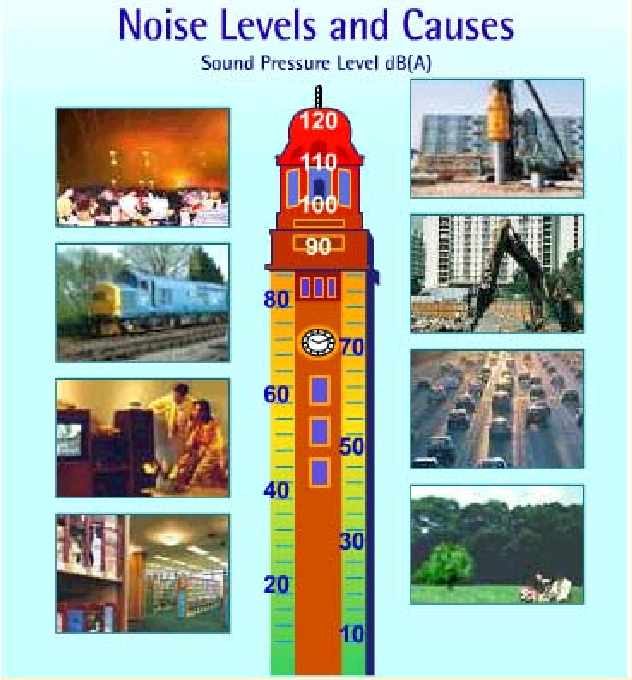
MEBS6008 Environmental Services II
http://www.hku.hk/mech/msc-courses/MEBS6008/index.html



Acoustic Treatment – Noise Control

Department of Mechanical Engineering
The University of Hong Kong

Content

- Basics
- The Sources
- The Path
- Sound Level at a Receiver Point
- Noise Control in Practice
- The Noise Control Ordinance

Basics - Acoustic Design Objective

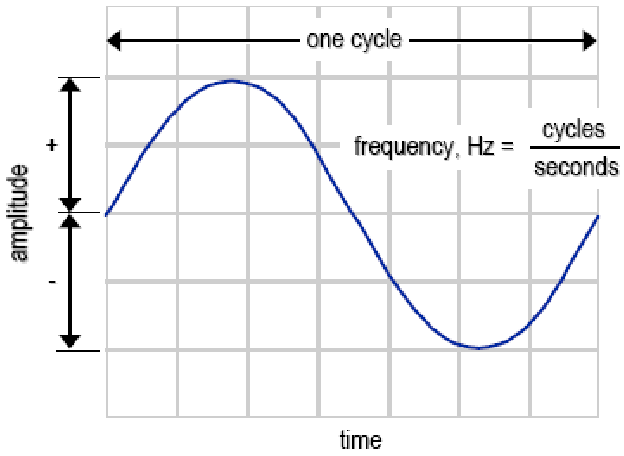
Noise is unwanted sound.

The primary objective for the acoustical design of HVAC systems and equipment is to ensure that the acoustical environment in a given space is not degraded.

Sound and vibration are created by a source, are transmitted along one or more paths, and reach a receiver.

Treatments and modifications can be applied to any or all of these elements to achieve an acceptable acoustical environment.

Basics - Comparison of Pitch and Frequency



Frequency

- an objective quantity
- independent of sound-pressure level.

Pitch

- subjective quantity
- primarily based on frequency
- dependent on sound-pressure level and composition
- not measured
- described with terms like bass and tenor

Basics - Octave Bands

octave band	center frequency (Hz)	frequency range (Hz)
1	63	45 to 90
2	125	90 to 180
3	250	180 to 355
4	500	355 to 710
5	1,000	710 to 1,400
6	2,000	1,400 to 2,800
7	4,000	2,800 to 5,600
8	8,000	5,600 to 11,200

Human ear perception: sounds at frequencies 20 to 16,000 Hz.

HVAC system sounds 45 to 11,200 Hz (11,156 data points).

HVAC sounds frequencies →smaller ranges (octave bands).

Center frequency = square root of the product of the lowest and highest frequencies in the band.

The frequency range (45 to 11,200 Hz) → eight octave bands with center frequencies of 63, 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz.

Basics - Sound Power and Sound Pressure

Sound power

Lamp bulb wattage

↓

Sound pressure

Brightness of lamp bulb

Sound power

- Acoustical energy emitted by the sound source
- Unaffected by the environment
- Expressed in terms of watts (W)

Sound pressure

- Pressure disturbance in the atmosphere
- What our ears hear and what sound meters measure
- Affected by strength of source, surroundings, and distance between source and receiver
- Also affected by room is carpeted or tiled/ furnished or bare

Basics - Sound Level

Decibel

$$dB = 10 \log_{10} \left[\frac{\text{measured value}}{\text{reference value}} \right]$$

$$\log (a \times b) = \log a + \log b$$

$$\log \left(\frac{a}{b} \right) = \log a - \log b$$

Sound Power Level

$$L_w = 10 \log_{10} \left[\frac{\text{sound power, W}}{10^{-12}\ \text{W}} \right]$$

The reference value used for calculating sound-power level is 10^{-12} watts.

Basics - Sound Pressure Level

$$L_p = 20 \log_{10}\left[\frac{\text{sound pressure, } \mu\text{Pa}}{20\ \mu\text{Pa}}\right]$$

or

$$= 10 \log_{10}\left[\frac{\text{sound pressure, } \mu\text{Pa}}{20\ \mu\text{Pa}}\right]^2$$

The reference value used for calculating sound-pressure level is 2×10^{-5} Pa.

Reference values are the threshold of hearing.

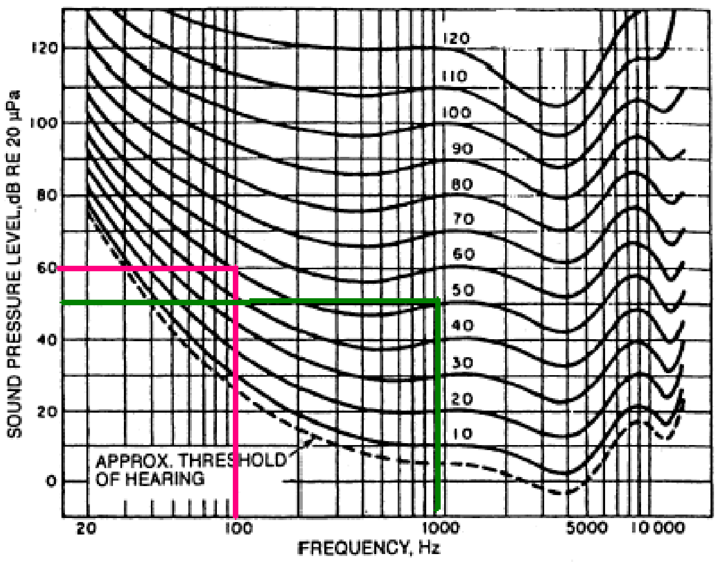
Sound power is proportional to the square of sound pressure

→ multiplier 20 is used (not 10).

Typical Sound Pressures and Sound Pressure Levels

Source	Sound Pressure, Pa	Sound Pressure Level, dB re 20 μPa	Subjective Reaction
Military jet takeoff at 30 m	200	140	Extreme danger
Artillery fire at 3 m	63.2	130	
Passenger jet takeoff at 30 m	20	120	Threshold of pain
Loud rock band	6.3	110	Threshold of discomfort
Platform of subway station (steel wheels)	2	100	
Unmuffled large diesel engine at 40 m	0.6	90	Very loud
Computer printout room	0.2	80	
Freight train at 30 m	0.06	70	
Conversational speech at 1 m	0.02	60	
Window air conditioner at 1 m	0.006	50	Moderate
Quiet residential area	0.002	40	
Whispered conversation at 2 m	0.0006	30	
Buzzing insect at 1 m	0.0002	20	Perceptible
Threshold of good hearing	0.00006	10	Faint
Threshold of excellent youthful hearing	0.00002	0	Threshold of hearing

Basics - Sensation of Loudness



Loudness Contour

The sensation of loudness = f(sound pressure & frequency).

Each contour approximates an equal loudness level across the frequency range shown.

Human ear is more sensitive to high frequencies than low frequencies.

Ear's sensitivity at a particular frequency changes with sound-pressure level.

Loudness to human ear : 60 dB 100 Hz = 50 dB at 1,000 Hz.

Human ears are less sensitive to low-frequency sounds.

Human ear not respond linearly to pressure and frequency.

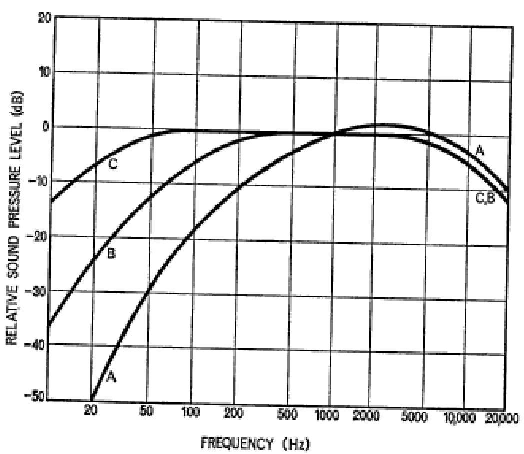
Basics - Single-Number Rating Methods

Human ear : sound as loudness and pitch

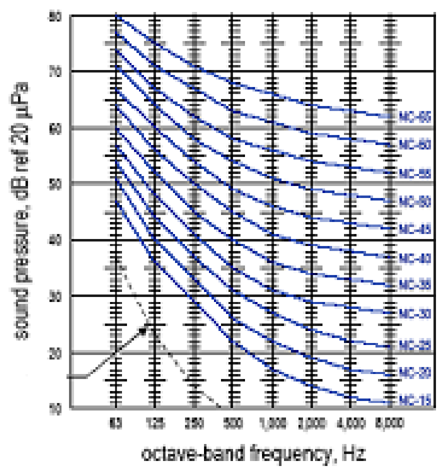
Electronic Sound-measuring equipment : Sound as pressure and frequency.

