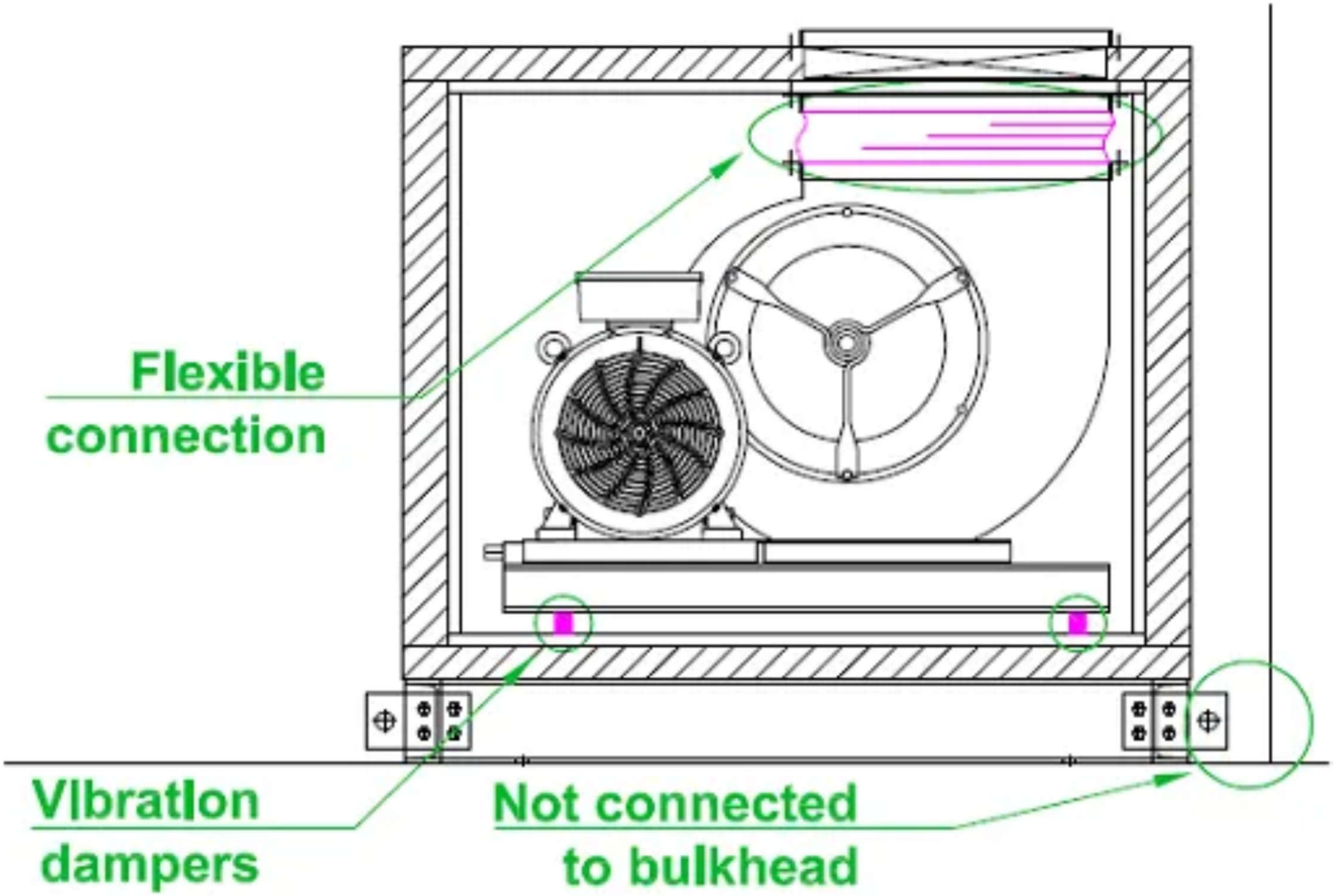
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Minimum clearance at air handling unit (AHU) and cabinet fan inlet



(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

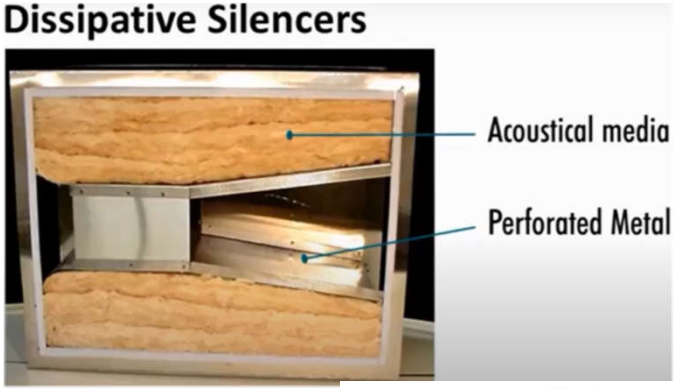
Flexible arrangement of fan for noise and vibration control

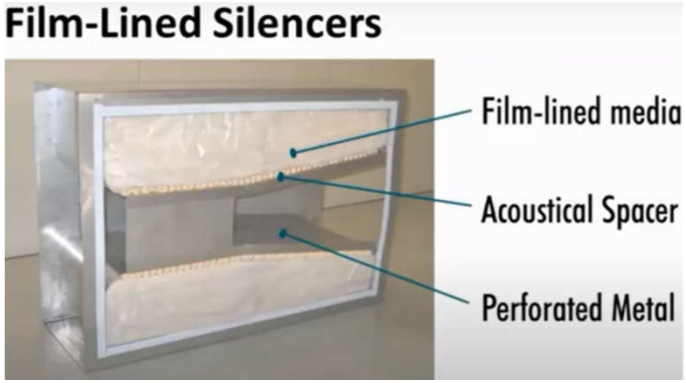


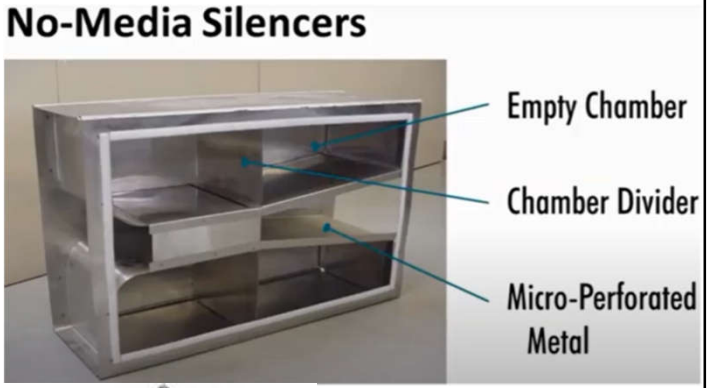
(Source: http://www.heinenhopman.com/noise-control-part-4-reduce-hvac-noise-issues/)

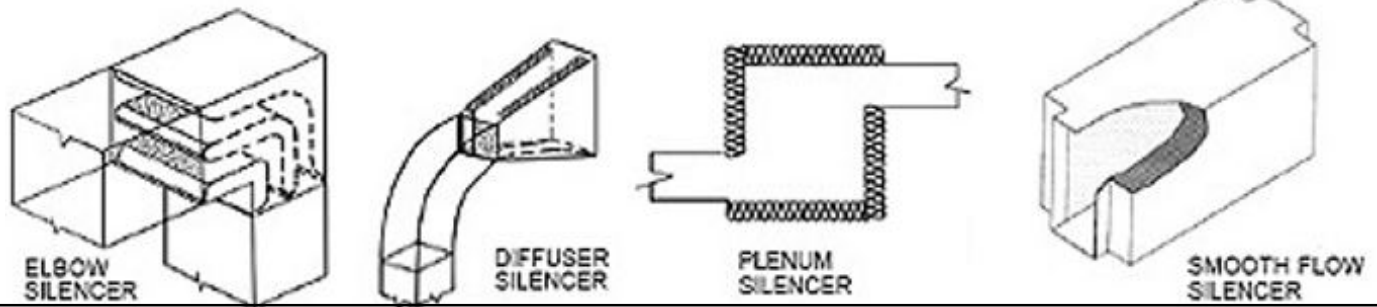
Fan systems

- Types of silencers
  - 1. Dissipative (standard, with media)
  - 2. Film-lined (encapsulated, wrapped, bagged fill)
  - 3. No-media (reactive, packless)

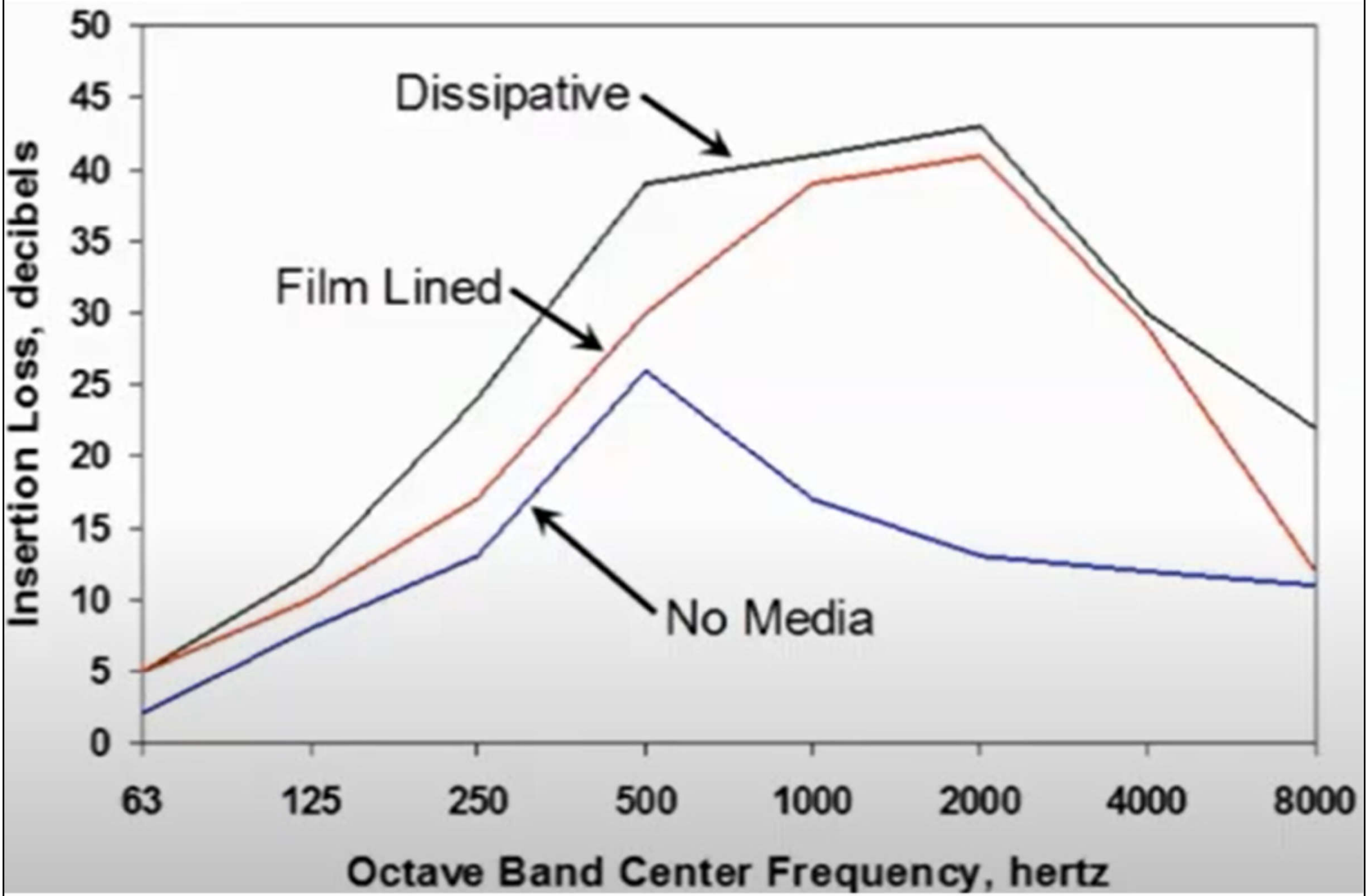








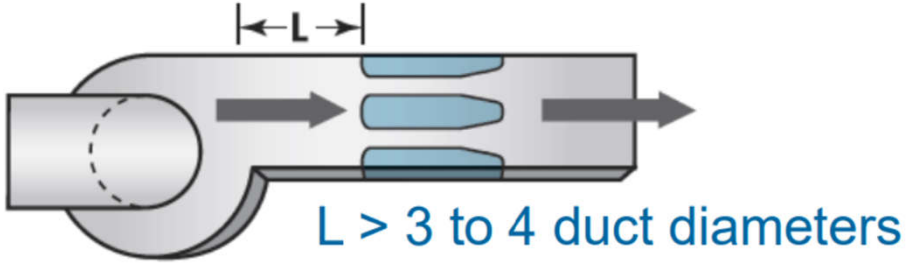
Comparison of different types of silencers

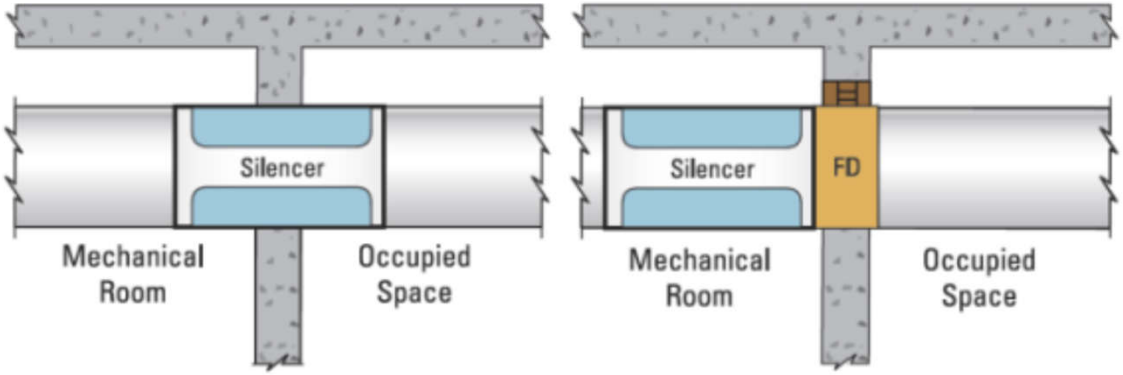


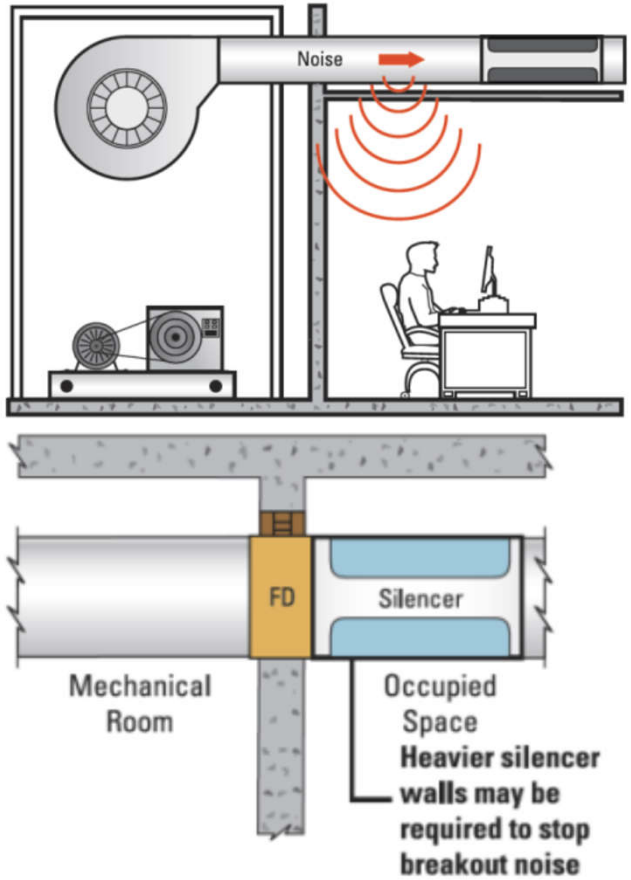
(Source: Air Equipment LLC)