Single-number descriptors to express both the intensity and quality of a sound :-

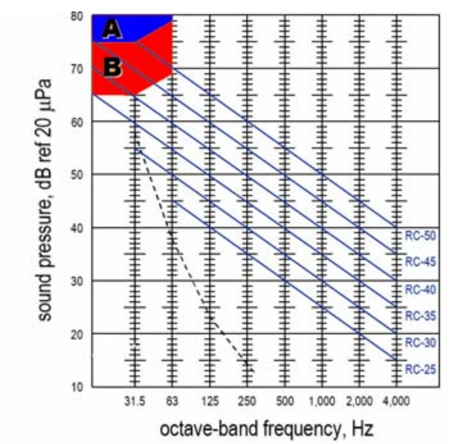
1) A-weighting network



2) Noise criteria (NC)



3) Room criteria (RC)



Basics - A-weighted Sound Pressure Level (SPL)

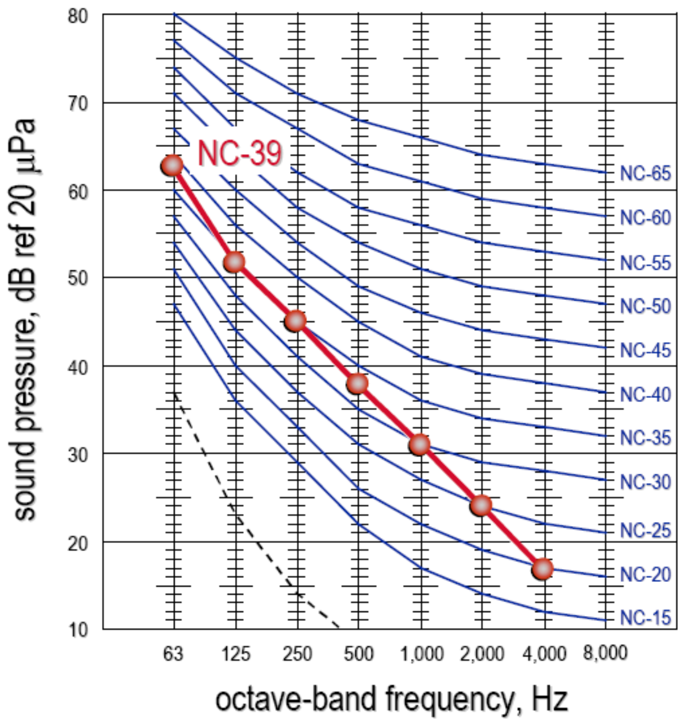
octave band	center frequency (Hz)	actual sound pressure (dB)	A-weighting factor (dB)	A-weighted sound pressure (dB)
1	63	63	– 26	37
2	125	52	– 16	36
3	250	45	– 9	36
4	500	38	– 3	35
5	1,000	31	+ 0	31
6	2,000	24	+ 1	25
7	4,000	16	+ 1	17
8	8,000	10	+ 0	10

Steps to calculate A-weighted SPL

1) List actual sound-pressure levels for the eight octave bands
2) Add or subtract the decibel values represented by the A-weighting curve.
3) Logarithmically sum all eight octave bands to get an overall A-weighted SPL.

Most sound meters can automatically calculate & display the A-weighted SPL.

Basics - Noise criteria (NC)



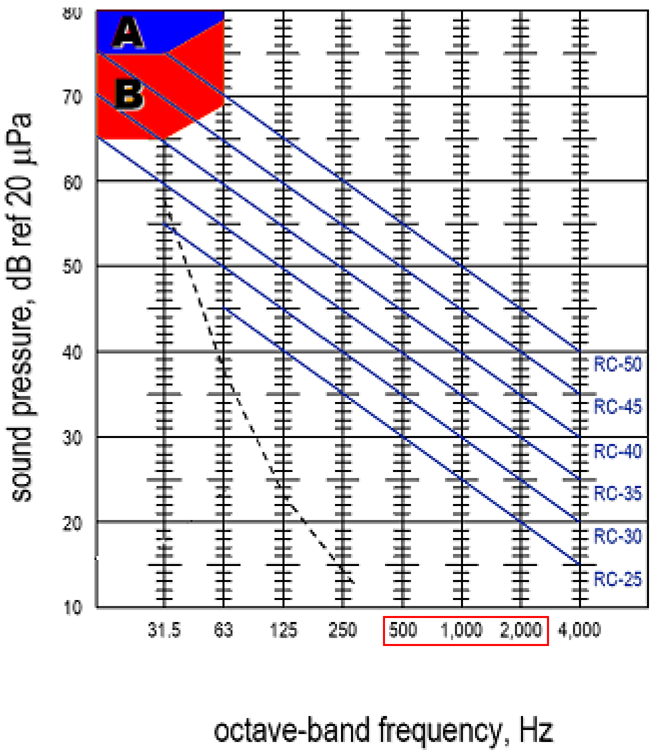
The steps to calculate an NC rating:-

1) Plot the octave-band sound-pressure levels on the NC chart.

2) The highest curve crossed by the plotted data determines the NC rating.

Example: plotting the sound pressure levels on the NC curves → NC-39

Basics - Room criteria (RC) curves



Steps to determine RC rating are as follows: -

1)Plot the octave-band SPLs on the RC chart.

2) The speech interference level = arithmetic average of the sound pressure levels in the 500 Hz, 1,000 Hz, and 2,000 Hz octave bands.

Perceptible vibration : The sound level in the octave bands between 16 Hz and 63 Hz →regions (A and B).

Region A: High probability that noise-induced vibration levels in lightweight wall and ceiling constructions. Anticipate audible rattles in light fixtures, doors, windows.

Region B: Noise-induced vibration levels in lightweight wall and ceiling constructions may be felt. Slight possibility of rattles in light fixtures, doors, windows.

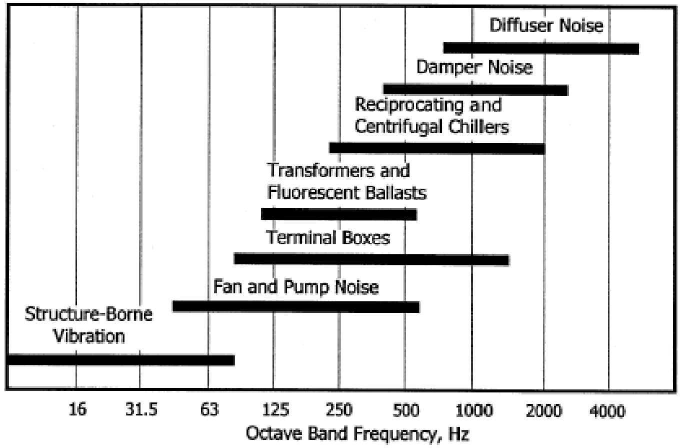
Basics - Setting a Design Goal

Type of Area	NC or RC Level	Approx dBA
Churches and Schools		
Sanctuaries	20—30	25—35
Libraries	30—40	35—45
Schools & classrooms	30—40	35—45
Laboratories	35—45	40—50
Recreation halls	35—50	40—55
Corridors & halls	35—50	40—55
Public Buildings		
Libraries, museums	30—40	35—45
Court rooms	30—40	35—45
Post offices, lobbies	35—45	40—50
Gen. banking areas	35—45	40—50
Washrooms, toilets	40—50	45—55
Restaurants, Lounges, Cafeterias		
Restaurants	35—45	40—50
Cocktail lounges	35—40	40—45
Nightclubs	35—45	40—50
Cafeterias	40—50	45—55
Retail Stores		
Clothing stores	35—45	40—50
Department stores (upper floors)	35—45	40—50
Department stores (main floors)	40—50	45—55
Small retail stores	40—50	45—55
Supermarkets	40—50	45—55
Offices		
Board rooms	20—30	25—35
Conference rooms	25—35	30—40
Executive offices	30—40	35—45
General offices	30—45	35—50
Reception rooms	30—45	35—50
General open offices	35—45	40—50
Drafting rooms	35—45	40—50
Halls & corridors	40—55	45—60

Goals to be achieved:-

- NC or RC
- A balanced distribution of sound energy over a broad frequency range
- No audible tonal or other characteristics such as whine, whistle, hum, or rumble
- No noticeable time-varying levels from beats or other system induced aerodynamic instability
- No fluctuations in level such as a throbbing or pulsing

The Sources - Sound Pressure Level of Some Equipment



Frequencies at Which Various Types of Mechanical and Electrical Equipment Generally Control Sound Spectra

If manufacturer's data are not available, the sound pressure level L_{pA}, in dBA, for centrifugal chillers at a distance (1 m) from the chiller can be calculated as

$$L_{pA} = 60 + 11 \log \mathrm{TR} \quad \text{where TR = refrigeration capacity, in tons.}$$

For reciprocating chillers, L_{pA} in dBA at a distance of 1 m is

$$L_{pA} = 71 + 9 \log \mathrm{TR} \quad \text{where TR = refrigeration capacity, in tons.}$$

The sound pressure level L_p, in dB, at the center frequency of various octave bands can be obtained by adding the following values at each octave band to the calculated L_{pA}:

	Center frequency of octave bands, Hz						
	63	125	250	500	1k	2k	4k
Centrifugal chiller	−8	−5	−6	−7	−8	−5	−8
Reciprocating chiller	−19	−11	−7	−1	−4	−9	−14

The Sources - Sound Pressure Level of Some Equipment

Circulating pumps

L_{pA} at a distance of 1 m is

$$L_{pA} = 77 + 10 \log \text{hp}$$

where hp power input to the pump, hp.

Cooling towers

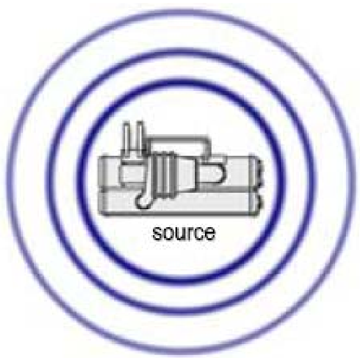
The overall sound power level is given by:

$$L_W \approx 12 + 10 \lg P$$

where L_W is the sound power level (dB) and P is the fan sound power (W).

For fan, predicting equation was found giving very inaccurate result→ use manufacturer data

The Path - Free field



In theory, a free field is a homogeneous, isotropic medium that is free from boundaries.

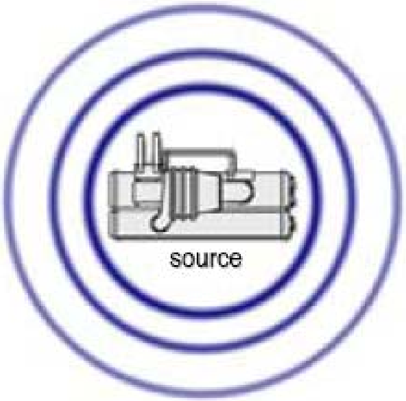
In practice, an example of a free field over a reflecting plane would be a large open area void of obstructions.

An ideal sound source radiates sound equally in all directions in which sound-pressure waves in a spherical pattern.

At equal distances from the source, the sound pressure is same in all directions.

Doubling of the distance from the source spreads the sound over four times as much surface area.

The Path - Free-Field



Using values for the speed of sound for air at 20°C and 100 kPa, the relationship between sound power level and sound pressure level for a nondirectional sound source is

$$L_w = L_p + 20 \log r + 11$$

where

L_w = sound power level, dB re 10^{-12} W
L_p = sound pressure level dB re 20 μPa
r = distance from nondirectional sound source, m

$$L_{p2} = L_{p1} - 20 \log_{10} [r_2 / r_1]$$

where,

L_{p2} = sound-pressure level at distance r_2

L_{p1} = sound-pressure level at distance r_1

r_1 = distance from the source where L_{p1} was measured

r_2 = distance from the source to where the sound pressure (L_{p2}) is desired

The Path - Free field

Free-Field Over Reflecting Plane.

In cases of unavailability of completely free field measurements can only be made in a free field over a reflecting plane.

That is, the sound source is placed on a hard floor or on pavement outdoors.

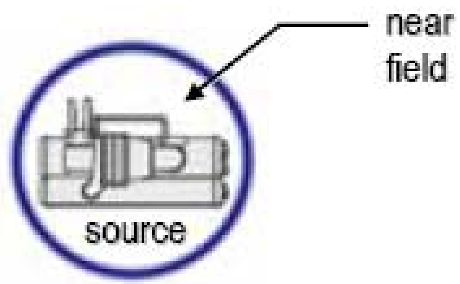
Since the sound is then radiated into a hemisphere rather than a full sphere, the relationship for L_w and L_p for a non-directional sound source becomes

$$L_w = L_p + 20\log r + 8$$

where

L_w = sound power level, dB re 10^{-12} W
L_p = sound pressure level dB re 20 µPa
r = distance from nondirectional sound source, m

The Path - Near field



The near field is an area adjacent to the source where sound not behave as in a free field.

Most sound sources, including all HVAC equipment, do not radiate sound in perfectly spherical waves.

This is due to the irregular shape of the equipment and different magnitudes of sounds radiating from the various surfaces of the equipment.

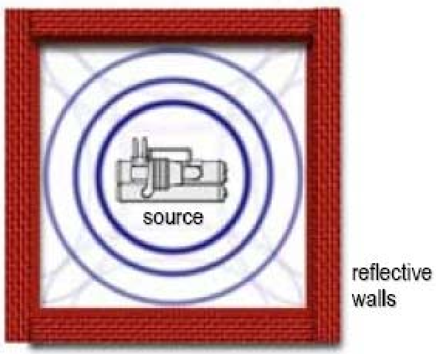
These irregularities cause pressure-wave interactions →the behavior of the sound waves unpredictable.

Sound-pressure measurements should not, therefore, be made in the near field.

The size of the near field depends on the type of source and dimensions of the equipment.

The Path - Reverberant field

Reverberant Field



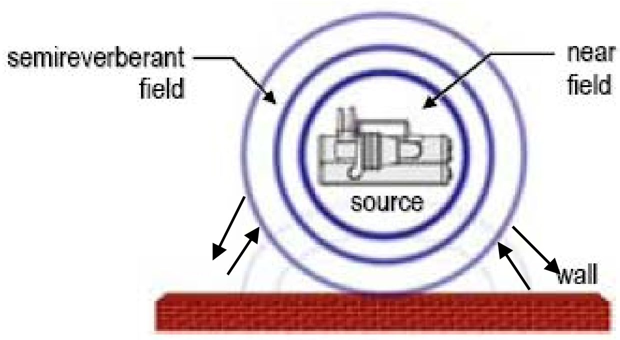
Reverberant fields exist in rooms with reflective walls, floors, and ceilings.

When a sound source is placed in an enclosed room, the sound waves from the source bounce back and forth between the reflective walls many times.

This can create a uniform, or diffuse, sound field.

In a perfectly reverberant room, the sound-pressure level is equal at all points within the room.

The Path - Semi-reverberant field



Buildings :between a free field and a reverberant one.

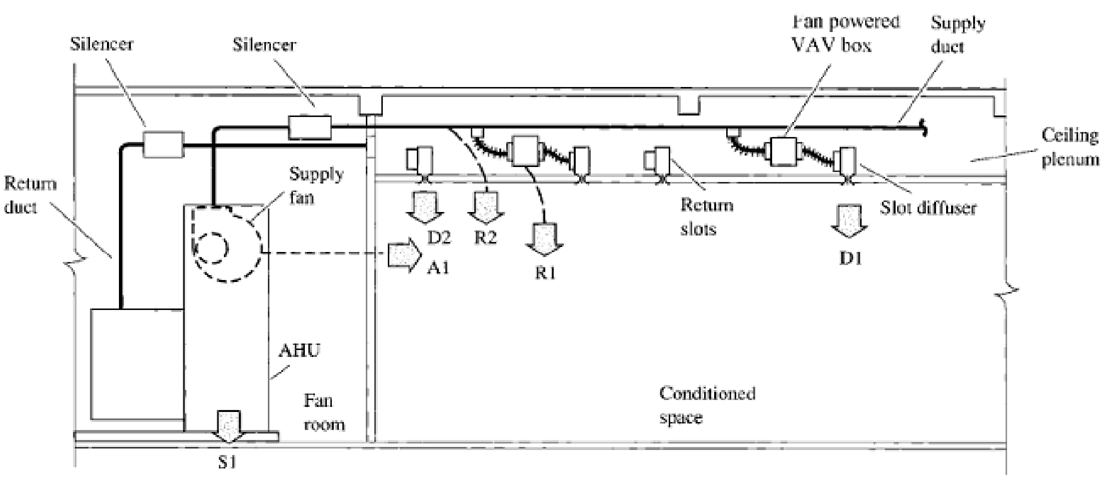
Some of the sound is reflected by walls, floor, and ceiling (but a portion of the sound is absorbed or transmitted).

When a small sound source is placed in the center of a room, close to the source, in the near field, sound measurement is unpredictable.

Near the wall, in the reverberant field, the reflected sound begins to add to the sound coming directly from the source.

The *reduction* in sound level due to the distance from the source tends to be cancelled out by the *addition* of the sound reflecting off the wall → ***a near-constant sound-pressure level near the wall.***

The Path – Air Conditioning System



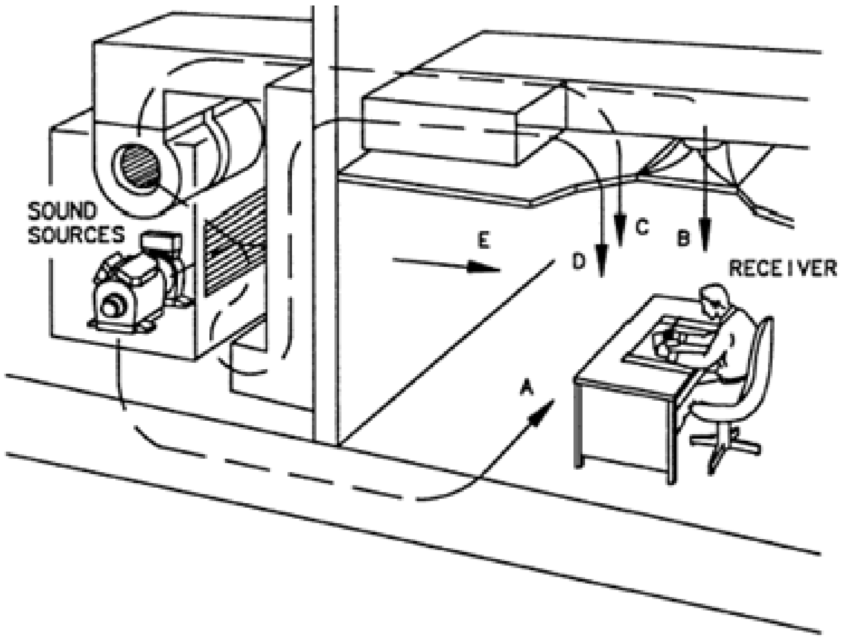
The receiver is the person working in the adjacent conditioned space.

The supply duct provides one of the paths for sound to travel from the source to the receiver.

To specify the maximum allowable equipment sound power not exceeding the sound-pressure target for the space.

Duct–borne	D1	Fan → Silencer → Supply duct → Elbows → Branch power division → Flexible duct → Space effect
	D2	Fan → Silencer → Return duct → Elbow → Ceiling plenum → Space effect
Radiated sound	R1	VAV box → Ceiling plenum → Space effect
	R2	Supply duct breakout → Ceiling plenum → Space effect
Airborne	A1	Fan → Fan room → Wall → Space effect
Structure-borne	S1	Fan → Building structure

The Path – Air Conditioning System



Path A: Structure-borne path through floor
Path B: Airborne path through supply air system
Path C: Duct breakout from supply air duct
Path D: Airborne path through return air system
Path E: Airborne path through mechanical equipment room wall

Airborne sound

Sound in air is called **airborne sound** or simply sound.

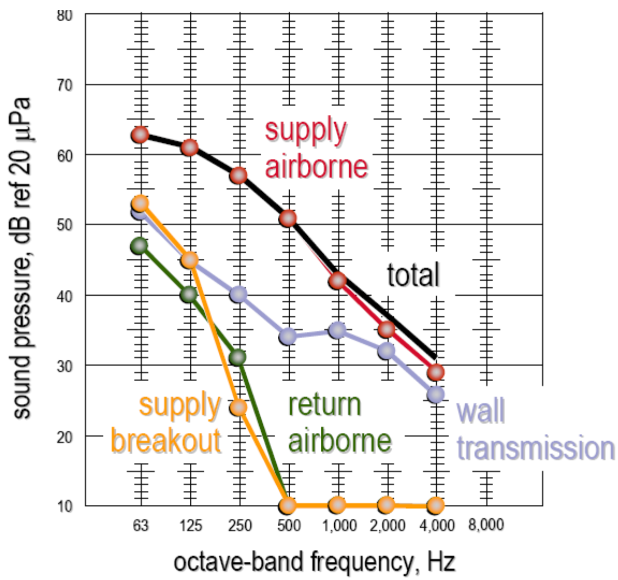
Generated by a vibrating surface or a turbulent fluid stream.

Structure borne sound

In solids, sound travels as bending waves, compression waves, torsion waves, shear waves and others.

Sound in solids is generally called **structure borne sound**.

The Path – Air Conditioning System



One piece of equipment may contain several sound sources.

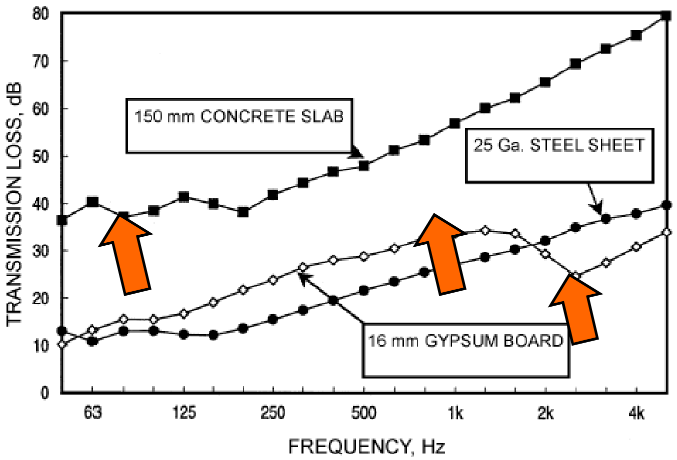
For example,a packaged rooftop air conditioner contains supply and exhaust (or return) fans, compressors, and condenser fans.

Sound may travel from a single source to the receiver along multiple paths: supply airborne, supply breakout, return airborne, and transmission through the adjacent wall.

The total sound heard = the sum of all the sounds from various sources traveling along several paths.

Supply airborne path contributes to the total sound-pressure level in the space much more than the other three paths.