Fan systems

- Silencer positioning
  - For low regenerated noise and low pressure drop
  - To minimise breakout noise

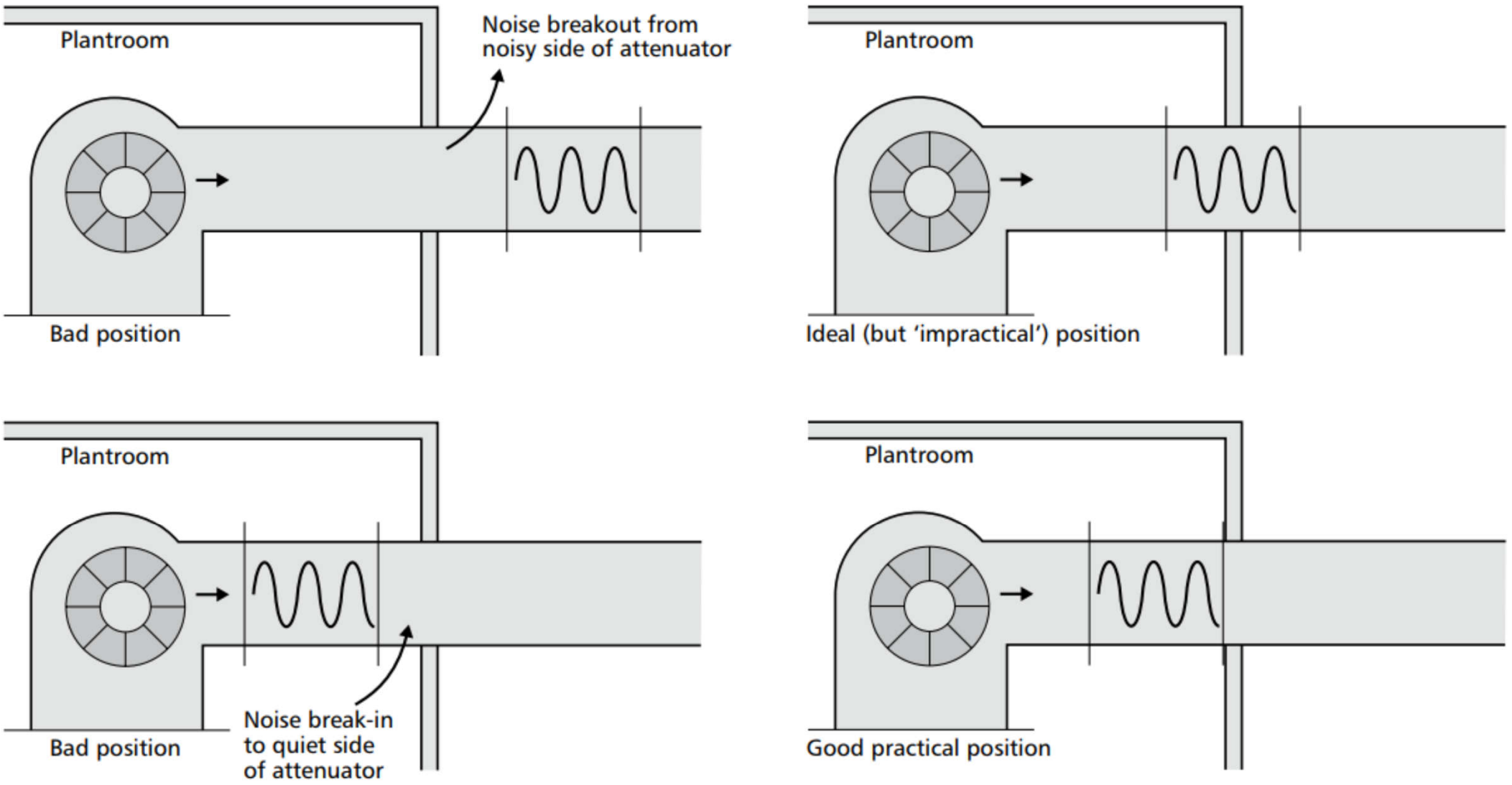






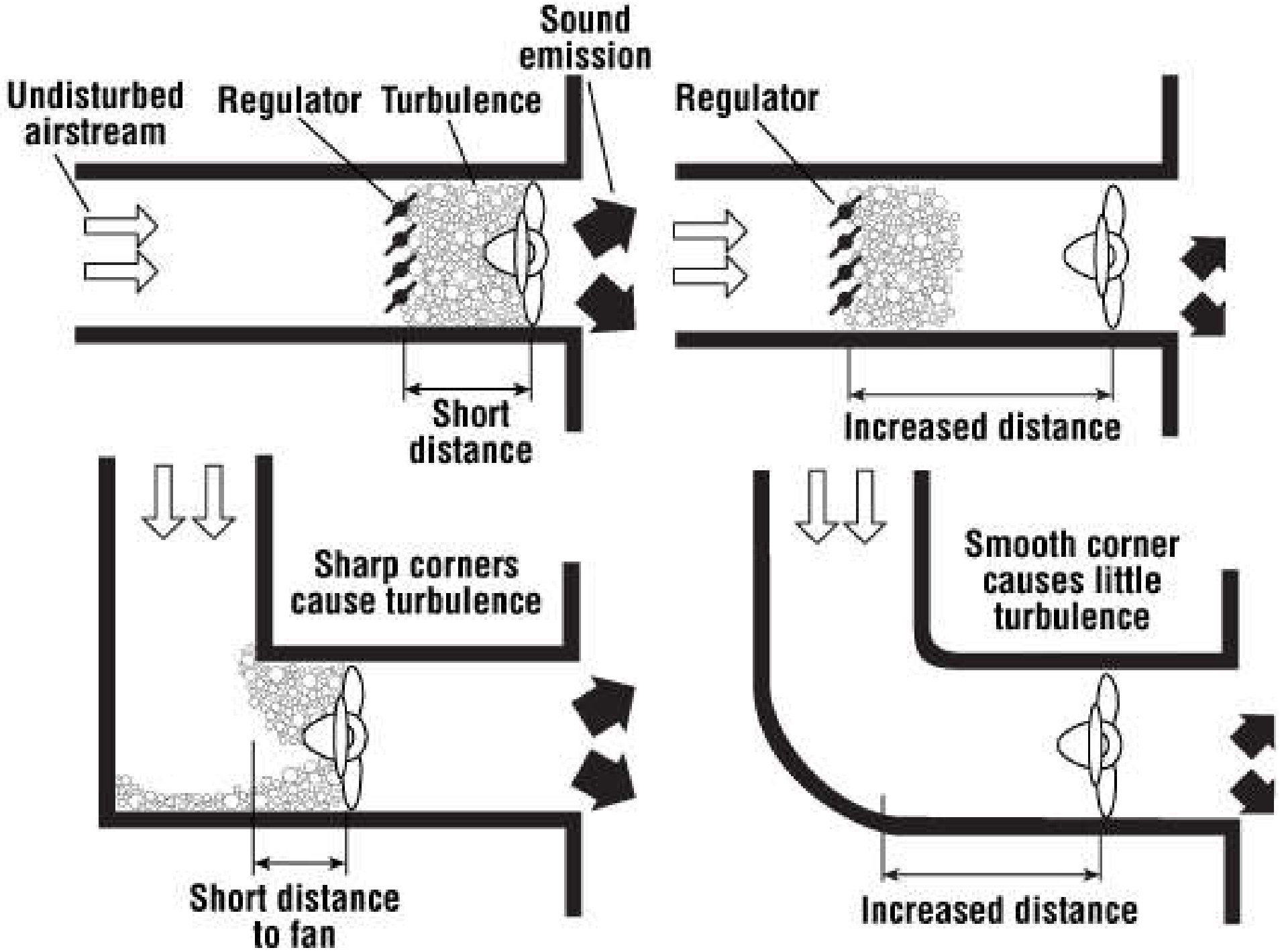
(Source: Price Industries)

Correct positioning of a silencer in a plant room



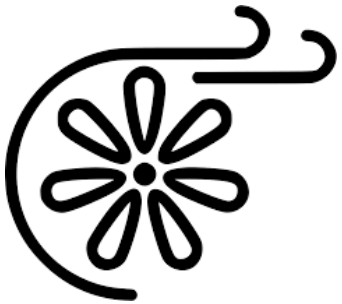
(Source: CIBSE, 2016. *Noise and Vibration Control for Building Services Systems, CIBSE Guide B4: 2016*, Chartered Institution of Building Services Engineers (CIBSE), London.)

How to avoid turbulence in a fan-duct system



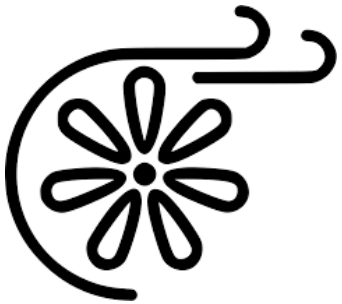
(Source: https://www.ccohs.ca/oshanswers/phys_agents/noise_control.html)

Fan systems



- Fan noise calculation (room side)
  - Methodology (for each octave band)
    - Start with the fan sound power level, L_w and correct this for attenuations along the ductwork and into the room
      - Attenuation of straight duct
      - Reflections at bends
      - Attenuation at branches
      - Reflections from the end of the duct
  - L_w at the diffuser = Fan L_w – attenuations
    - L_p at a position in the room depends on L_w at diffuser and the effect of distance (diffuser to position) and room absorption

Fan systems



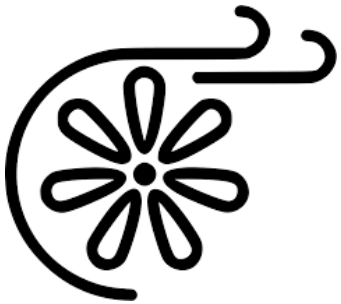
- Regenerated noise (self noise)
  - Note that in high velocity systems there will be secondary noise sources at bends and dampers within the ductwork
  - These will need to be considered separately and the appropriate attenuations applied from where they occur within the ductwork to the room as before
  - The levels in the room from the secondary sources must be added to that from the fan to obtain the overall level in the room

Corrections for the octave band levels

Sound path (s)	Speed range r/min	Correction Kokt, dB								$L_{WA(s)} - L_{WA}$ dB	$L_{Wt(s)} - L_{WA(s)}$ dB
		Octave band, mid-frequency, Hz									
		63	125	250	500	1 000	2 000	4 000	8 000		
To outlet duct (1)	0 – 1000	-2	2	-2	-3	-6	-7	-11	-15	0	5,9
To inlet duct (2)	0 – 1000	1	-2	-3	-4	-2	-7	-9	-15	1,3	7,1
Through the casing (3)	0 – 1000	-14	-7	-5	-4	-6	-9	-18	-25	-1,7	3,0
To fan outlet (open-discharge fan) (4)	0 – 1000	-14	-2	-4	-3	-6	-7	-11	-15	-0,2	3,5

(Source: https://slideplayer.com/slide/14449393/)

Fan systems

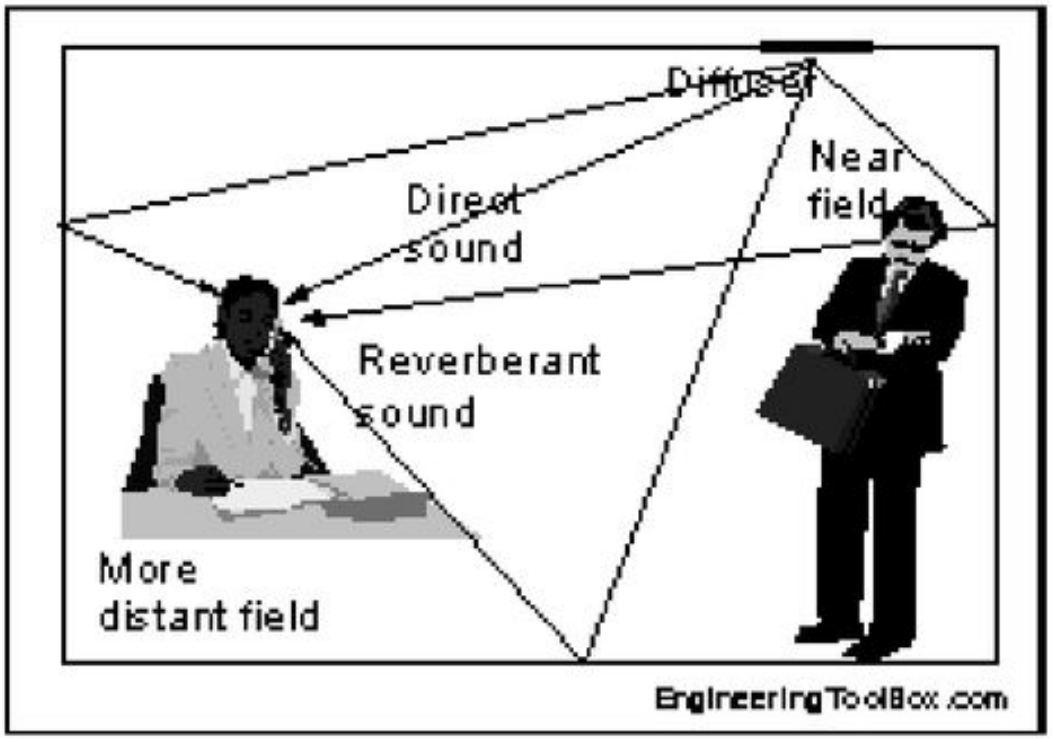


- Attenuation of sound power level (SPL)
  - Straight duct (energy removed to support duct wall vibration)
  - Bends (certain frequencies are reflected back at bends)
  - Plenum chambers / changes in cross section (sound is reflected if the cross section changes abruptly)
  - Branches (sound power is shared if the duct splits into branches)
  - End reflection (due to impedance mismatch)

Sound pressure level (SPL or *Lp*) in the room

- Sound Power Level, L_w at the diffuser is the fan L_w minus the attenuations plus any regen noise.

$$Lp = Lw + 10\lg\left[\frac{Q}{4\pi r^2} + \frac{4}{R_c}\right]$$



- Q = geometric directivity 2, 4, or 8
- R_c = room constant (m^2)
- r = distance (diffuser to position)
  usually 1m for the worst position (closest to the diffuser)