The Path - Transmission Loss (TL) of Partition



Sound Transmission Loss Spectra for Single Layers of Some Common Materials

TL depends on material properties, such as stiffness and internal damping.

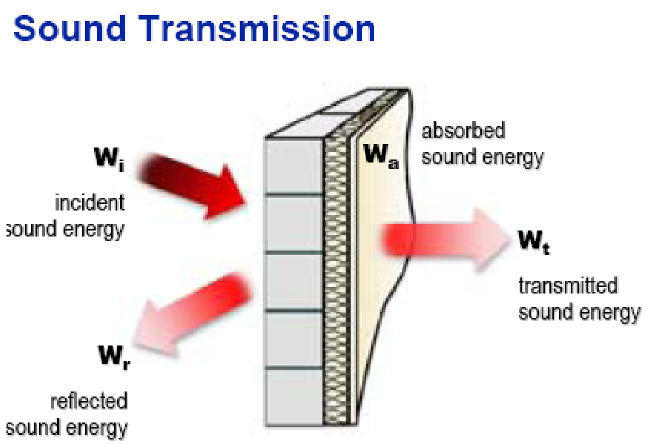
16 mm gypsum board→TL depends mainly on the surface mass of the wall at frequencies below about 1 kHz (match with mass law)

At higher frequencies, there is a dip in the TL curve(coincidence dip) the →the wavelength of flexural vibrations in the wall coincides with the wavelength of sound in the air.

150 mm concrete slab has a coincidence frequency at 100Hz

The coincidence dip for the 25 gage (0.531 mm thick) steel sheet occurs at about 2.5kHz.

The Path –
Transmission Loss (TL) of Partition



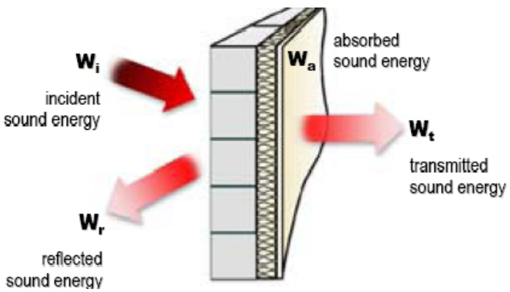
The total sound energy that strikes a surface is either reflected, absorbed by the material, or transmitted through the material.

Materials that are dense (such as masonry block or wallboard) or stiff (such as glass) are generally better at reducing transmitted sound than materials that are lightweight or flexible.

Increasing the thickness of a material reduces the amount of sound transmitted through it.

High-frequency sound is more easily reduced than low-frequency sound when it pass through material.

The Path – Transmission Loss (TL) of Partition



The reverberant sound pressure level in receiving room is given by :

$$SPL_2 = SPL_1 - R + 10 \log S_p - 10 \log A \text{ dB}$$

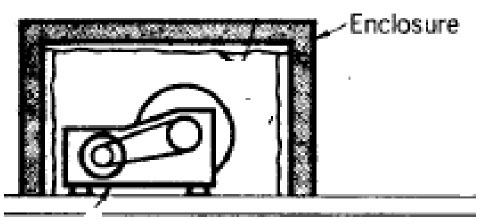
where SPL_2 is the reverberant sound pressure level in the receiving room, dB
SPL_1 is the average sound pressure level on the source side of the partition, dB
R is the sound reduction index of the partition, dB
S_p is the area of the partition, m^2
A is the total absorption ($= S.\bar{\alpha}$) in the receiving room, m^2 units
S is the surface area in the receiving room, m^2
$\bar{\alpha}$ is the average absorption coefficient in the receiving room

The Path –
Noise reduction by enclosure

Sound Absorption of Materials

The absorptivity of a material depends on thickness, frequency of the sound, and whether there is a reflective surface located behind the absorptive material.

The absorptivity of a material is described as absorption coefficient.



Reduction in reverberant sound pressure level

in a room due to the enclosure of a source in the same room:

$$SPL_1 - SPL_2 = R - 10 \log S_E + 10 \log A_E$$

SPL_1 and SPL_2 are respectively, the reverberant sound pressure levels in the room before and after enclosure of the source, dB

R is the sound reduction index of the enclosure wall

S_E is the amount of surface area of the enclosure radiating into the room, m²

A_E is the total absorption inside the enclosure, $S_E\bar{\alpha}_E$, m² units

$\bar{\alpha}_E$ is the average absorption coefficient inside the enclosure.

The Path –
Noise reduction by Sound Barrier

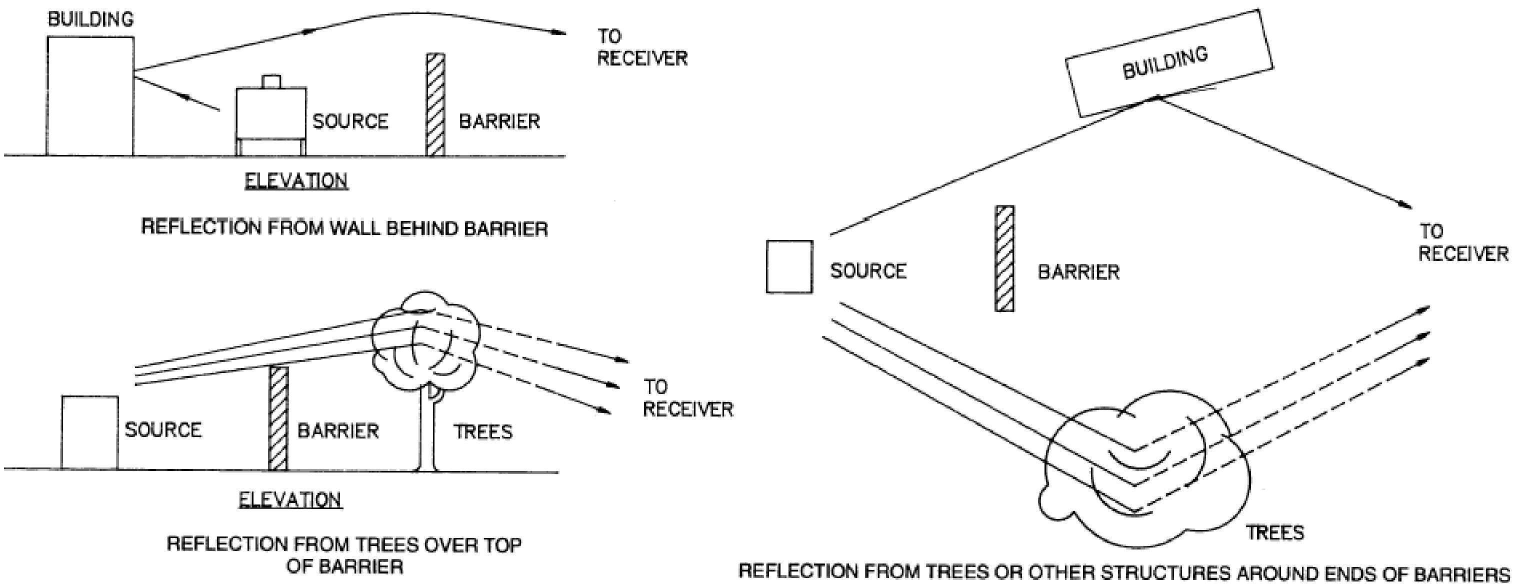
A sound barrier is a solid structure that intercepts the direct sound path from a sound source to a receiver.

It reduces the sound pressure level within its shadow zone.

Maximum reduction in SPL = 24 dB due to Scattering and refraction of sound into the shadow zone formed by the barrier

Practical constructions, size and space restrictions often limit sound barrier performance to 10 to 15 dB.

The Path –
Noise reduction by Sound Barrier

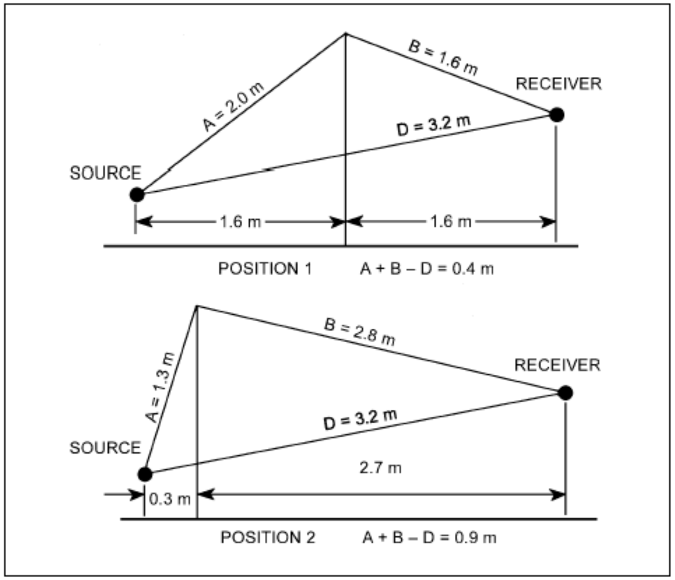


The Path –
Noise reduction by Sound Barrier

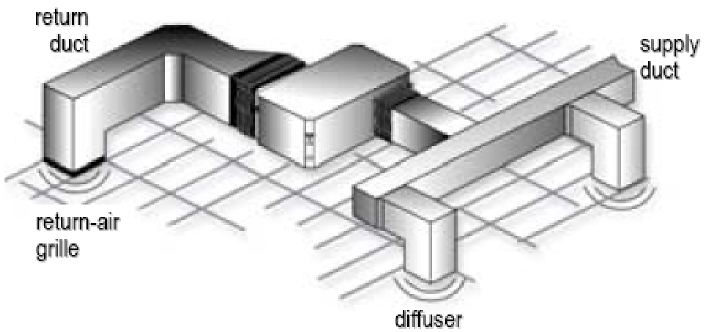
Path-Length Difference, m	Insertion Loss, dB Octave Band Center Frequency, Hz							
	31	63	125	250	500	1000	2000	4000
0.003	5	5	5	5	5	6	7	8
0.006	5	5	5	5	5	6	8	9
0.015	5	5	5	5	6	7	9	10
0.03	5	5	5	6	7	9	11	13
0.06	5	5	6	8	9	11	13	16
0.15	6	7	9	10	12	15	18	20
0.3	7	8	10	12	14	17	20	22
0.6	8	10	12	14	17	20	22	23
1.5	10	12	14	17	20	22	23	24
3.0	12	15	17	20	22	23	24	24
6.1	15	18	20	22	23	24	24	24
15.2	18	20	23	24	24	24	24	24

Insertion Loss Values of an Ideal Solid Barrier

Path-length difference = $A + B - D$



The Path –
Noise control in Ventilation System



<u>Step 1- Minimize flow resistance and turbulence in air distribution system</u>

High flow resistance increases the required fan pressure and results in higher fan noise. Turbulence increases the flow noise generated by duct fittings and dampers.

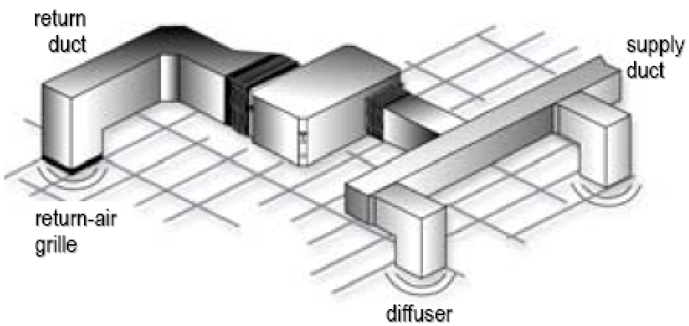
<u>Step 2 - Select of a fan</u>

A fan operating close peak efficiency at design point. Not oversize or undersize fan => inefficient point.

<u>Step 3- design duct connections (the fan inlet and outlet) for uniform & straight air flow</u>

Else, turbulence at the fan inlet and outlet and in flow separation at the fan blades →increase fan noise

The Path –
Noise control in Ventilation System



<u>Step 4 - Selection of Silencer</u>
Duct silencers not largely increase fan total static pressure. Maximum static pressure losses = 87 Pa

<u>Step 5 – Flow velocity and duct area</u>
Duct airflow velocity <7.5 m/s near critical noise areas by expanding the duct cross-section area.

<u>Step 6 – Turning vanes at elbows & discharge point far from them</u>
Use turning vanes in large 90° rectangular elbows and place grilles, diffusers and registers far from them.

<u>Step 7 – Vibration Isolators/ Flexible Connectors</u>
Vibration isolation for ceiling supported pipes and pipe flexible connectors between equipment & pipes.

The Path –
Noise control in Ventilation System

Silencers used in HVAC&R systems :

<u>Dissipative silencers.</u>

Dissipative silencers use perforated metal surfaces covering acoustic grade fiberglass to attenuate sound over a broad range of frequencies.

<u>Packless silencers</u>

The facing material can be made of galvanized or aluminum sheet with perforation.

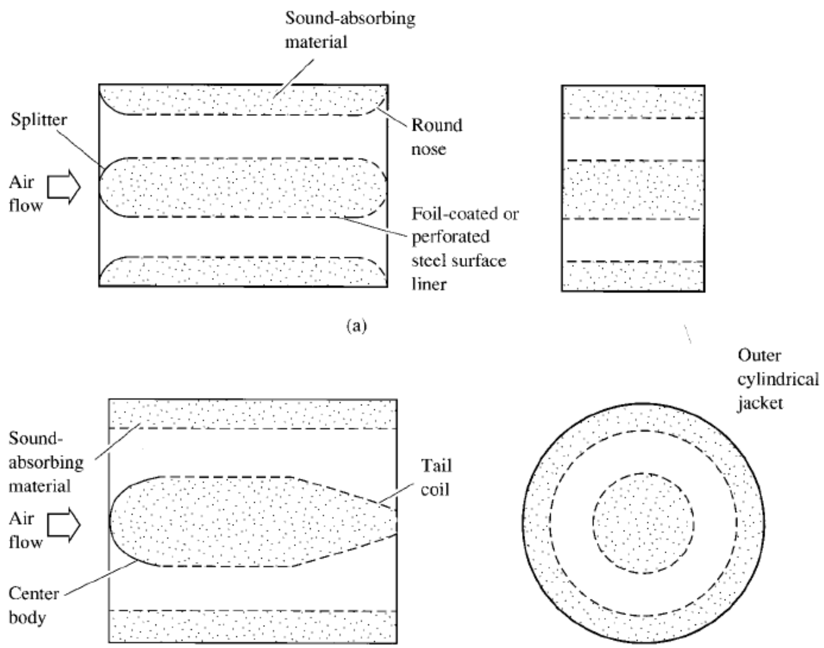
There is no fibrous fill. Noise is attenuated by means of acoustically resistive perforations in the splitters.

<u>Active silencers</u>

These silencers produce low-frequency inverse sound waves to cancel the unwanted noise.

The Path –
Noise control in Ventilation System

Dissipative Silencer



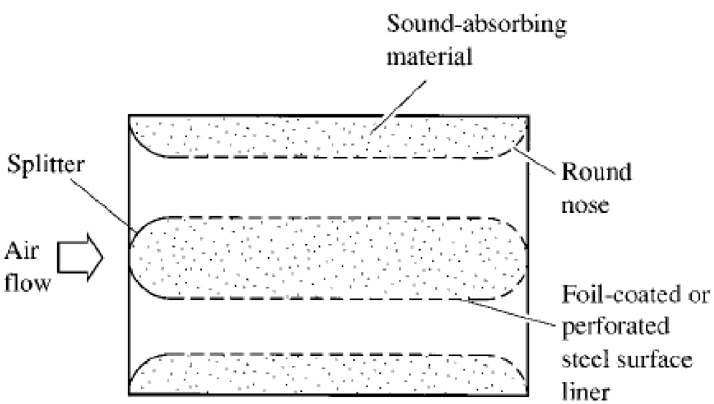
A silencer is for reduction of the sound power level of a fan, an airflow noise, or other sound source transmitted along a duct-borne path or airborne path.

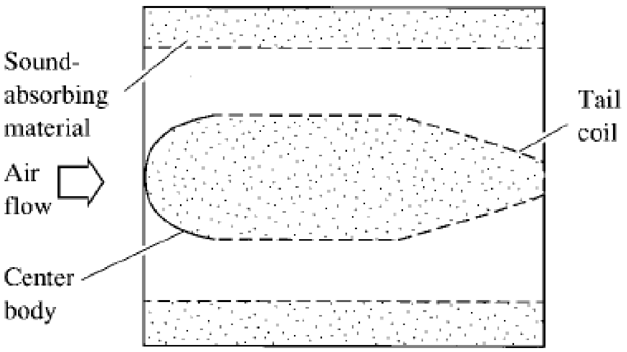
Rectangular and cylindrical silencers: (a) rectangular silencer and (b) cylindrical silencer.

A say 2m length prefabricated silencer is effective in frequencies between 63 and 4000 Hz

The Path –
Noise control in Ventilation System

Dissipative Silencer





Inside the rectangular casing are a number of flat splitters, depending on the width of the silencer.

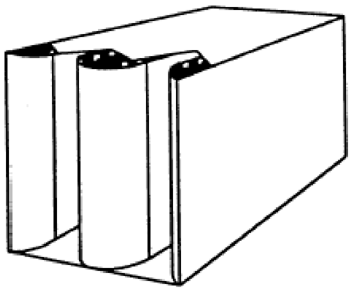
These splitters direct the airflow into small sound-attenuating passages.

The splitter is made from an envelope containing sound-attenuating material, such as fiberglass or mineral wool, with protected non-eroding facing.

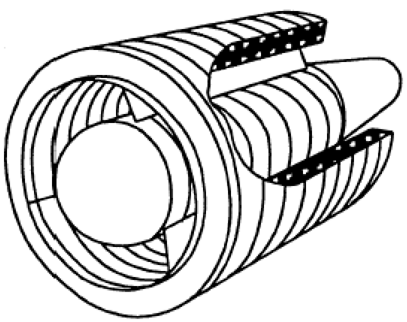
The thickness of a splitter is often between 25 and 100 mm.

The Path –
Noise control in Ventilation System

Dissipative Silencer



Rectangular Duct Silencer



Circular Duct Silencer

Splitters often have a round instead of a flat nose, to reduce their airflow resistance.

A rectangular silencer is often connected with rectangular ducts or sometimes with rectangular fan intakes and discharges.

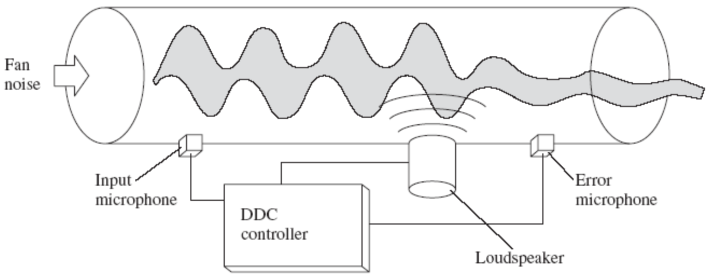
A cylindrical silencer has an outer cylindrical jacket and an inner concentric center body.

Both the cylindrical jacket and the center body contain sound-attenuating material and non-eroding facing.

A cylindrical silencer is often used in conjunction with vane-axial fans and in round duct systems.

The Path –
Noise control in Ventilation System

Active Silencers



Active silencers use ducted enclosure to cancel duct-borne, low-frequency fan noise (including rumbles)

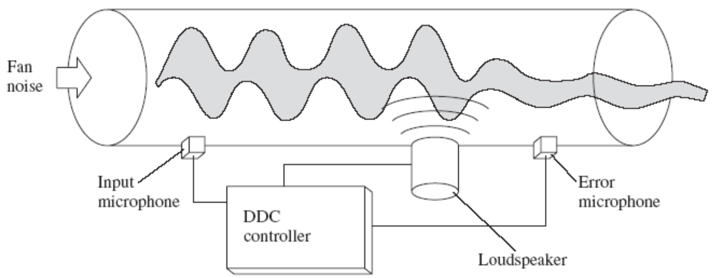
This is done by producing sound waves of equal amplitude and opposite phase.

The primary sound source is the unwanted fan noise.

The secondary sound source canceling the unwanted source comprises the inverse sound waves from a loudspeaker.

The Path –
Noise control in Ventilation System

Active Silencers



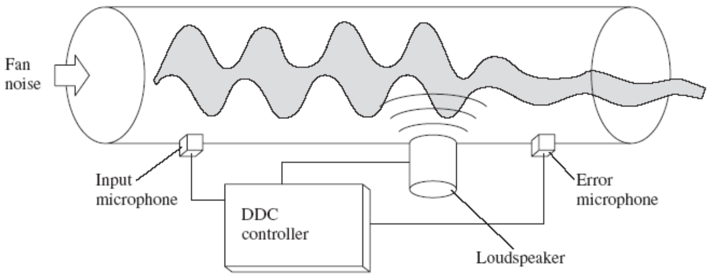
Fan noise is propagated along a duct, an input microphone measures noise and sends an electric signal proportional to the sound wave to the controller.

The controller calculates the amplitude, frequency, and phase of the propagating sound and sends a cancel signal to the loudspeaker.

The loudspeaker broadcasts sound waves of the same amplitude and frequency as the unwanted noise (180° out of phase).

The Path –
Noise control in Ventilation System

Active Silencers



The destructive interference between these two sound sources results in the cancellation of the incident fan noise by the secondary source broadcasted by the loudspeaker.

An error microphone measures the residual noise optimize the performance of the active silencer.

Active silencer has a good sound attenuation in frequencies between 31 and 125 Hz

Air velocity in an active silencer not exceeding 7.5 m/s.

The input power only at 40 W.