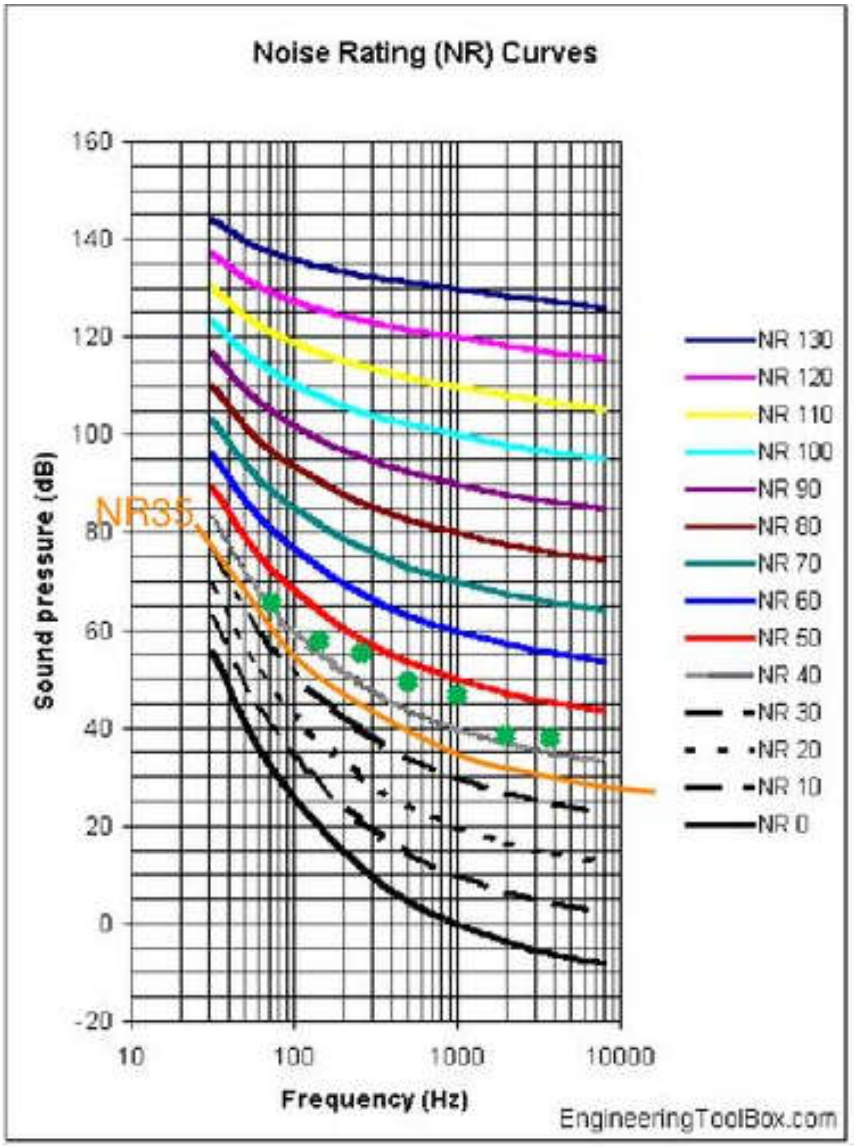
(Source: https://slideplayer.com/slide/14449393/)

Checking with NR or NC curves

- Plot the octave band room Lp's on NR curves to find the attenuation required.
- The difference between the Lp's and the target NR gives the additional attenuation required
- Say target is NR35

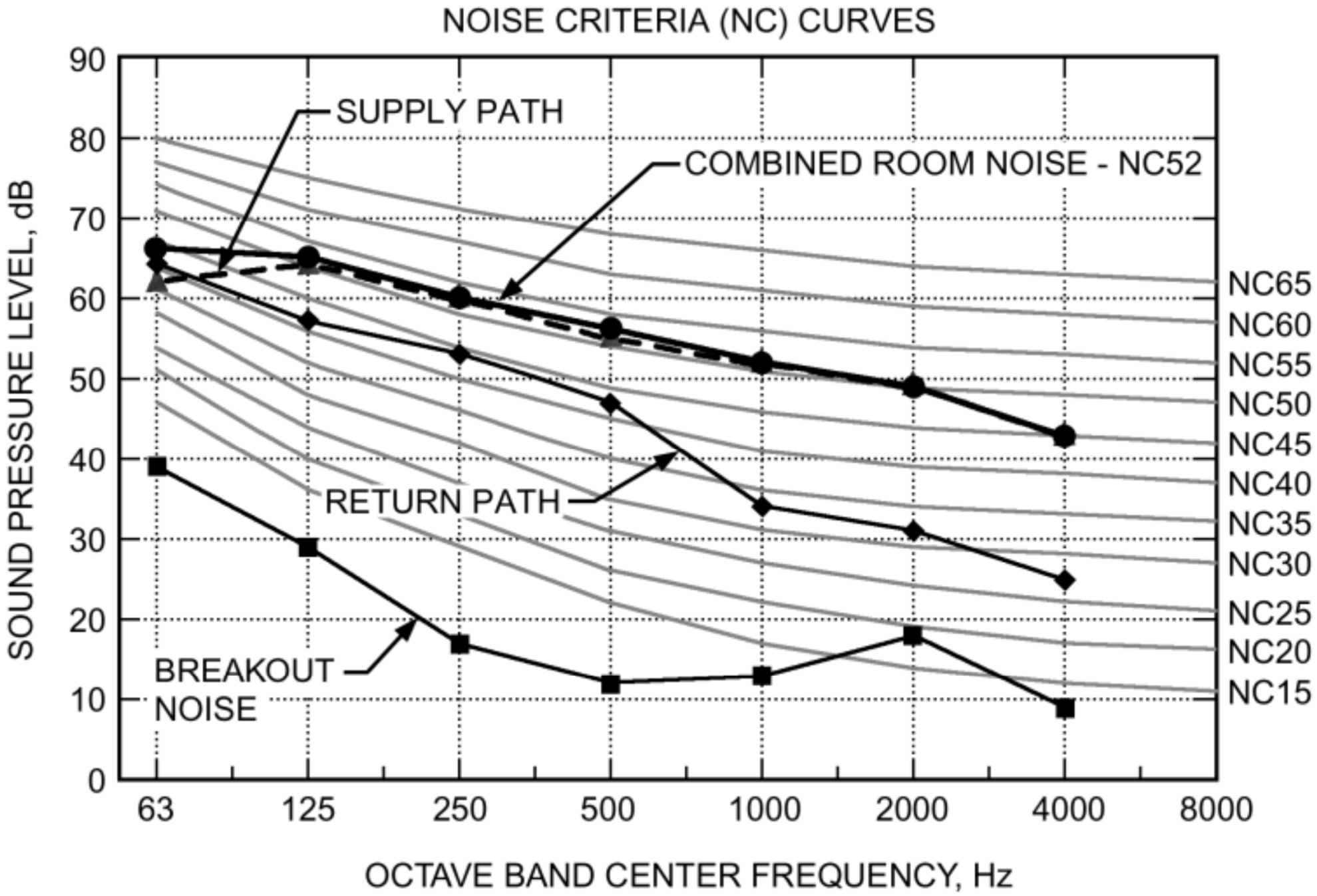
Example

	63	125	250	500	1k	2k	4k
NR35	64	53	45	38	35	32	30
Calculated	65	58	56	49	48	39	38
Atten. R'qd	1	5	11	11	13	7	8



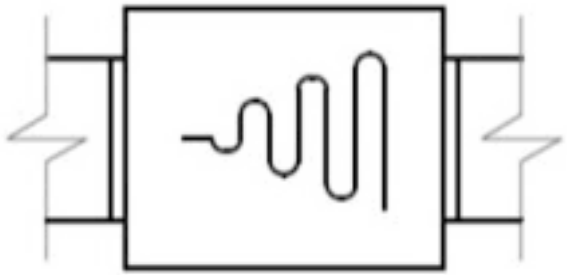
(Source: https://slideplayer.com/slide/14449393/)

Combined room noise NC rating calculated for supply path, return path and breakout noise



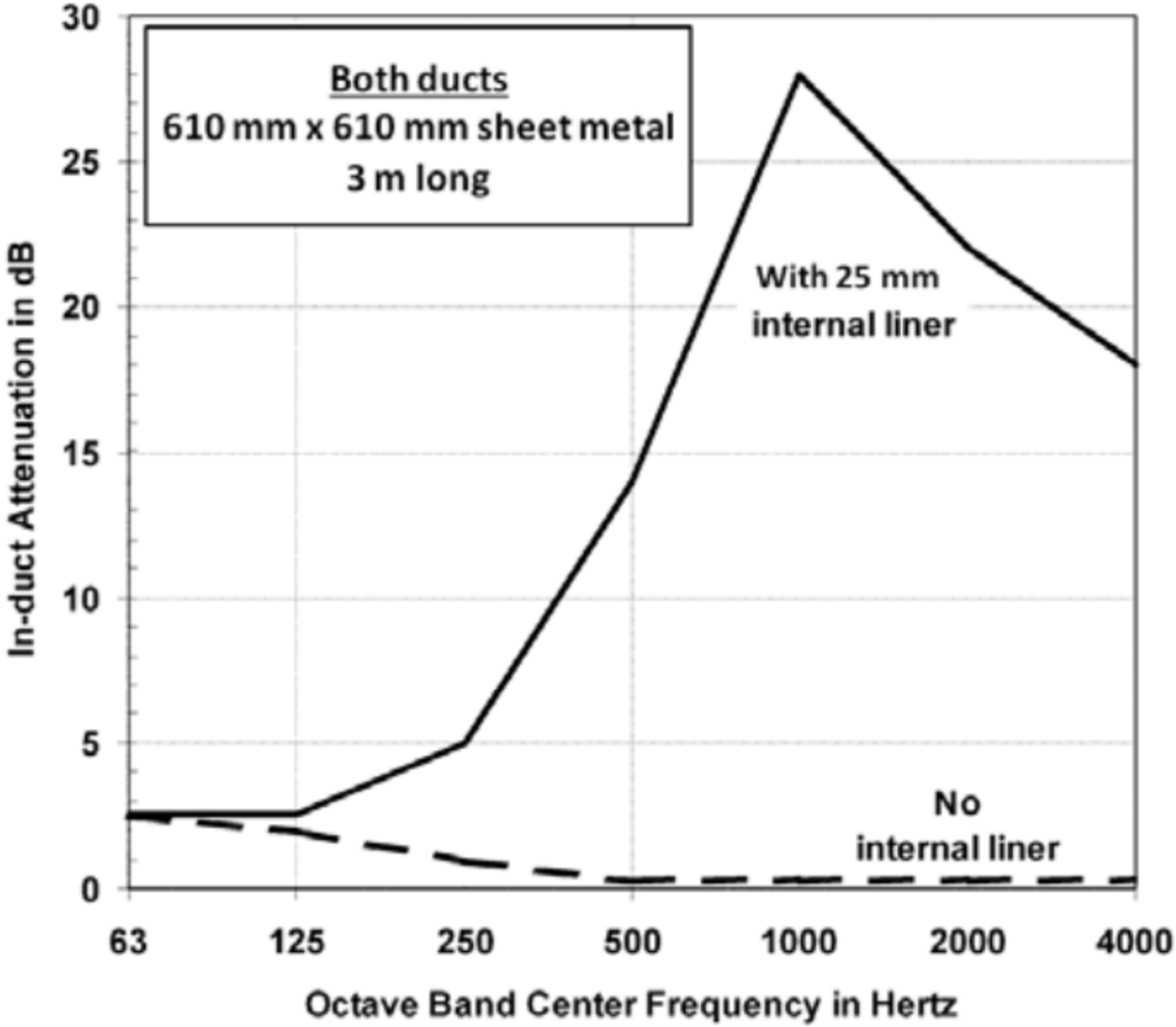
(Source: ASHRAE, 2019. *ASHRAE HVAC Applications Handbook 2020*, SI edition, Chp. 49 Sound and Vibration Control)

Ductwork noise



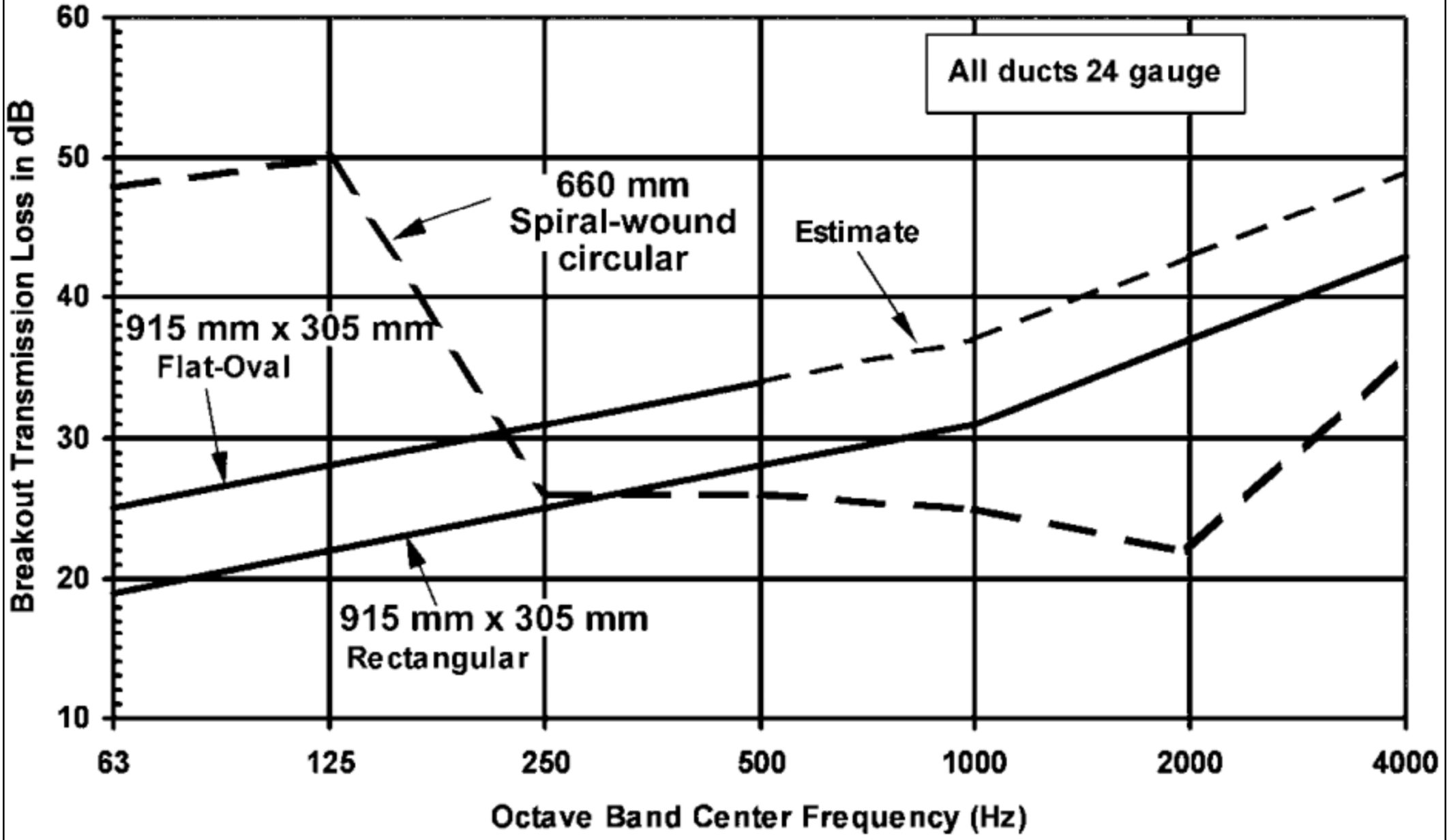
- Noise through ductwork
  - Noise travelling through the ductwork
  - Noise breaking out from the ductwork
  - Airflow noise through grills or diffusers
- Air velocity within a duct system influences the noise levels significantly
  - Regenerated noise can be created by transition pieces, bends, dampers, grilles and diffusers Regenerated noise can be avoided by limiting the air velocities within the duct system

Attenuation for lined and unlined sheet metal ductwork



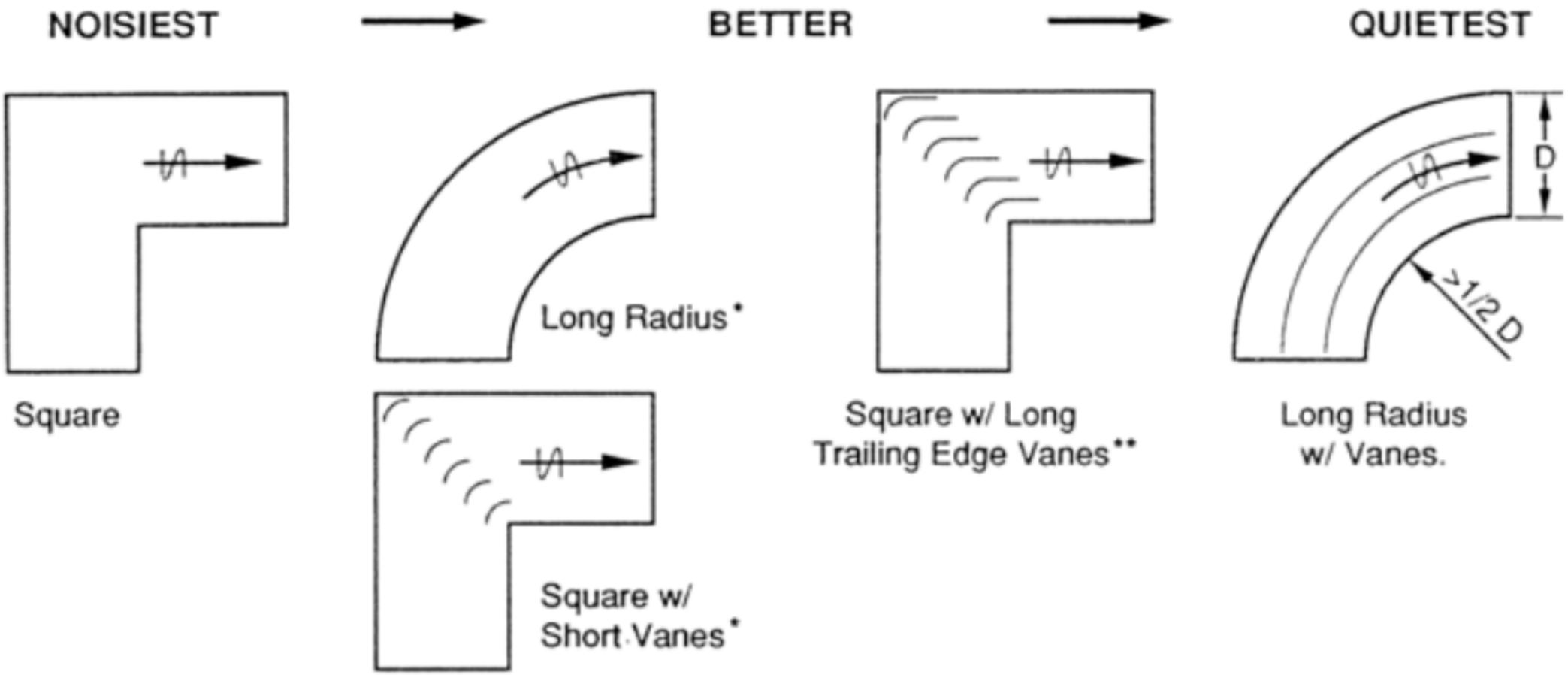
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Breakout transmission loss for three types of sheet metal ductwork



(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Guidelines for minimizing regenerated noise in elbows

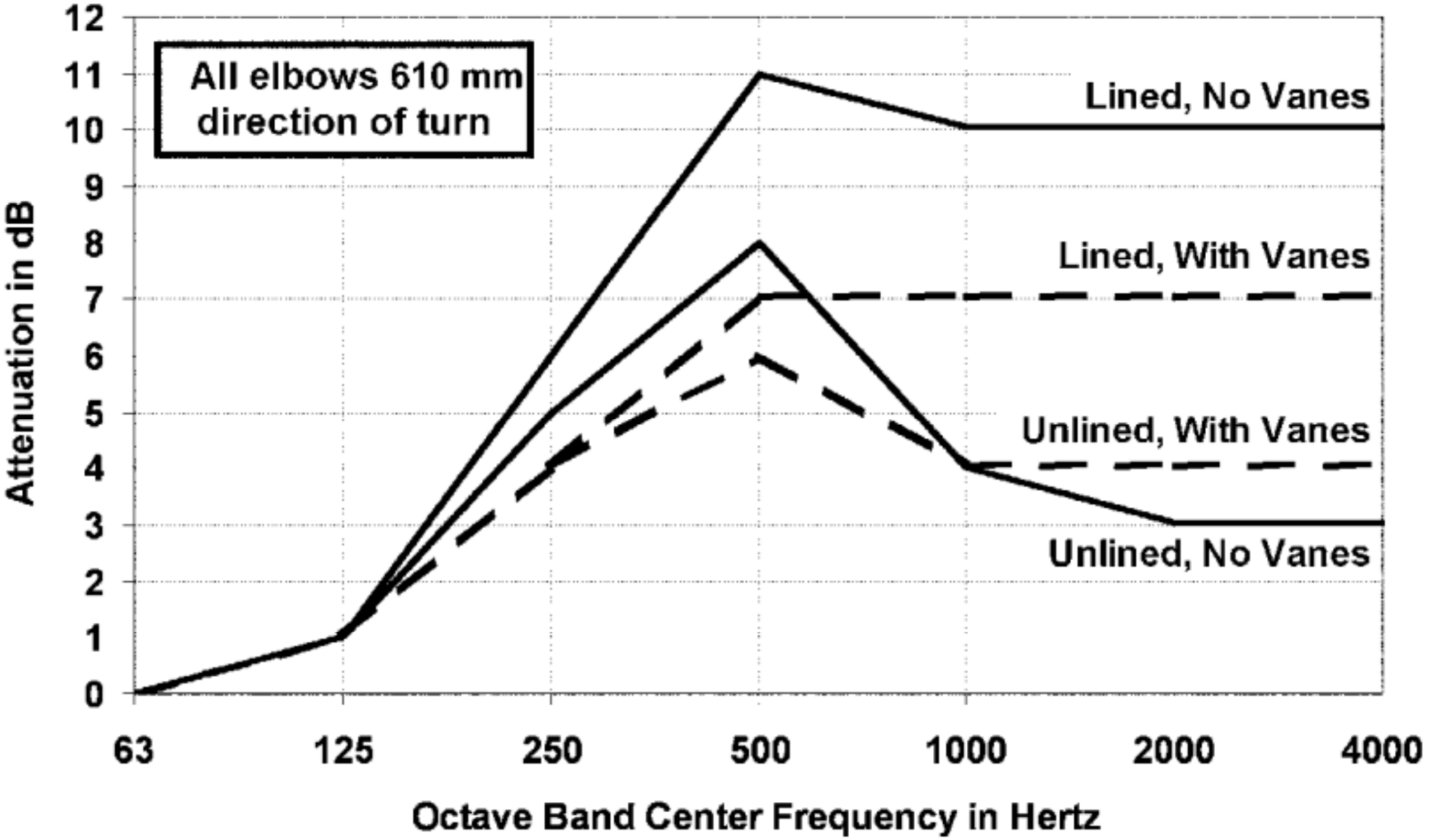


* Airflow velocity and proximity of upstream and downstream fittings and fans determine which type is preferable.

** Trailing edge length should be at least 3 times the vane spacing.

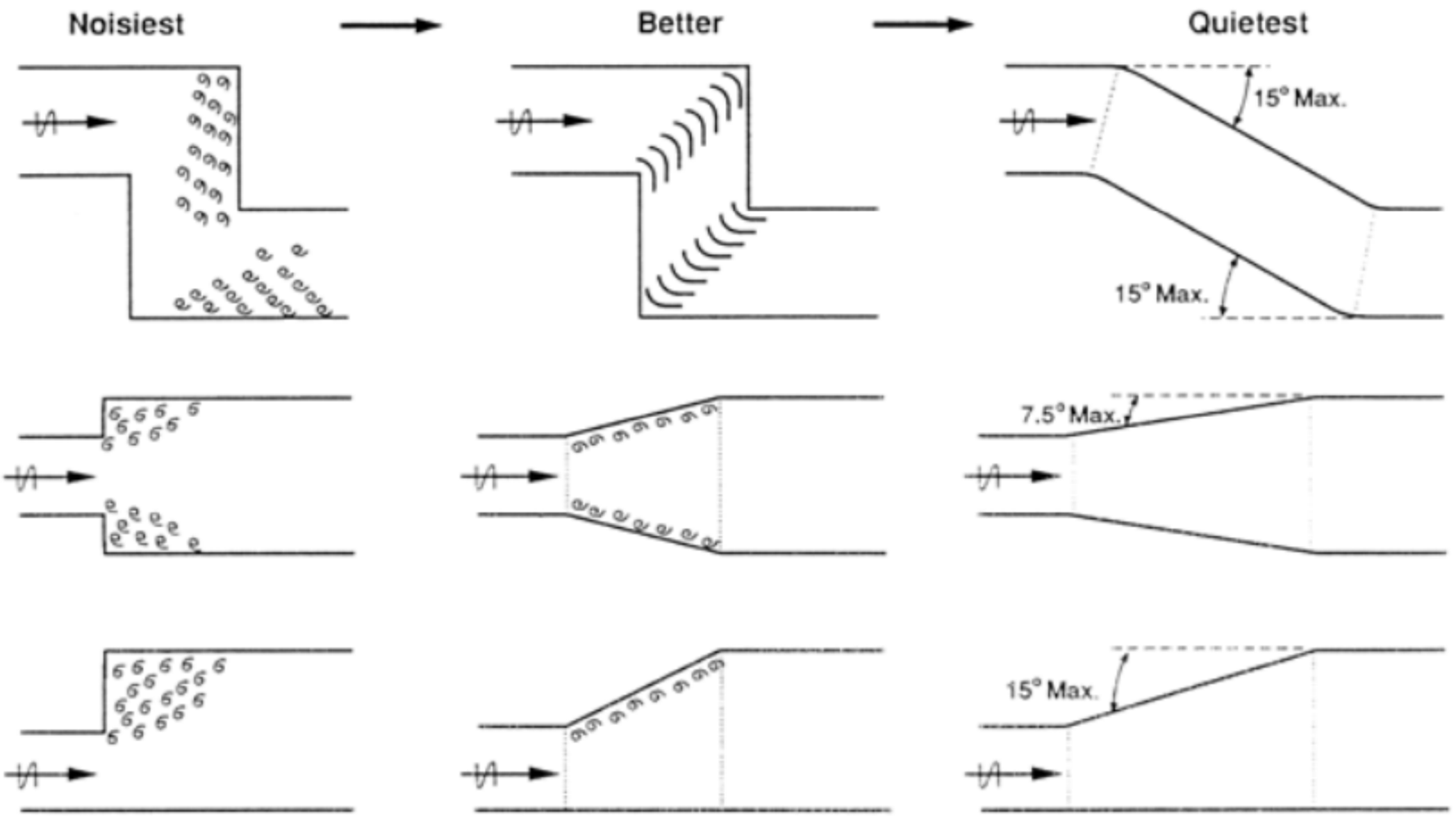
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Attenuation of rectangular elbows with and without turning vanes (lined and unlined)



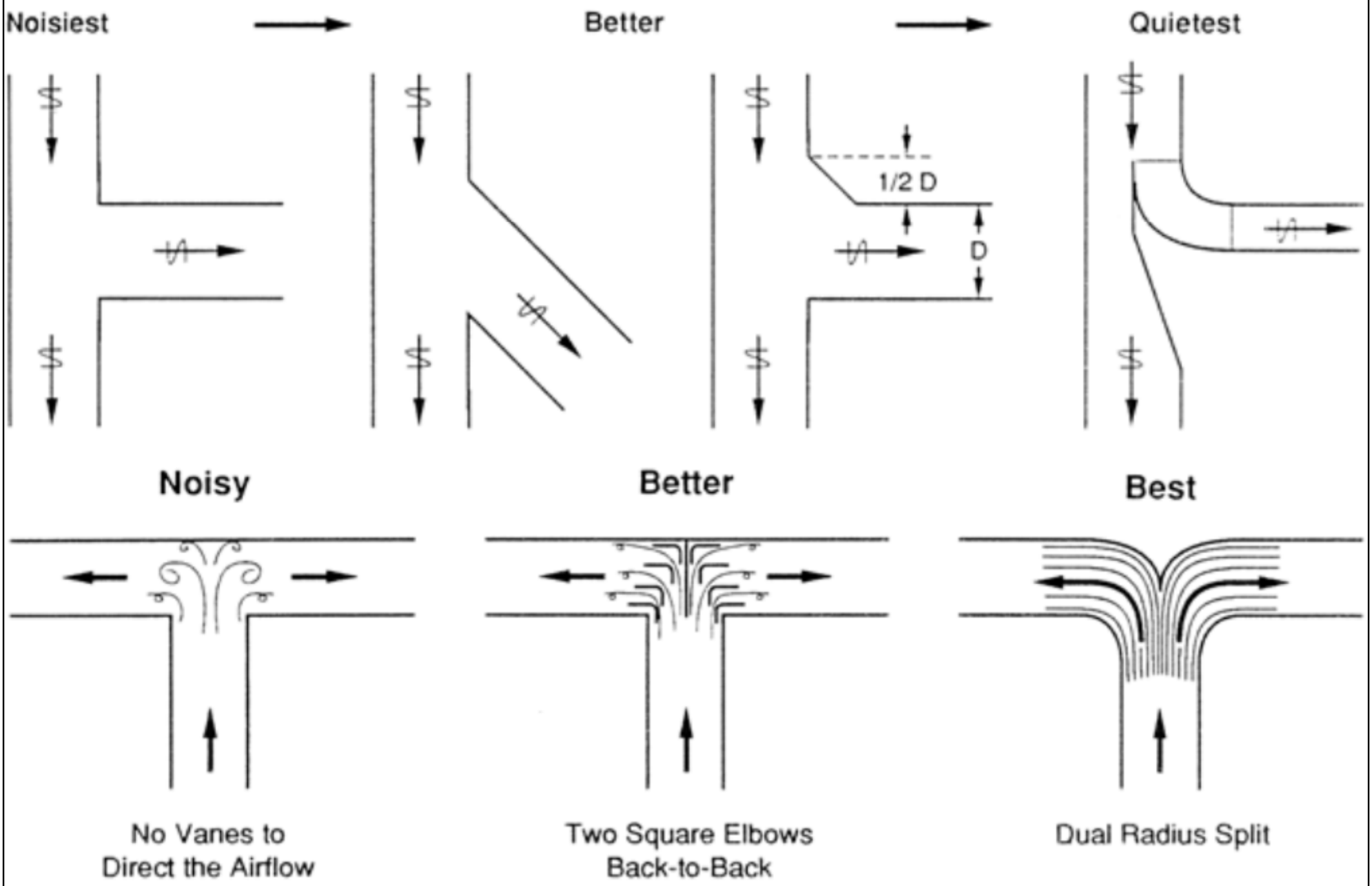
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Guidelines for minimizing regenerated noise in transitions and offsets