The Path –
Noise control in Ventilation System

Approximate attenuation of unlined sheet metal ducts at octave frequencies

Duct section	Mean dimension or diameter / mm	Attenuation / dB·m^{-1} for stated octave band / Hz			
		63	125	250	500 and above
Rectangular	≤300	1.0	0.7	0.3	0.3
	300–450	1.0	0.7	0.3	0.2
	450–900	0.6	0.4	0.3	0.1
	>900	0.5	0.3	0.2	0.1
Circular	<900	0.1	0.1	0.1	0.1
	>900	0.03	0.03	0.03	0.06

Unlined straight ducts

Attenuation of noise in straight unlined ducts is mainly through transfer of energy from the sound wave to the duct wall.

This energy then appears as either breakout noise from the duct or as duct vibration.

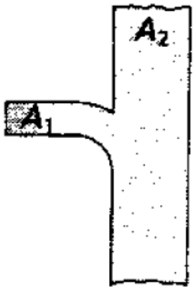
A duct with stiff walls will vibrate less than one with flexible walls, and will therefore have both lower attenuation and lower breakout noise.

Duct attenuation is expressed as decibels per metre (dB·m^{-1}) and is lower for circular ducts than for rectangular, as circular ducts have greater wall stiffness than rectangular ducts.

The Path –
Noise control in Ventilation System

Duct take-offs

When airflow is taken from the main duct by a junction or side branch, it is assumed that the sound power divides as the areas of the ducts as in Figure. The attenuation is given by equation.



A_1 = cross sectional area of branch 1

A_2 = cross sectional area of branch 2

$$\Delta L = 10 \lg \frac{A_1 + A_2}{A_1}$$

where ΔL is the attenuation (dB), A_1 is the cross sectional area of the take-off branch (m^2) and A_2 is the cross sectional area of the main duct after the branch (m^2).

The Path –
Noise control in Ventilation System

Approximate attenuation of unlined and lined square elbows without turning vanes

Frequency × width / kHz·mm	Attenuation / dB	
	Unlined	Lined
<50	0	0
50–100	1	1
100–200	5	6
200–400	8	11
400–800	4	10
>800	3	10

Approximate attenuation of unlined and lined square elbows with turning vanes

Frequency × width / kHz·mm	Attenuation / dB	
	Unlined	Lined
<50	0	0
50–100	1	1
100–200	4	4
200–400	6	7
> 400	4	7

The Path –
Noise control in Ventilation System

End reflection loss at octave band frequencies

Duct dimension, *D* / mm	End reflection loss / dB at stated octave band / Hz				
	63	125	250	500	1000
150	18	13	8	4	1
300	13	8	4	1	0
450	10	6	2	1	0
600	8	4	1	0	0
750	6	2	1	0	0
1000	5	2	1	0	0
1200	4	1	0	0	0

End reflection loss

The change in propagation medium (when sound travels from duct termination into a room)→ reflection of sound back up the duct.

The effect is greatest at long wavelength (i.e. low frequencies)

This leads to a contribution to the control of low frequency noise from the system.

Sound Level at a Receiver Point

When a source sounds in a room, energy travels from a source to the room boundaries, where some is absorbed and some of it is reflected back into the room.

The relation between sound pressure level and sound power level in real room may be found by

$$L_p = L_W - (10 \lg r) - (5 \lg V) - (3 \lg f) + 12$$

where L_p is the sound pressure level (dB), L_W is the sound power level (dB), r is the distance from a source (m), V is the volume of the room (m^2) and f is the frequency (Hz).

Sound Level at a Receiver Point

For a normally furnished room with regular proportions and acoustical characteristics between `average' and `medium-dead' and room volume < 430 m^3, a point source of source could be found by: -

$$L_p = L_W + A - B$$

Average: rooms with suspended ceilings or soft furnishings, carpeted and with drapes, e.g. typical office spaces.

Medium-dead: rooms with suspended ceilings, carpets and soft furnishings, e.g. executive offices.

Values of constant A for equation

Room volume / m^3	Value of A / dB for stated octave band / Hz						
	63	125	250	500	1000	2000	4000
42	4	3	2	1	0	–1	–2
71	3	2	1	0	–1	–2	–3
113	2	1	0	–1	–2	–3	–4
170	1	0	–1	–2	–3	–4	–5
283	0	–1	–2	–3	–4	–5	–6
425	–1	–2	–3	–4	–5	–6	–7

Values for constant B for equation

Distance from point source / m	Value of B / dB
0.9	5
1.2	6
1.5	7
1.8	8
2.4	9
3.0	10
4.0	11
4.9	12
6.1	13

Sound pressure level at a given location in a room

The sound power level information on a source to predict the sound pressure level at a given location due to a source of known sound power level depends on:

(1) room volume,
(2) room furnishings and surface treatments,
(3) magnitude of the sound source(s), and
(4) distance from the sound source(s) to the point of observation.

The relationship between source sound power level & room SPL :

$$L_p = L_w + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right)$$

where

L_p = sound pressure level, dB re 20μPa
L_w = sound power level, dB re 10^{-12} W
Q = directivity of the sound source (dimensionless)
r = distance from the source, m
R = room constant, $S\bar{\alpha}/(1-\bar{\alpha})$
S = sum of all surface areas, m^2
$\bar{\alpha}$ = average absorption coefficient of room surfaces at given frequency

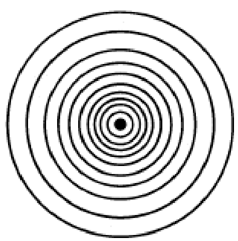
$$\bar{\alpha} = \frac{S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3 + \ldots \text{etc.}}{S}$$

S is the total surface area of the room

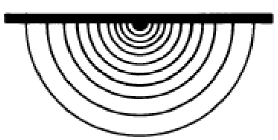
The sound pressure level at a given location in a room

$$L_p = L_w + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right)$$

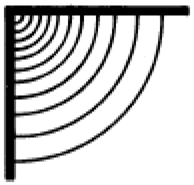
Position of source	*Directivity Factor* Q
Near centre of room	1
At centre of wall, floor or ceiling	2
Centre of edge formed by junction of two adjacent surfaces	4
Corner formed by junction of three adjacent surfaces	8



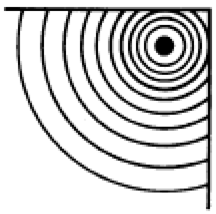
UNIFORM SPHERICAL RADIATION, $Q = 1$ NO REFLECTING SURFACES



UNIFORM HEMISPHERICAL RADIATION, $Q = 2$ SINGLE REFLECTING SURFACE

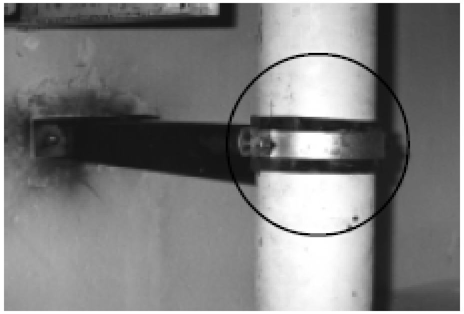


UNIFORM RADIATION OVER 1/4 OF A SPHERE, $Q = 4$ TWO REFLECTING SURFACES

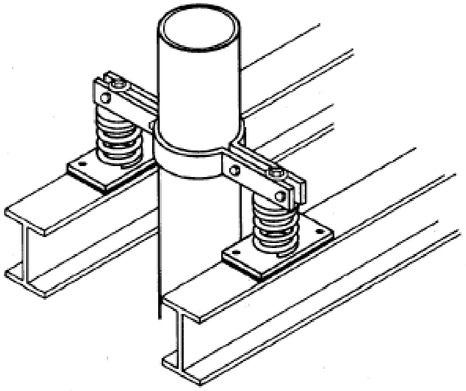


UNIFORM RADIATION OVER 1/8 OF A SPHERE, $Q = 8$ THREE REFLECTING SURFACES

Noise Control in Practice



Installation of Mountings with Rubber for Isolation
(Noise Reduction: 5dB(A))



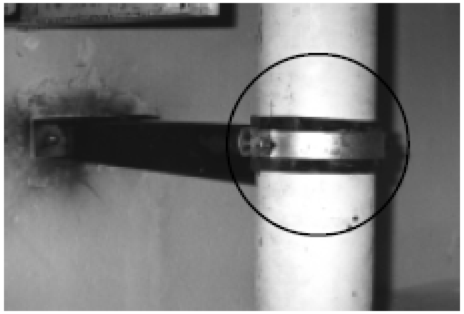
Spring Isolated Riser System

All piping has mechanical vibration (equipment and flow-induced vibration and noise)→ transmitted by the pipe wall and the water column.

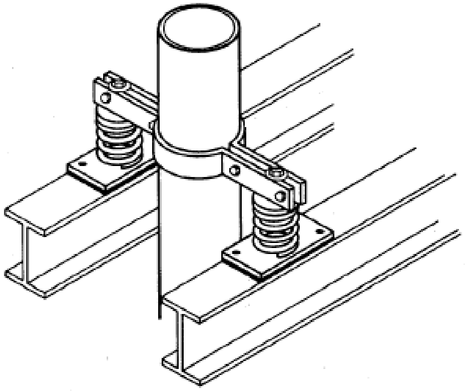
The piping system must be flexible enough to

- Reduce vibration transmission along the connected piping,
- Permit equipment movement without reducing the performance of vibration isolators, and
- Accommodate equipment movement or thermal movement of the piping at connections without imposing undue strain on the connections and equipment.

Noise Control in Practice



Installation of Mountings with Rubber for Isolation
(Noise Reduction: 5dB(A))



Spring Isolated Riser System

Minimized by sizing pipe so that

- the velocity is 1.2 m/s maximum for pipe 50 mm and smaller and

- using a pressure drop limitation of 400 Pa per metre of pipe length with a maximum velocity of 3 m/s for larger pipe sizes.

Flow noise and vibration can be reintroduced by

-turbulence,

-sharp pressure drops, and

-entrained air.

Noise Control in Practice

Flexible Pipe Connectors

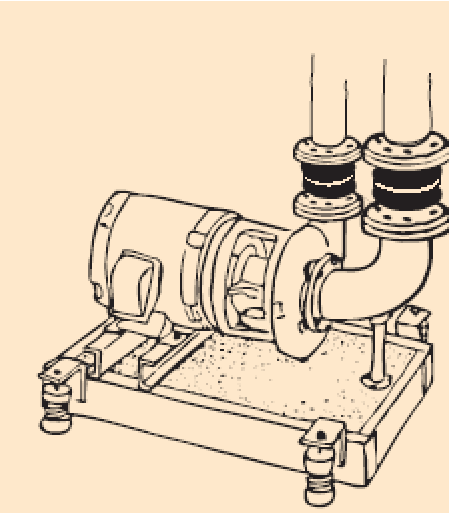
(1) They provide piping flexibility to permit isolators to function properly,

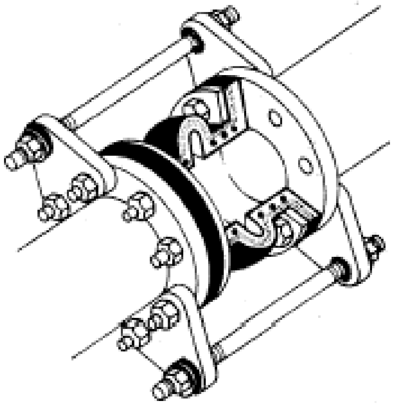
(2) They protect equipment from strain from misalignment and expansion or contraction of piping, and

(3) They attenuate noise and vibration transmission along the piping .