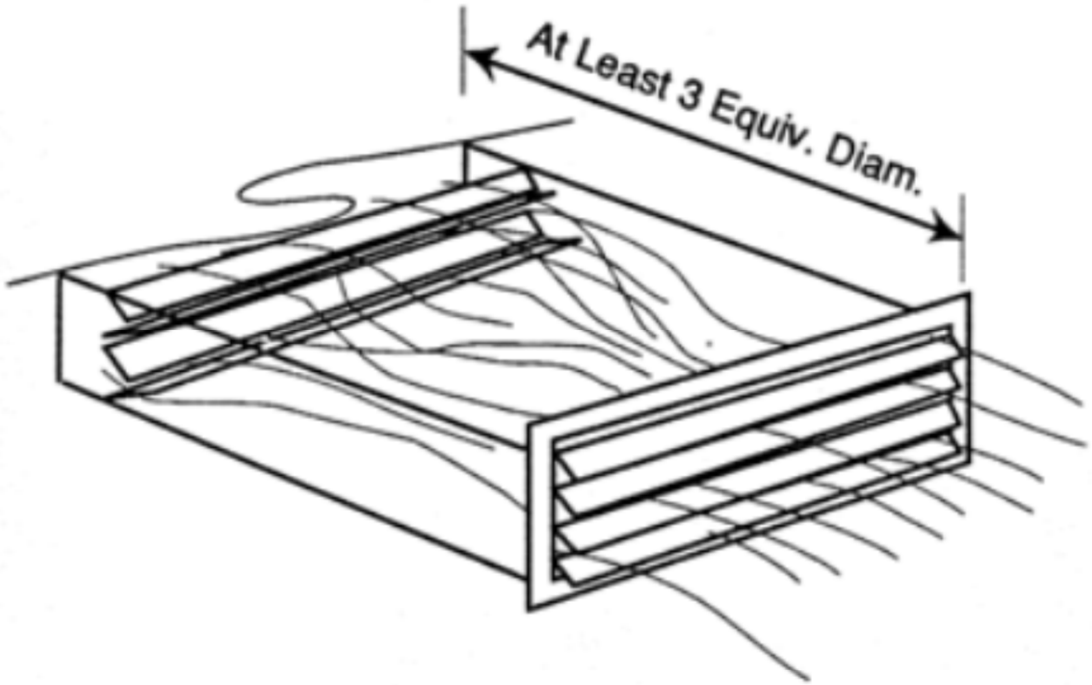
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Guidelines for minimizing regenerated noise in takeoffs and duct tees

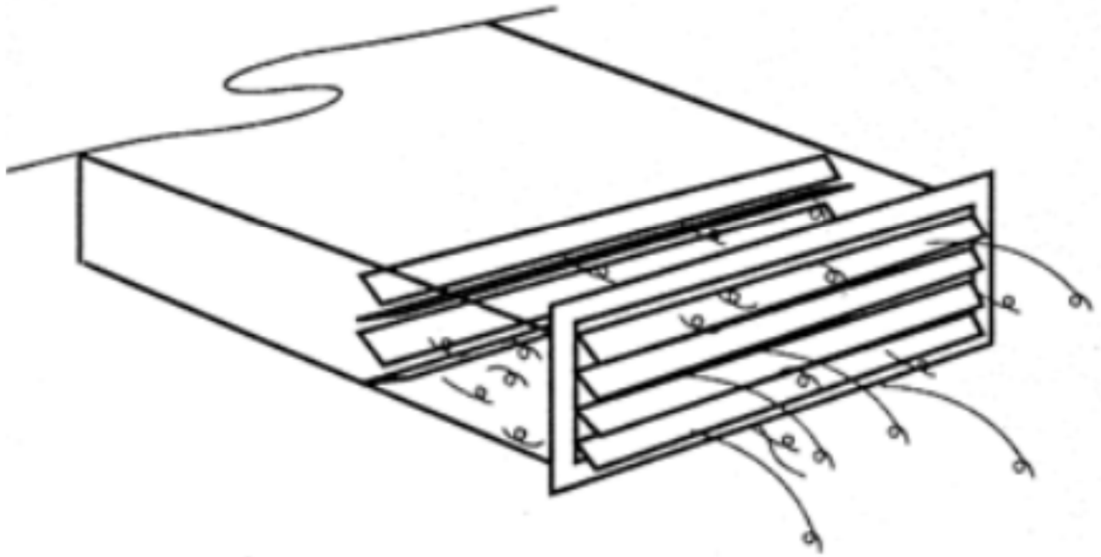


(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

The effect of installing a damper behind a grille



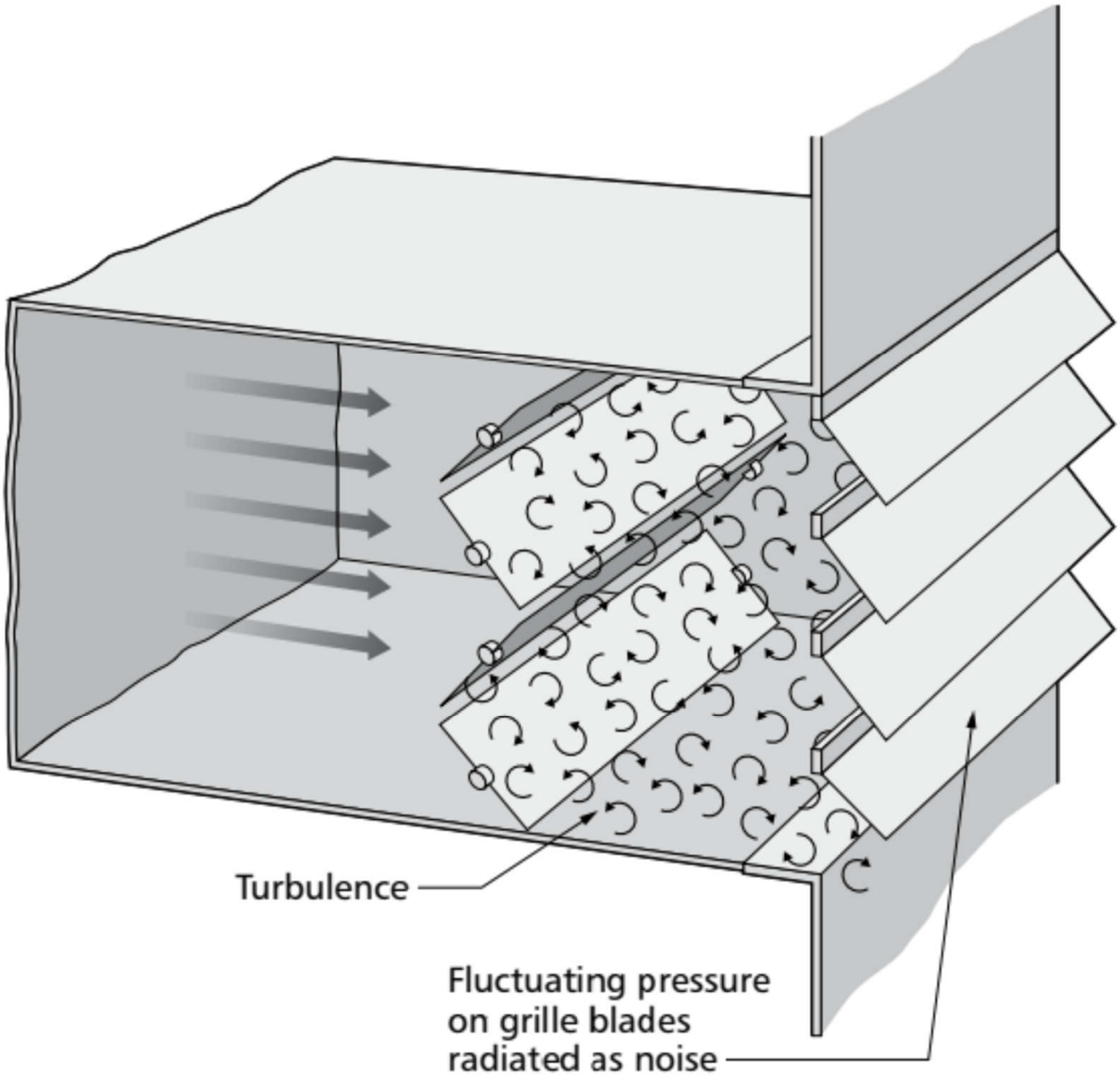
Without damper or with damper at least 3 equivalent duct diameters upstream manufacturer's grille noise data is valid for design purposes



A damper within 3 equivalent duct diametersof a grill increases the noise – up to 5dB if the damper is wide open, as much as 15–40dB if the damper is half closed

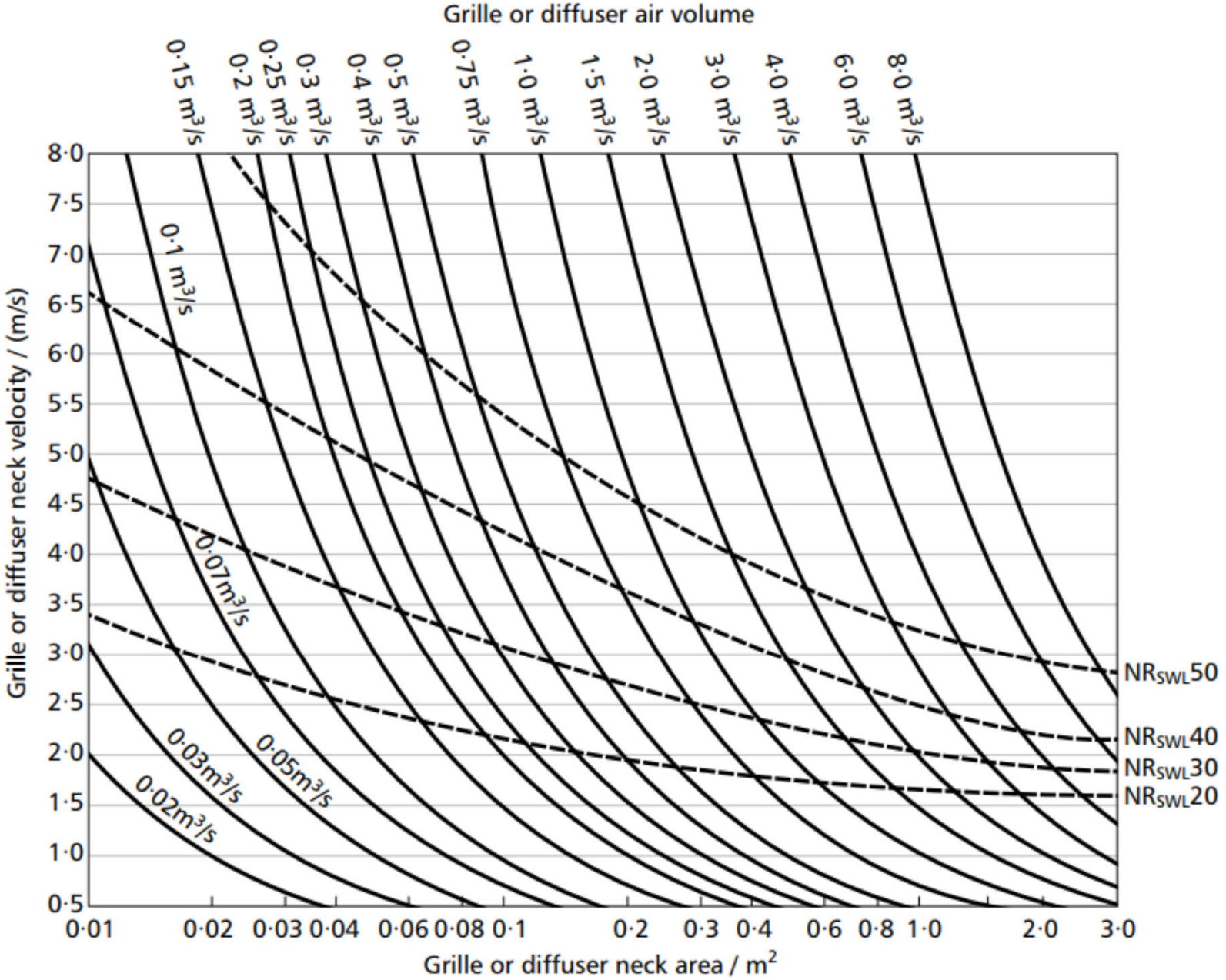
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Noise generated by damper/grille combination



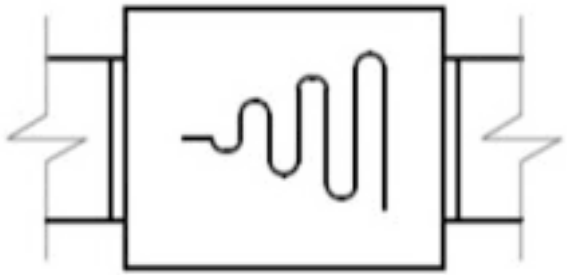
(Source: CIBSE, 2016. *Noise and Vibration Control for Building Services Systems, CIBSE Guide B4: 2016*, Chartered Institution of Building Services Engineers (CIBSE), London.)

Grille or diffuser noise levels plotted as a function of (a) air velocity in the diffuser neck, (b) area of diffuser neck, (c) volume through diffuser



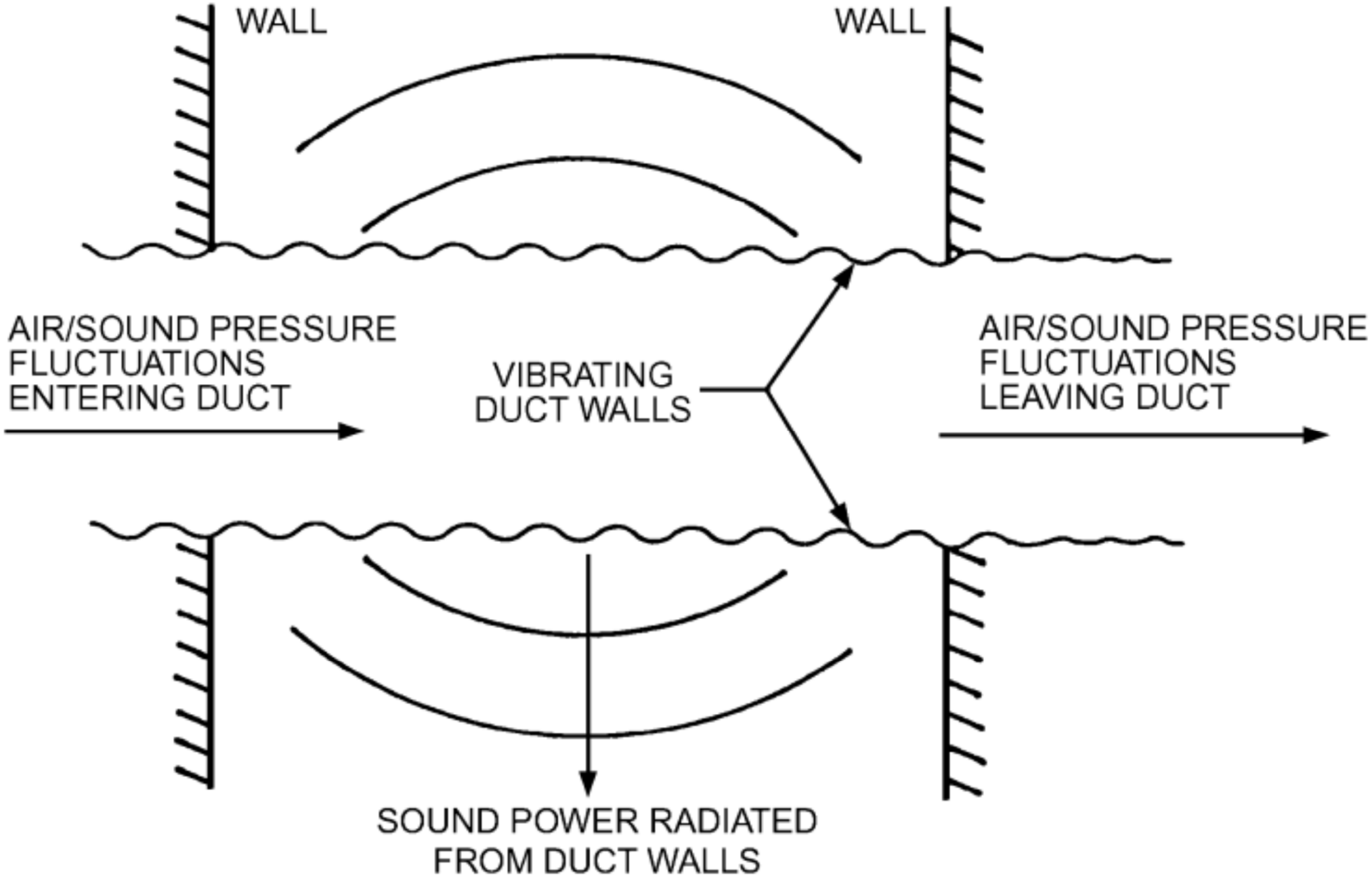
(Source: CIBSE, 2016. *Noise and Vibration Control for Building Services Systems, CIBSE Guide B4: 2016*, Chartered Institution of Building Services Engineers (CIBSE), London.)

Ductwork noise



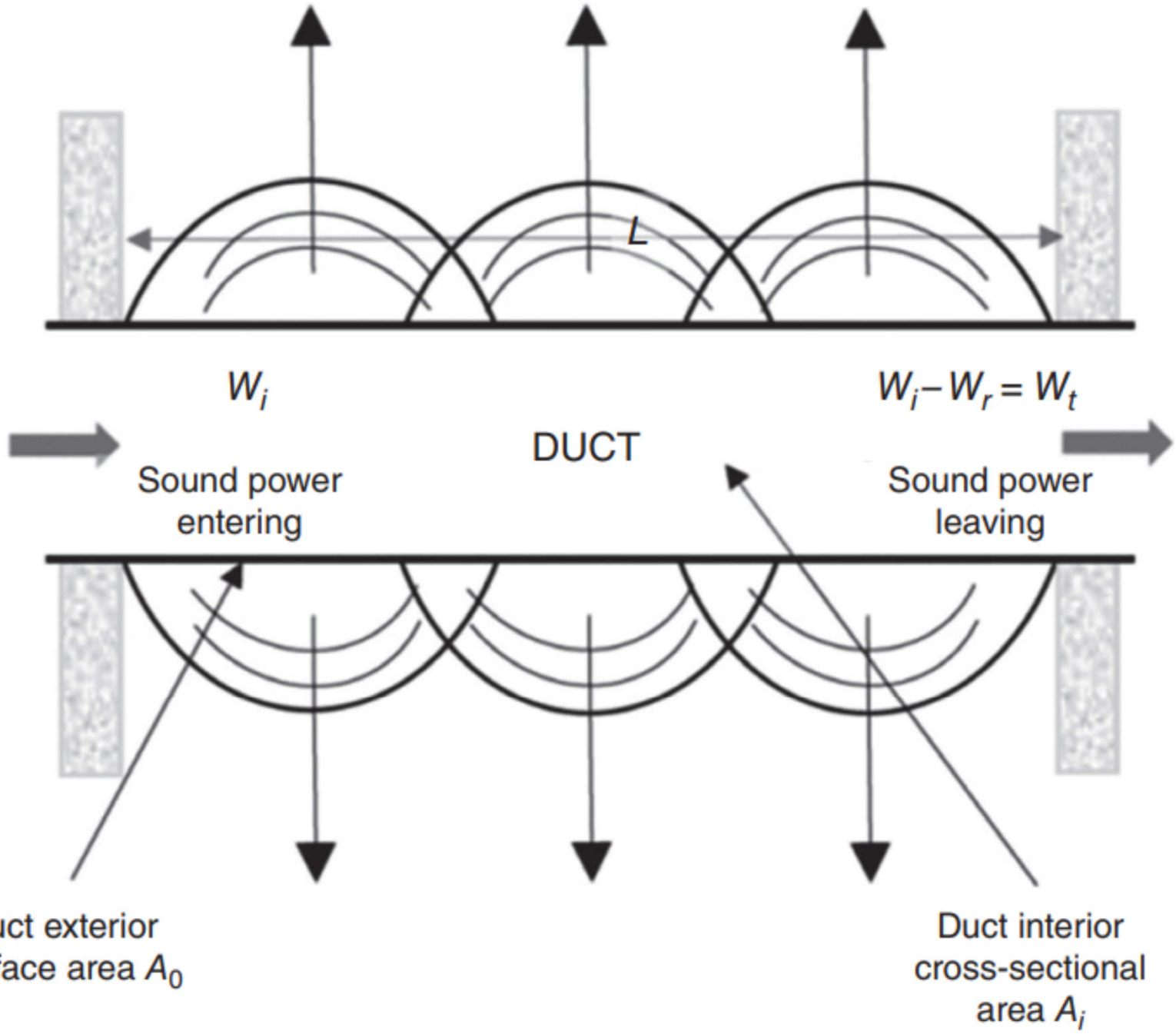
- Breakout is the sound associated with fan or airflow noise inside a duct that radiates through duct walls in to the surrounding area
- Breakout transmission loss (BTL) refers to the reduction of noise that is transmitted through a duct wall
- The best way to improve low-frequency breakout performance is to increase the duct's stiffness

Transmission of rumble noise through duct walls



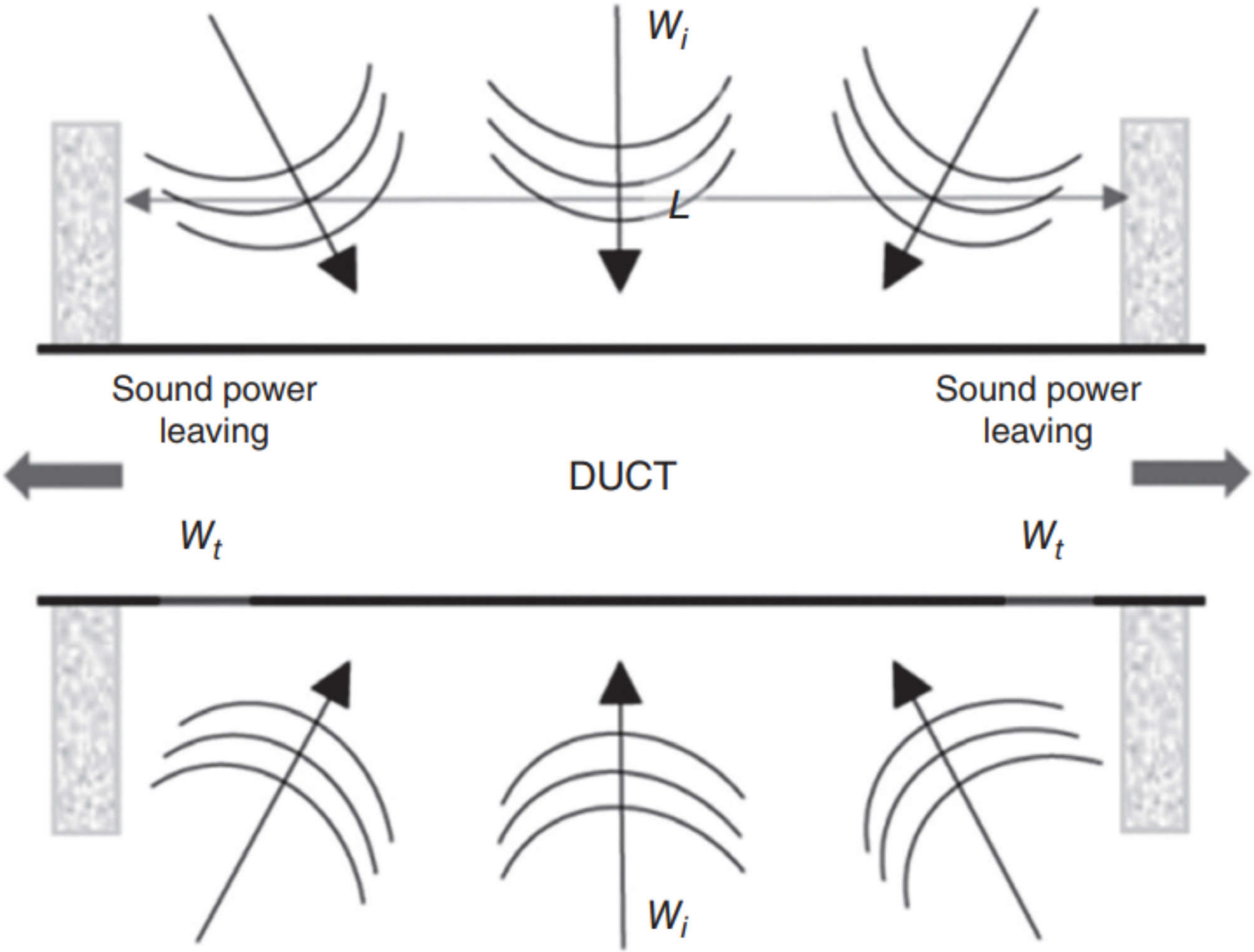
(Source: ASHRAE, 2019. *ASHRAE HVAC Applications Handbook 2020*, SI edition, Chp. 49 Sound and Vibration Control)

Duct breakout noise



(Source: Crocker M. J. & Arenas J. P., 2021. *Engineering Acoustics: Noise and Vibration Control*, Wiley, Hoboken, NJ. https://doi.org/10.1002/9781118693902)

Duct breakin noise



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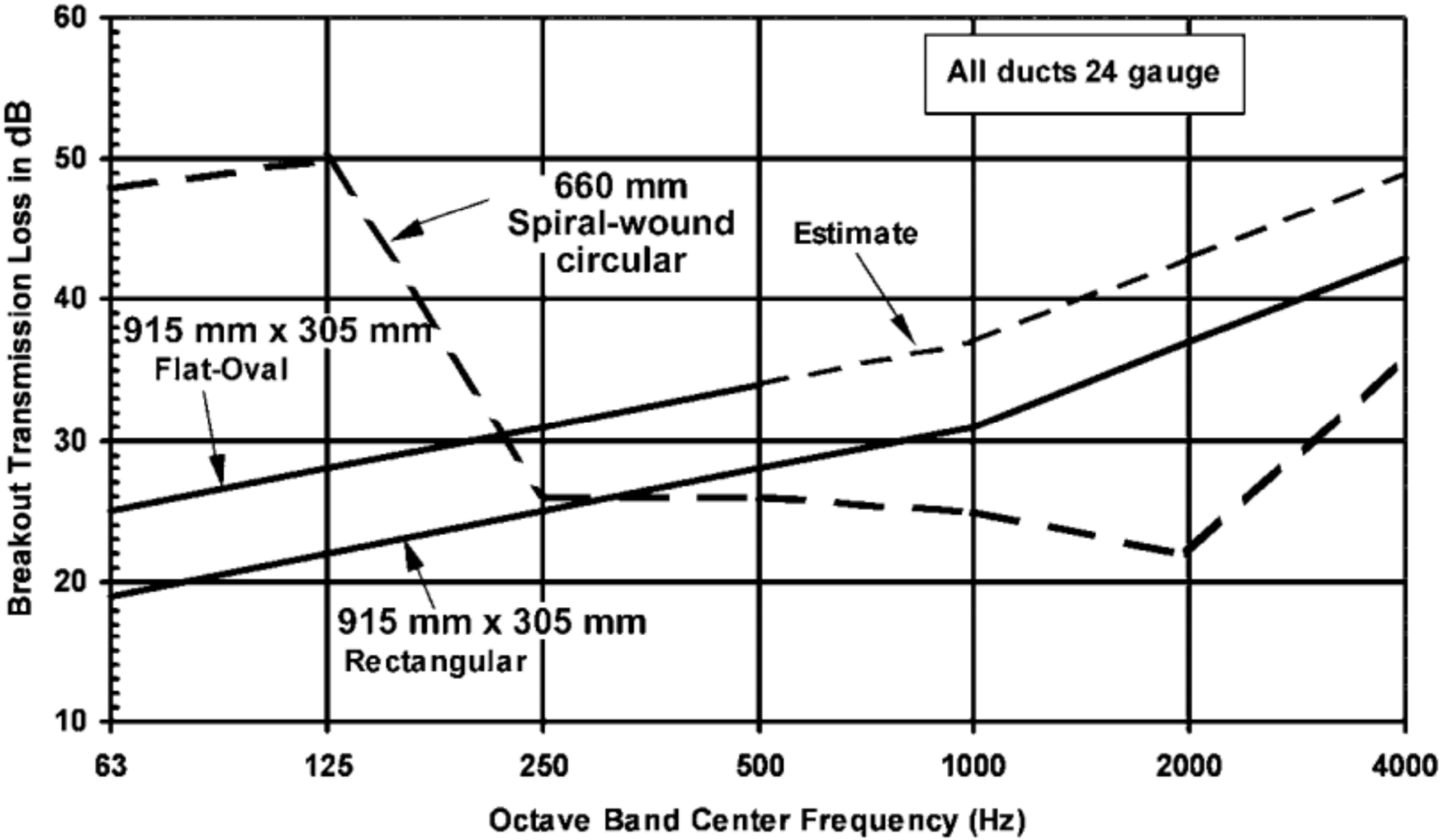
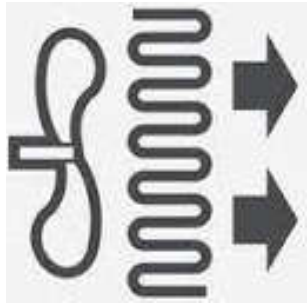
Breakout transmission loss for three types of sheet metal ductwork