The most common type of connector are arched or expansion joint type, a short length connector with one or more large radius arches, of rubber or metal.

All flexible connectors require end restraint to counteract the pressure thrust.

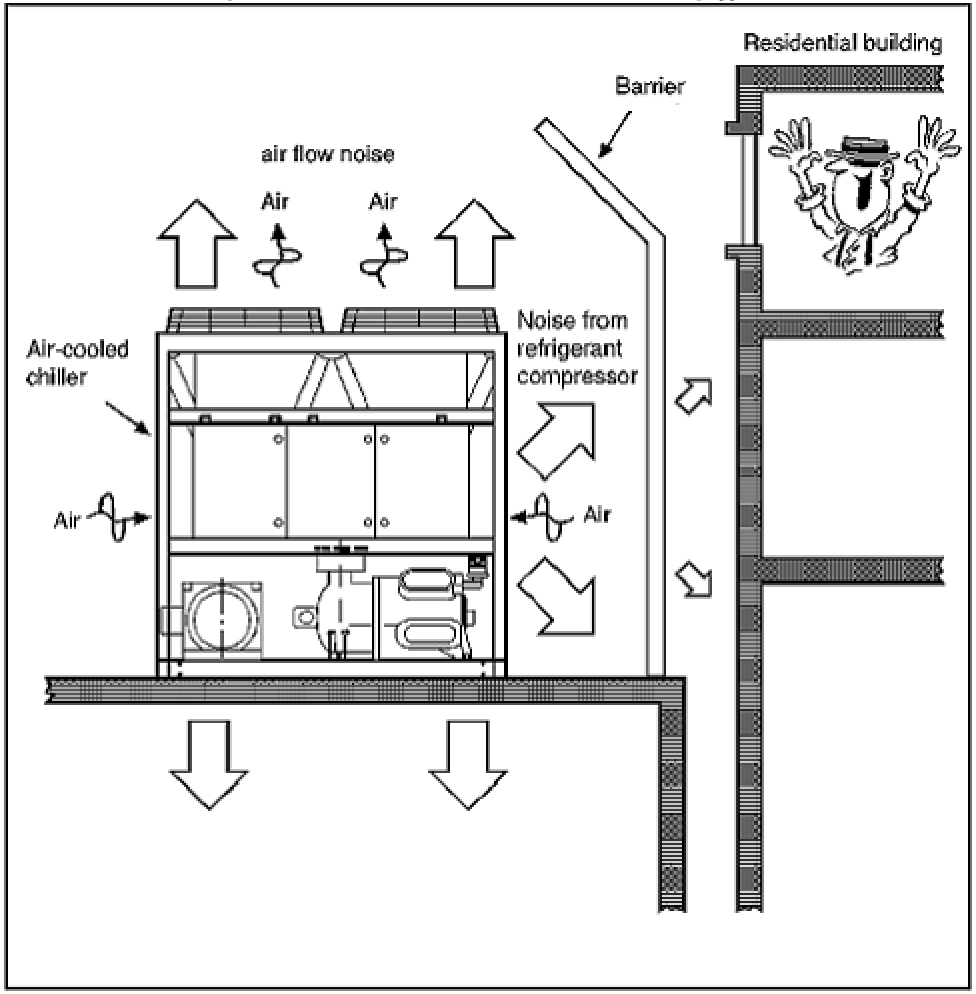




RUBBER EXPANSION JOINT
WITH CONTROL RODS

Noise Control in Practice

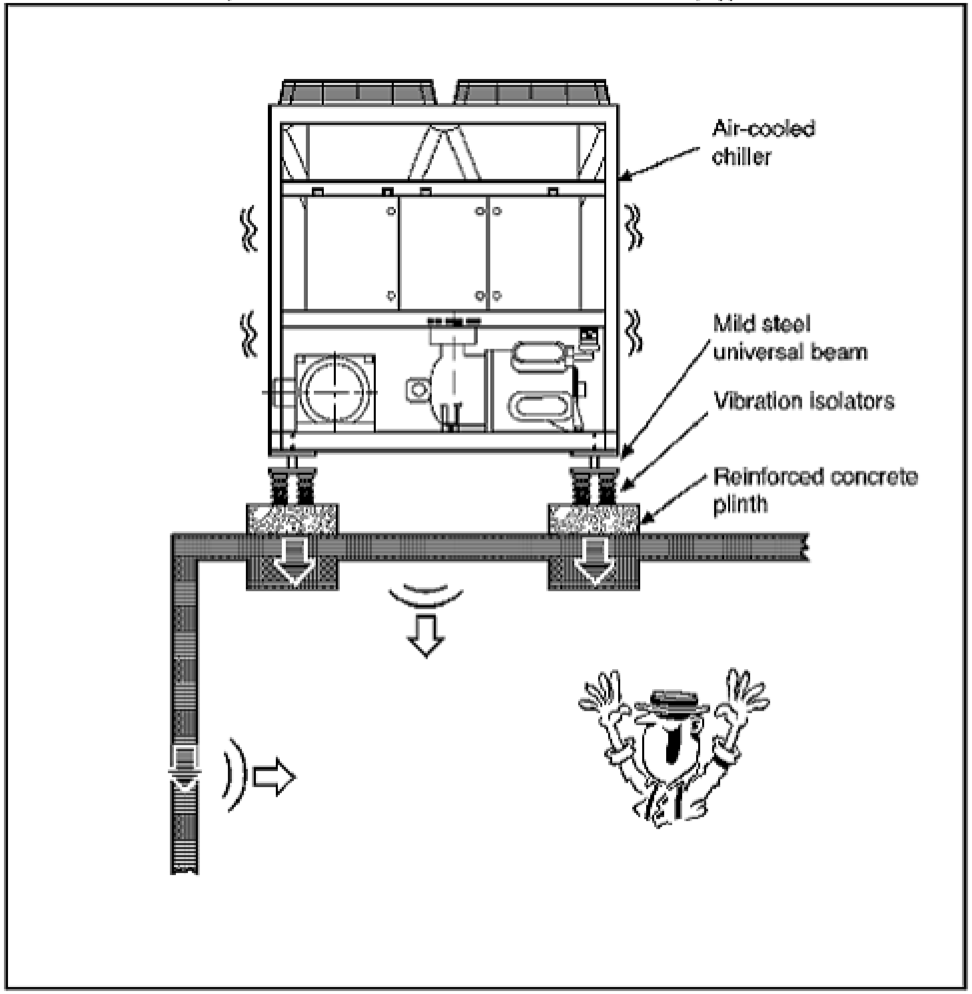
(NOISE REDUCTION UP TO 10dB(A))



Barrier for Air-cooled Chillers

Noise Control in Practice

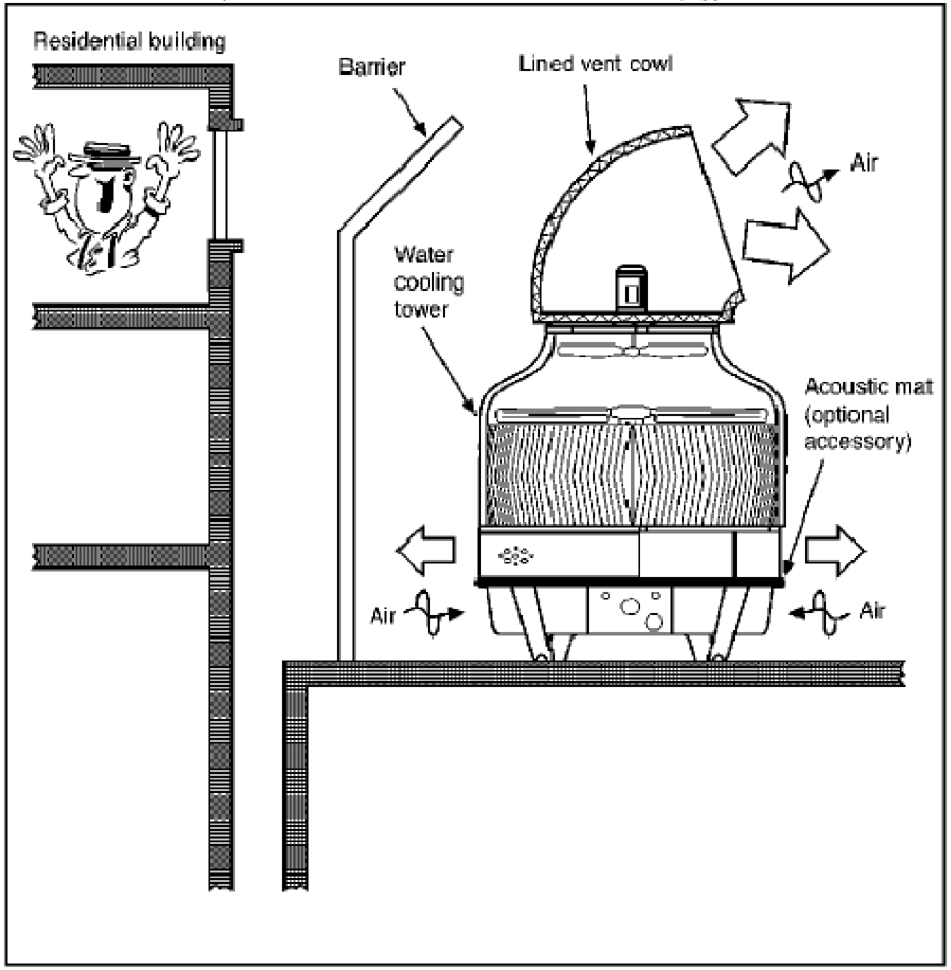
(NOISE REDUCTION UP TO 20dB(A))