(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

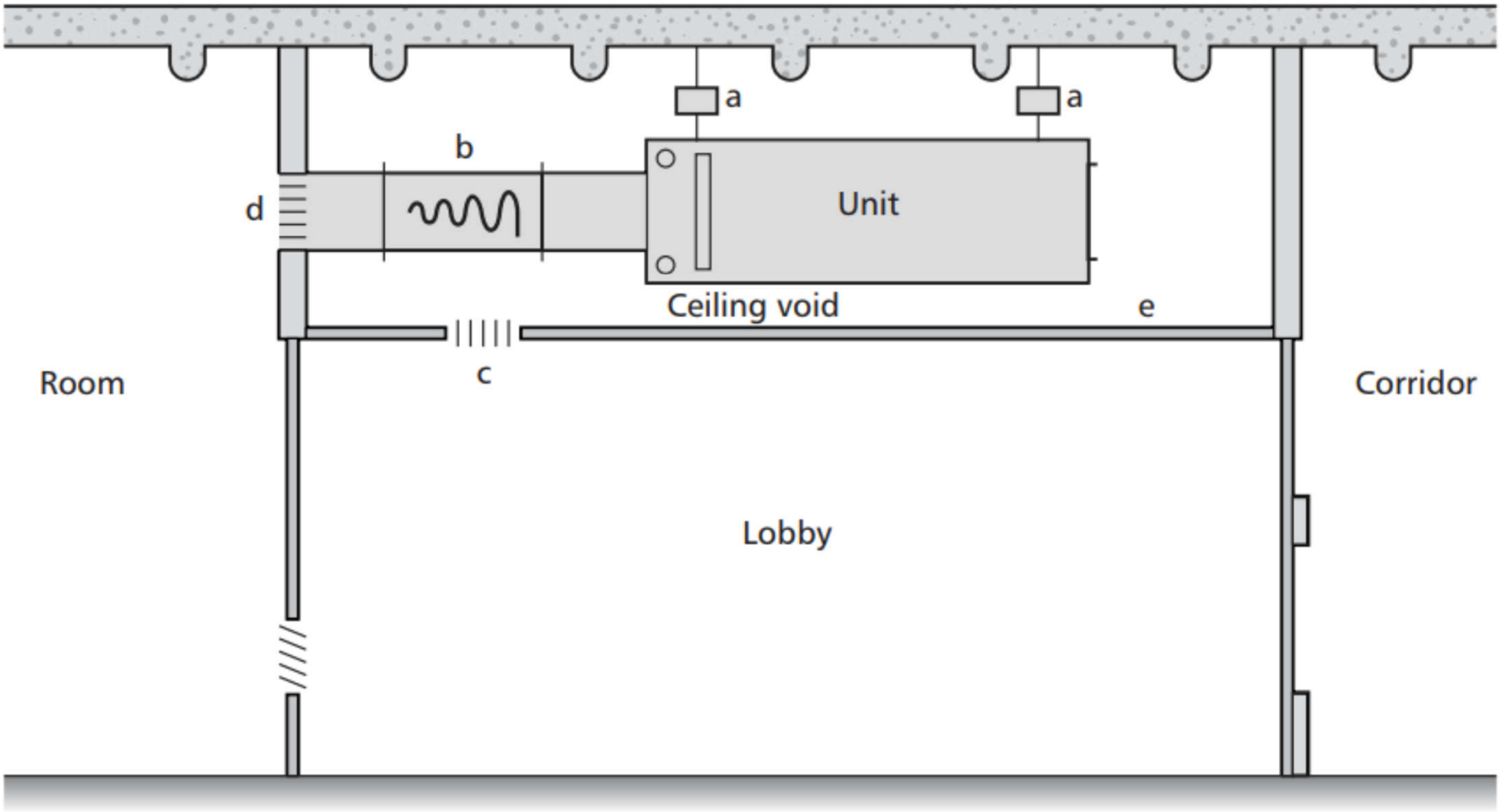
Terminal units



- Fan coil unit (FCU) design
  - Do not expect very low noise levels from a FCU installation; levels lower than NR30 are generally unrealistic unless special measures are taken
    - For ceiling void units, noise from the inlet is a key issue
    - For floor standing units, noise from the discharge of a fan coil is a key issue
  - Use max. number of discharge outlets possible to reduce air resistance hence the fan noise
  - For ceiling void installations don't position the return grilles directly under or near the unit inlet

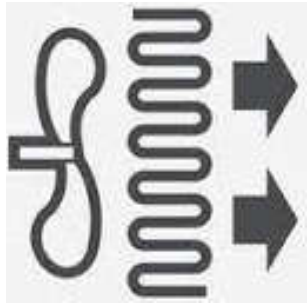
Fan coil unit installation in a hotel room

a Elastomeric hangers
b Possible attenuator
c Return air grille
d Outlet of conditioned quiet ventilation unit
e Ceiling void can be acoustically lined for additional noise reduction



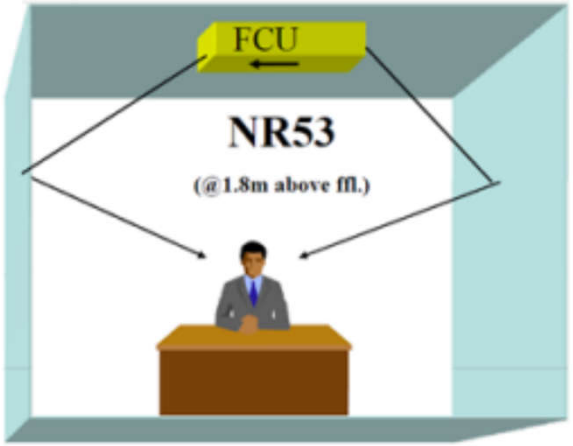
(Source: CIBSE, 2016. *Noise and Vibration Control for Building Services Systems, CIBSE Guide B4: 2016*, Chartered Institution of Building Services Engineers (CIBSE), London.)

Terminal units

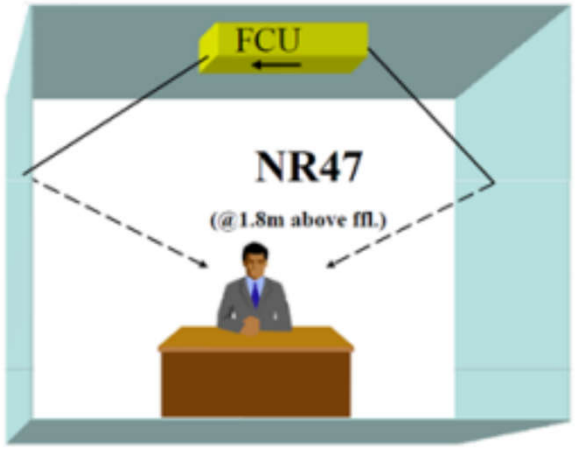


- Fan coil unit (FCU) design
  - False ceiling with good acoustic grade is necessary
  - Filters of the units needs to be cleaned before acoustic commissioning checks on site
    - FCUs are often used for drying the building and dust on site blocks the filters hence increase the noise levels
  - Beware of fresh air ducted directly to the inlet of a fan coil unit with no air break as this can impose a significant air resistance across some units
  - Minimise the air leakage from ducts since higher fan speeds is required to produce the specified duty

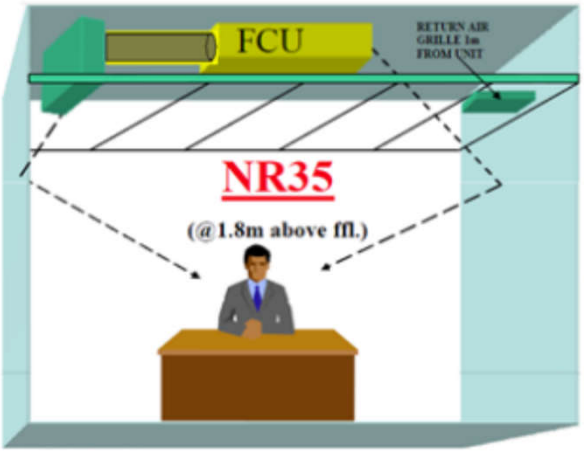
Different arrangements of fan coil unit (FCU) design and noise level



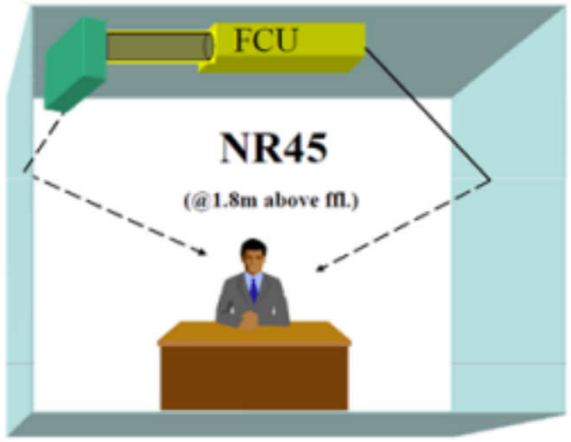
Chassis unit fixed to slab in hard room (no room absorption, no ductwork, no ceiling)



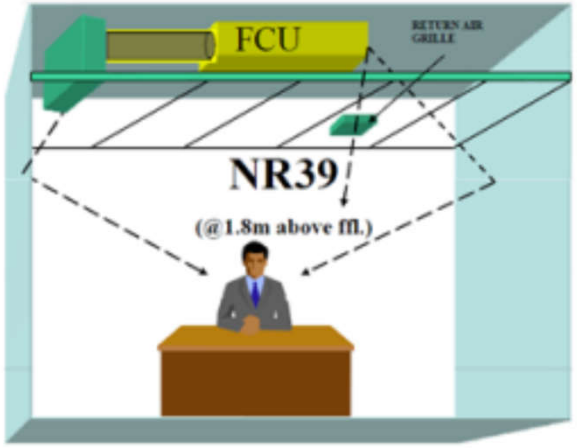
Chassis unit fixed to slab in furnished room (with room absorption, no ductwork, no ceiling)



Chassis unit mounted above a false ceiling with acoustic flex discharge ductwork in furnished room (with room absorption, 1 m of acoustic ductwork, plenum & grille, false ceiling, good return air position)



Chassis unit fixed to slab with acoustic discharge ductwork in furnished room (with room absorption, 1 m of acoustic ductwork, plenum & grille)

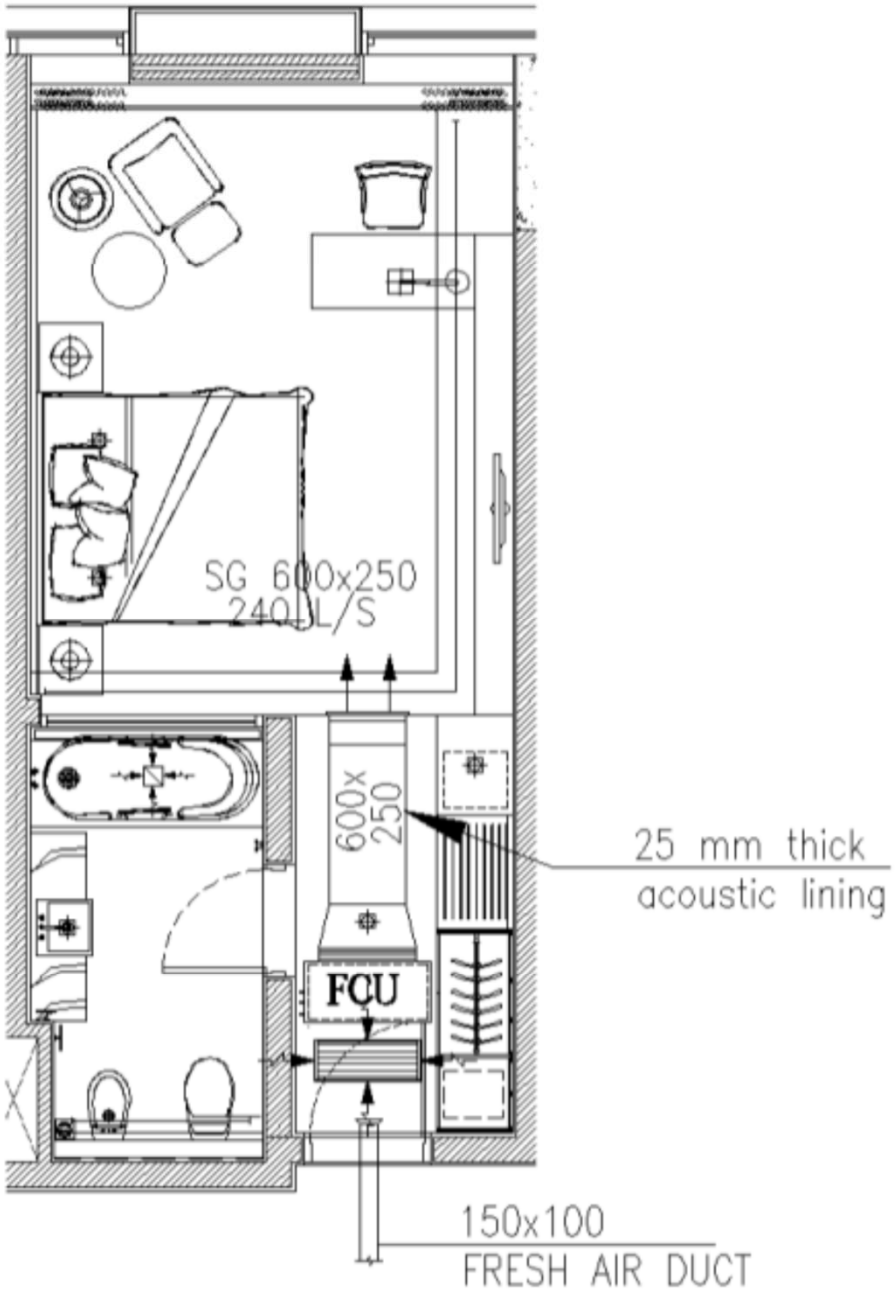


Chassis unit mounted above a false ceiling in furnished room with acoustic flex discharge ductwork (with room absorption, 1 m of acoustic ductwork, plenum & grille, poor return air position just under the unit)

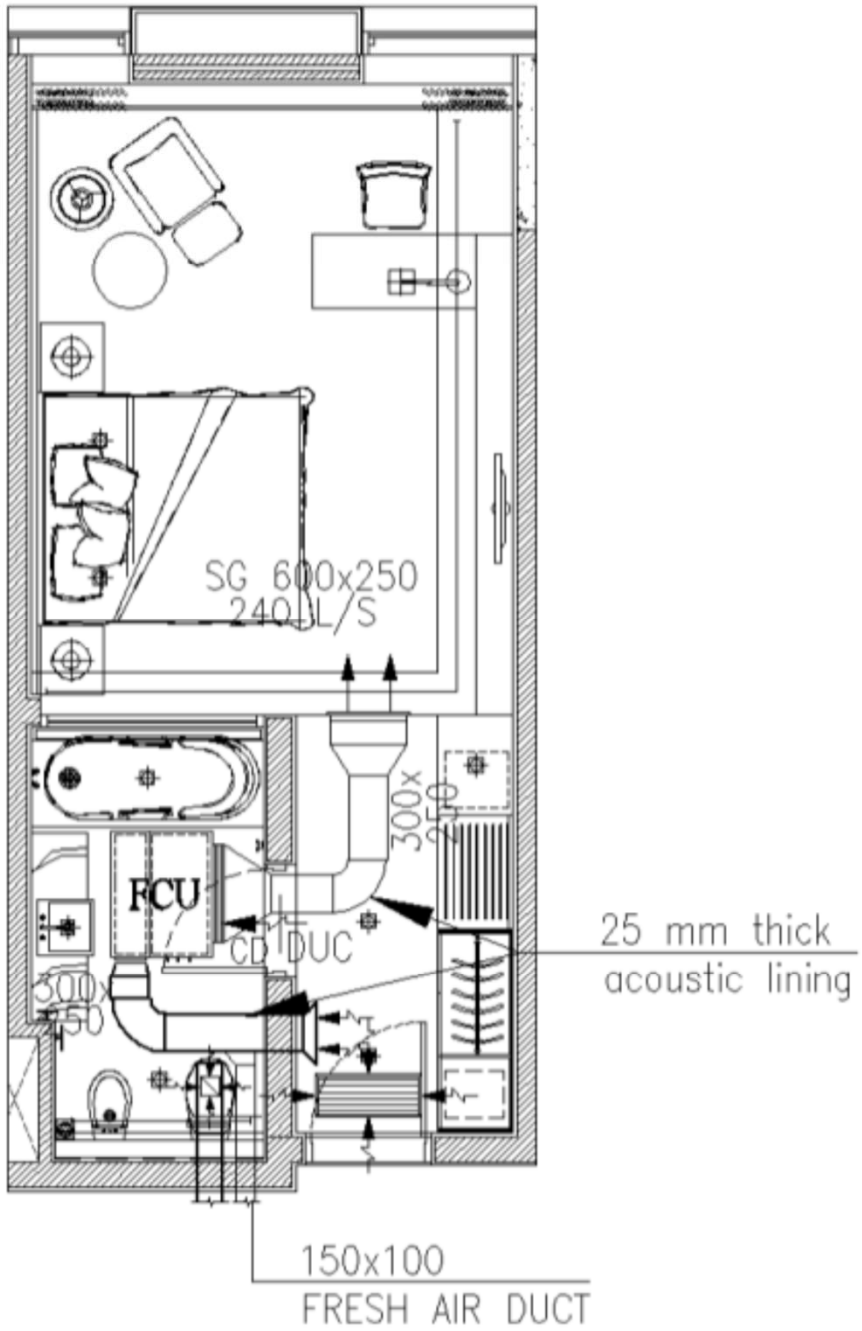
(Source: ASHRAE Qatar Oryx Chapter)

Fan coil unit (FCU) design examples for a hotel guestroom

Resultant noise ≥ NC 35

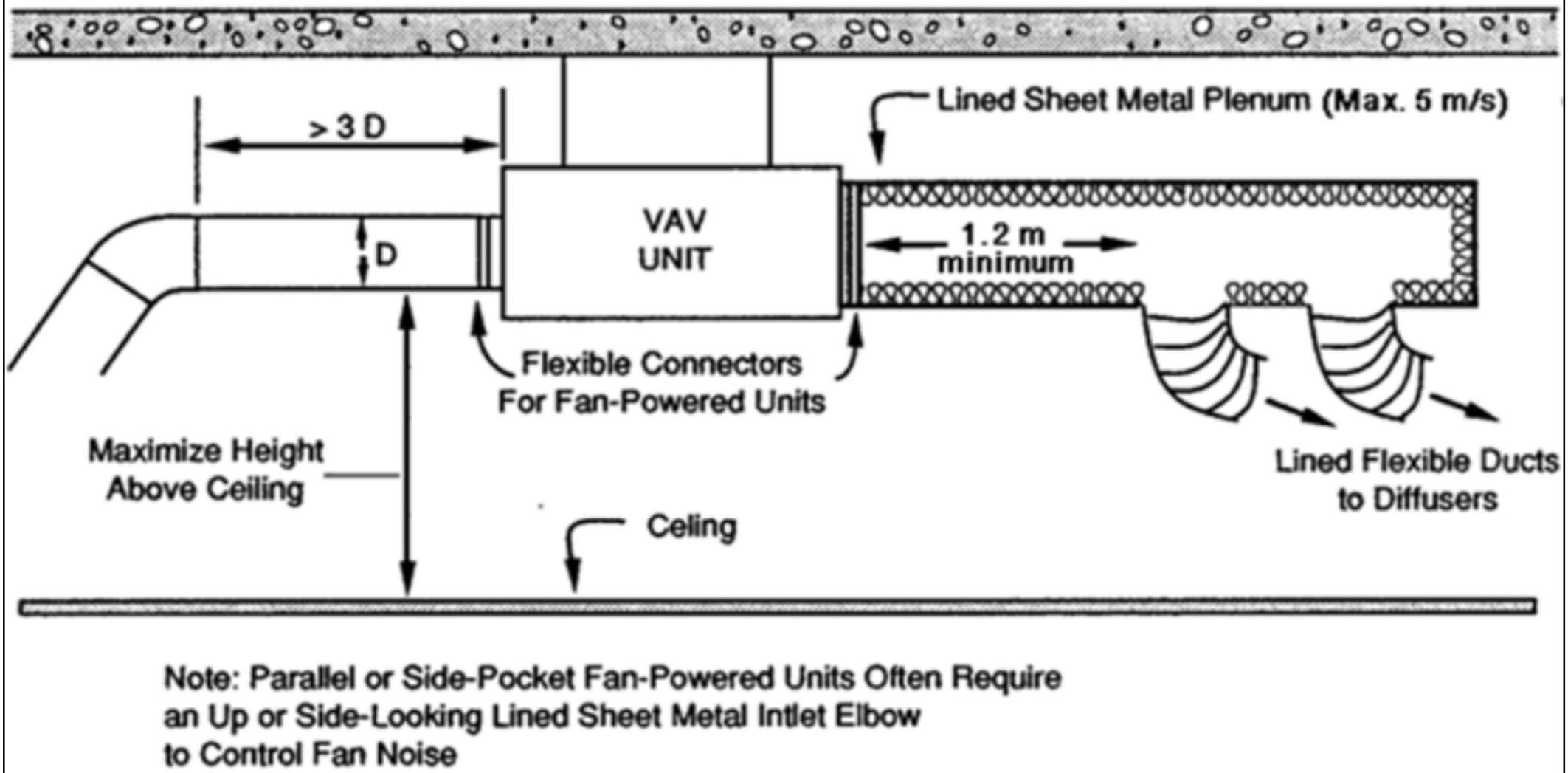


Resultant noise ≤ NC 30



(Source: ASHRAE Qatar Oryx Chapter)

Guidelines for variable air volume (VAV) terminal unit installation



(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

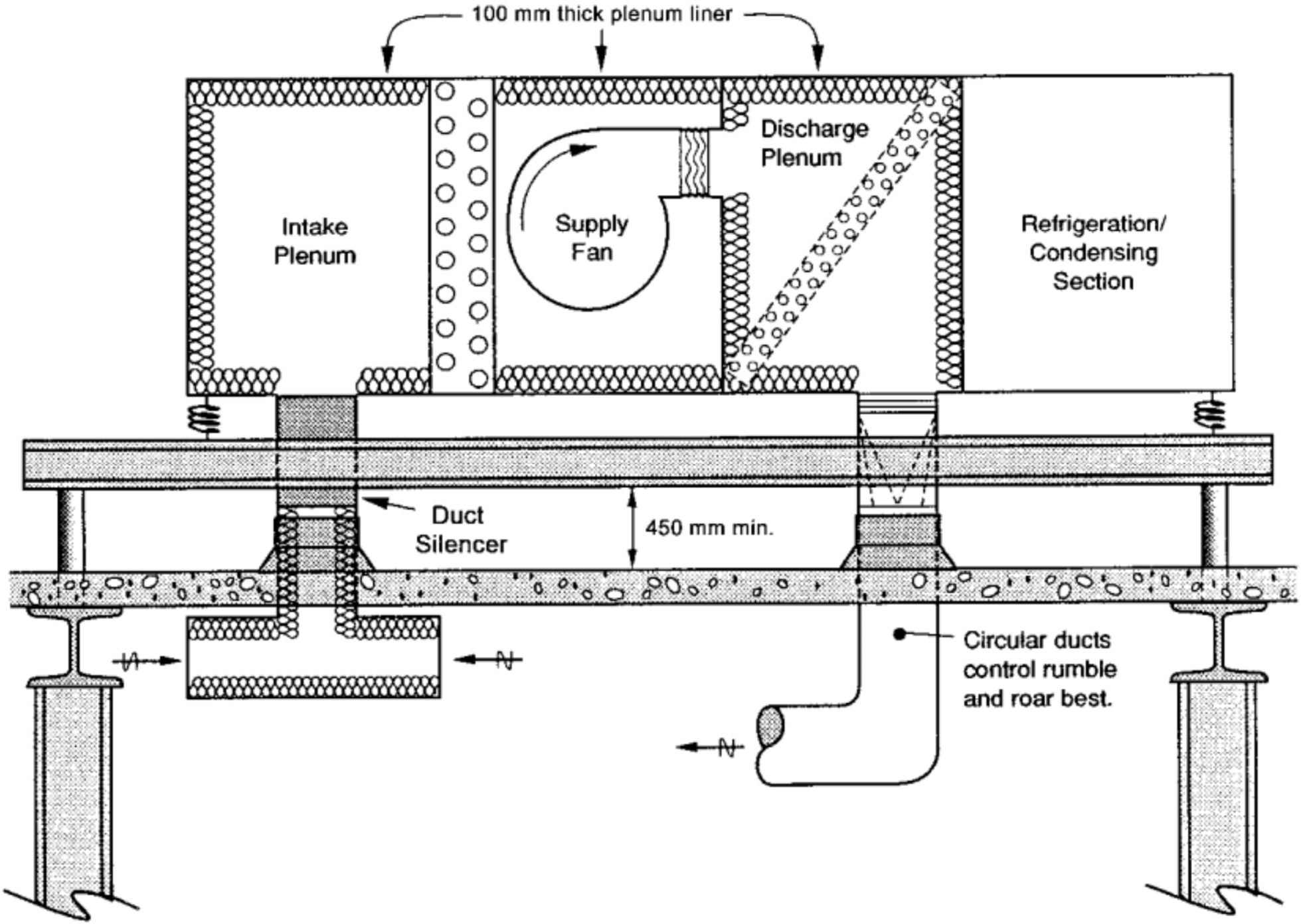
Sample acoustical specification for VAV terminal units

			Maximum Discharge L_W in dB re 1 pW Octave Band Center Frequency in Hz					
Mark	**Design Aiflow in L/s**	**Static Pressure in Pa**	**125**	**250**	**500**	**1000**	**2000**	**4000**
VAV-1	700	250	66	63	60	58	55	52
VAV-2	470	250	63	60	56	55	53	51
VAV-3	280	250	60	58	54	52	50	48

			Maximum Radiated L_W in dB re 1 picowatt Octave Band Center frequency in Hz					
Mark	**Design Aiflow in L/s**	**Static Pres-sure in Pa**	**125**	**250**	**500**	**1000**	**2000**	**4000**
VAV-1	700	250	62	53	48	45	43	41
VAV-2	470	250	58	48	42	40	37	35
VAV-3	280	250	55	48	40	36	34	31

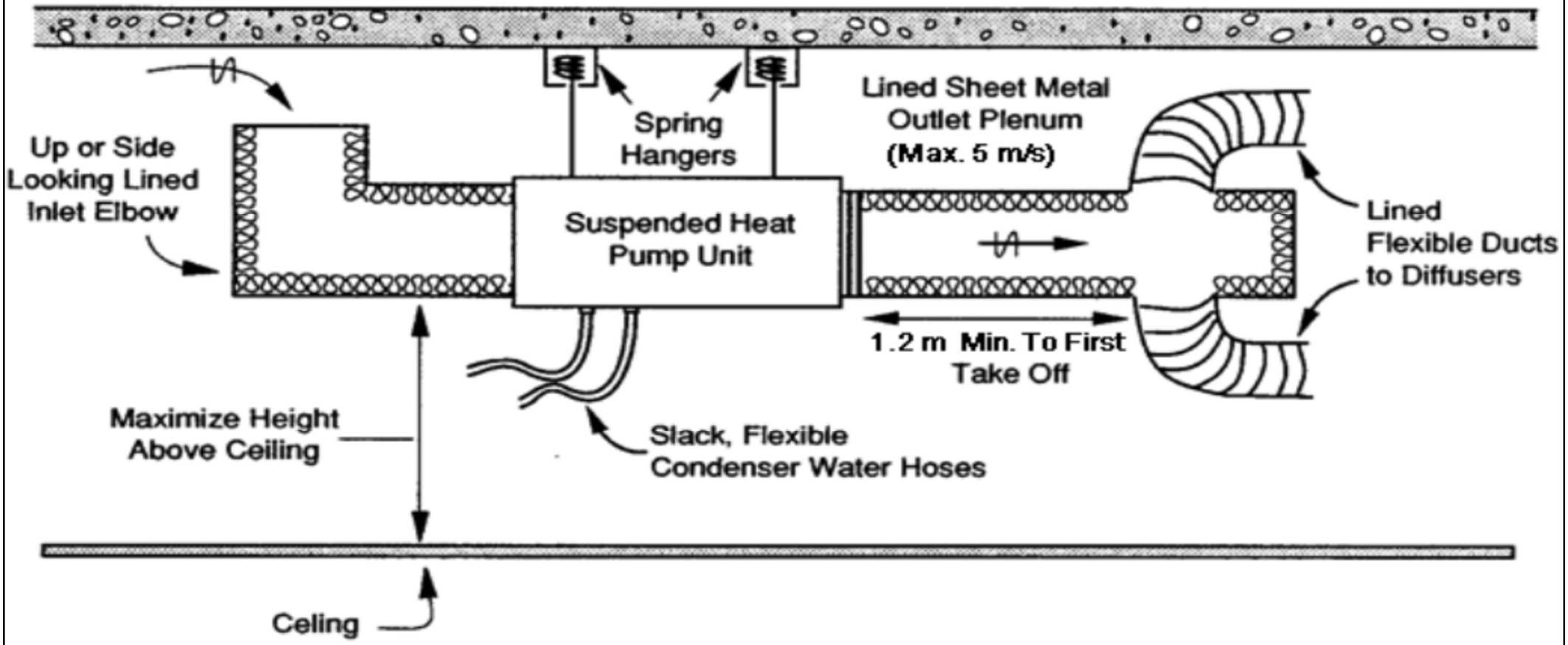
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Quietest rooftop unit installation with noise and vibration control



(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Guidelines for suspended heat pump units



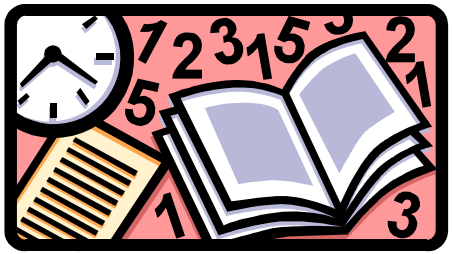
(Source: Schaffer M. E., 2011. *A Practical Guide to Noise and Vibration Control for HVAC Systems*, 2nd Edition (SI))

Further Reading

- Training videos:

  - Sources of HVAC Sound and How to Control Noise (14:24) https://youtu.be/SzwjQQvlvqE
  - 001 visualising noise control - fan design (16:13) https://youtu.be/8ZrNszFkQ1A
  - Webinar Recording: Vibration Isolation for Mechanical Systems (20:41) https://youtu.be/MCBnZ83C75A
  - HVAC Training - Terminal Silencers (26:13) https://youtu.be/naacRiAF23c
- HVAC Systems Noise Control https://www.cedengineering.com/userfiles/HVAC%20Systems%20Noise%20Control.pdf
  - Section - 3 Noise Descriptors
  - Section - 4 Controlling HVAC Noise and Vibration

References



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