Vibration Isolation of Air-cooled Chillers

Noise Control in Practice

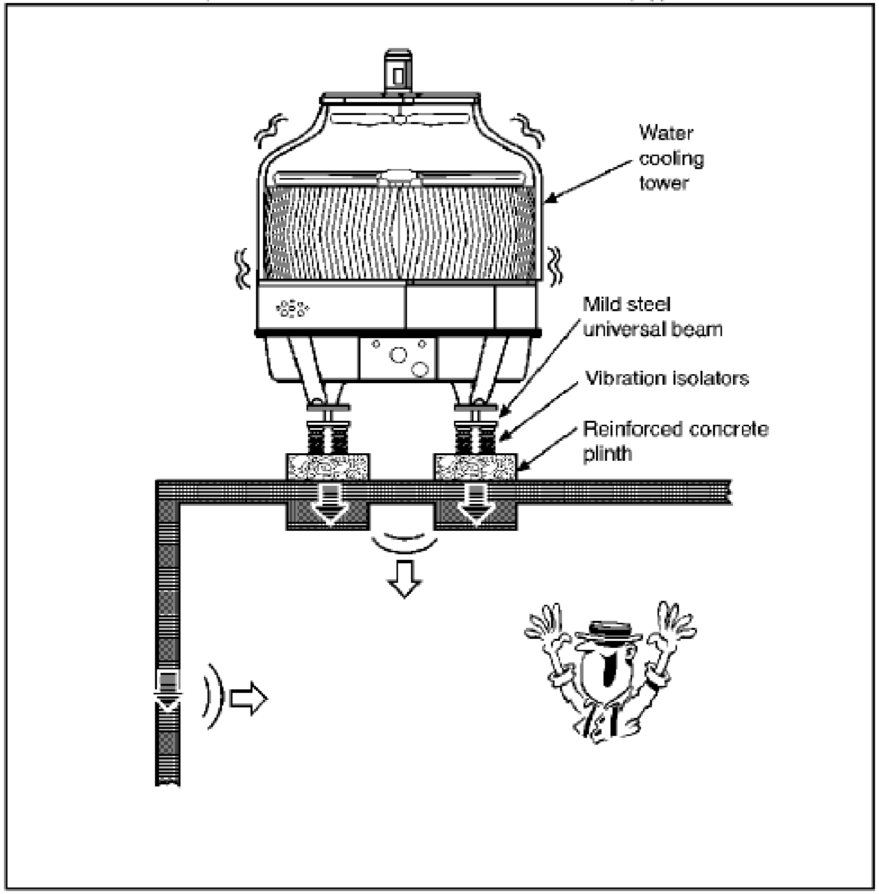
(NOISE REDUCTION UP TO 10dB(A))



Barrier and Vent Cowl for Water Cooling Towers

Noise Control in Practice

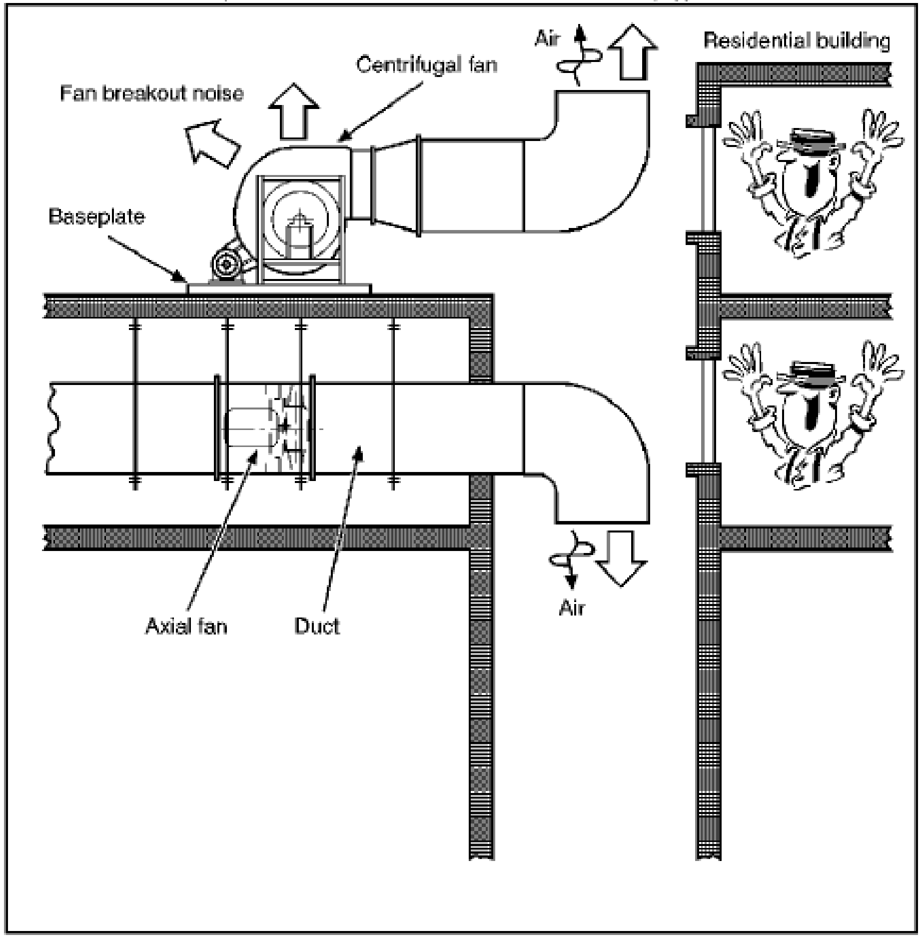
(NOISE REDUCTION UP TO 20dB(A))



Vibration Isolation of Water Cooling Towers

Noise Control in Practice

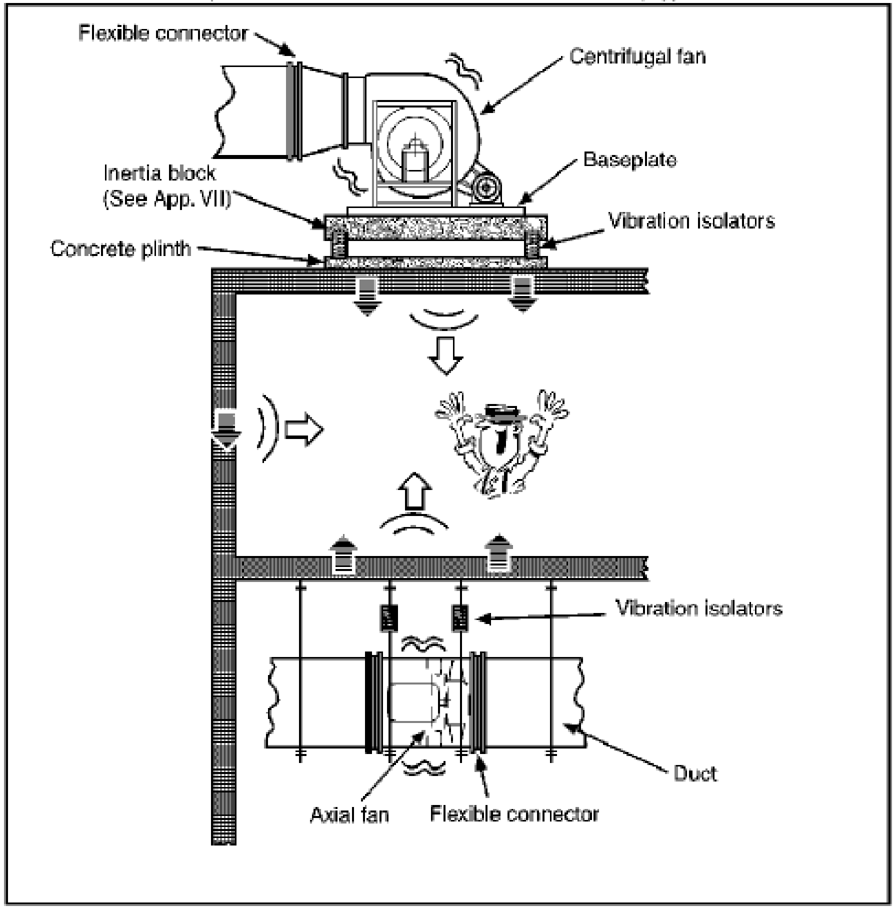
(NOISE REDUCTION UP TO 5dB(A))



Duct Diversion

Noise Control in Practice

(NOISE REDUCTION UP TO 20dB(A))



Vibration Isolation of Axial and Centrifugal Fans

The Noise Control Ordinance

1. Noise from domestic premises and public places (often referred to as general neighbourhood noise);
2. Noise from construction activities (including piling);
3. Noise from places other than domestic premises, public places or construction sites (for example, noise from industrial or commercial premises);
4. Noise from intruder alarm system installed in any premises or vehicle;
5. Noise from individual items of plant or equipment (referred to in the Ordinance as Product Noise, for example, noise from hand-held breaker and air compressor); and
6. Noise emission from motor vehicles.

When defining the acoustical design goal for an outdoor environment, to meet noise ordinance for example, the Environmental Protection Department specified A-weighted scale.

TECHNICAL MEMORANDUM FOR THE ASSESSMENT OF NOISE FROM PLACES OTHER THAN DOMESTIC PREMISES, PUBLIC PLACES OR CONSTRUCTION SITES

General Introduction to the Procedures

The Authority shall:

(a) determine the appropriate Acceptable Noise Level for the Noise Sensitive Receiver in question ;

(b) conduct measurements to obtain the Corrected Noise Level of the noise under investigation ; and

(c) compare the Corrected Noise Level with the Acceptable Noise Level to determine if a Noise Abatement Notice may be issued

DETERMINATION OF THE ACCEPTABLE NOISE LEVEL

The appropriate Acceptable Noise Level (ANL) for a particular Noise Sensitive Receiver (NSR) is dependent upon the character of the area within which the NSR is located, and the time of day under consideration.

The steps to be followed in determining an ANL are as follows:

(a) identify the NSR ;

(b) determine the Area Sensitivity Rating (ASR) of the area within which the NSR is located ; and

(c) determine the ANL by reference to the ASR and the time period under consideration.

The Noise Control Ordinance

Effect of Influencing Factors (IFs)

any industrial area, major road or the area within the boundary of Hong Kong International Airport shall be considered to be an IF.

Table 1 — Area Sensitivity Ratings (ASRs)

Type of Area Containing NSR \ Degree to which NSR is affected by IF	Not Affected	Indirectly Affected	Directly Affected
(i) Rural area, including country parks or village type developments	A	B	B
(ii) Low density residential area consisting of low-rise or isolated high-rise developments	A	B	C
(iii) Urban area	B	C	C
(iv) Area other than those above	B	B	C

Location of the Noise Sensitive Receiver (NSR)

any domestic premises, hotel, hostel, temporary housing accommodation, hospital, medical clinic, educational institution, place of public worship, library, court of law or performing arts centre

Any other premises or place, not being in the nature of either industrial or commercial premises, which is considered by the Authority to have a similar sensitivity to noise as the premises and places above

Determination of the Area Sensitivity Rating (ASR)

The ASR is a function of the type of area within which the NSR is located and the degree of the effect on the NSR of particular Influencing Factors (IFs)

The Noise Control Ordinance

Table 1 — Area Sensitivity Ratings (ASRs)

Type of Area Containing NSR \ Degree to which NSR is affected by IF	Not Affected	Indirectly Affected	Directly Affected
(i) Rural area, including country parks or village type developments	A	B	B
(ii) Low density residential area consisting of low-rise or isolated high-rise developments	A	B	C
(iii) Urban area	B	C	C
(iv) Area other than those above	B	B	C

The appropriate ANL, in dB(A), for a given NSR may be determined from Table 2, having regard to the appropriate ASR and the time period under consideration.

Table 2 — Acceptable Noise Levels (ANLs)

Time Period \ ASR	A	B	C
Day (0700 to 1900 hours)	60	65	70
Evening (1900 to 2300 hours)			
Night (2300 to 0700 hours)	50	55	60

Question and Answer