2. The flexible ducts can be enclosed in a solid enclosure constructed from timber, plasterboard or sheet steel, etc.
3. Add acoustic lining either glasswool or rockwool at least 1 inch thick;
4. Before enclosing flexible ducts, it should be noted that noise in the ceiling cavity will most likely penetrate the ceiling. This will happen more so if lightweight lay-in tiles are used. Fixed plasterboard ceilings give better acoustic performance than lightweight ceiling tiles.

Terminal Noise

The final links in the air distribution chain are the terminal air devices. These are the "grilles," "diffusers", "registers" and "vent covers" that go over the duct opening in the room. When selecting terminal devices; always select a device that has "noise criteria" rating of NC-30 or lower for the designed airflow rate.

NOISE REDUCTION STRATEGIES IN HVAC SYSTEMS

In HVAC systems, the source of noise is a combination of different processes, such as mechanical noise from fan(s), pump(s), compressor(s), motor(s), control dampers, VAV boxes and air outlets such as diffusers, grilles, dampers and registers. The HVAC noise that ultimately reach indoor space is made up of:

a. Low-frequency fan noise - Centrifugal fans generate highest noise in the low frequency range in or below the octave centered at 250-Hz.
b. Mid-frequency airflow or turbulence-generated noise – Terminal units, variable-air-volume (VAV) boxes produce their highest noise levels in the mid frequency range in the octaves centered at 250, 500 and 1000 Hz bands.
c. High-frequency damper and diffuser noises – Diffusers, and grilles, however, typically generate the highest noise levels in the octaves centered at 1000 Hz, or above.

It is important to appreciate that the sound energy can travel by several different paths. The airborne sound energy from the fan can propagate through the duct system in both directions from the fan, as well as into the fan room from the fan casing. Needless to say, each of these issues must be addressed, or else the design will fail.

The vibration energy of the fan can propagate through the fan room floor and other parts of the building structure, as well as through the walls of the duct system.

Note: *High frequency noise can be reduced using passive devices (attenuators, lining etc), but noise components at frequencies below 400-500 Hz are most difficult to attenuate.*

We will discuss various noise attenuation techniques in following paragraphs.

LOCATION OF EQUIPMENT

The installation position of equipment (chillers, air cooled condensers, cooling towers, exhaust fans etc.) is of critical importance in determining the noise level at the affected noise sensitive receivers. Where practicable, the equipment should be placed in a plant room with thick walls or at a much greater distance from the receiver or behind some large enough obstruction (e.g. a building or a barrier) such that the line of sight between receiver and the equipment is blocked. If noisy equipment has to be placed near a receiver due to spatial or other constraints, consider acoustic enclosures and barriers.

Air handlers are typically housed in mechanical rooms within the indoor space. These mechanical equipment rooms (MER) should be located away from sensitive areas and never on a roof directly over a critical space. If possible, isolate the equipment room by locating elevator cores, stairwells, rest rooms, storage rooms and corridors around its perimeter. The walls, floors and doors of MER must have high sound reduction indices and as the airborne sound easily passes through small gaps and cracks, the penetration points for pipes, cables and ducts through the walls must be well sealed. The doors must also be fitted with rubber sealing strips.

MER Size

As a rule, the larger the MER room, the quieter the HVAC system will be. It is important to have a sufficiently spacious mechanical room so that ductwork can be routed to accommodate insulation material and silencers. The air handler units and other mechanical equipment should be placed away from the walls or ceilings. There is a phenomenon called “close coupling,” in which a small air space will conduct cabinet vibratory motion to the wall or ceiling. A space of approximately 3 feet usually suffices. Provide a nominal 4 inch concrete housekeeping pad beneath equipment cabinets to minimize the effects of close coupling to the floor.

MER Wall Construction

The desired noise levels in the adjacent space and the amount of airflow determine the requirements for MER wall construction/treatment.

One method is to acoustically insulate the mechanical room walls and ceilings with fiber insulation mounted on wooden battens. The insulation shall be clad with perforated Aluminum sheet of 36 gauge. When sound strikes a surface, some of it is absorbed, some of it is reflected and some of it is transmitted through the surface. Dense surfaces, for the most part, will isolate sound well, but reflect sound back into the room. Porous surfaces, for the most part, will absorb sound well, but will not isolate. Acoustic insulation reduces the level of noise because while the sound waves are reflected back and forth in the room and interact with the sound-absorbing materials to lose some energy each time.

Wherever possible, plan the entrance to the MER from a non-critical buffer space such as a freight elevator lobby or janitor’s closet. If this is done, a solid core wood door or hollow metal door with glass fiber packing may be used. The door should have quality gaskets and drop seals to form an airtight seal all around.

MER Equipment

Right sizing of HVAC equipment and distribution system matching the turndown capabilities to the load being served is in essence, a fundamental engineering component to sustainable design. Besides high possibility of higher noise levels at source, an oversized equipment will short-cycle, frequently switching on & off which mean startup noise every time the equipment kicks in. Choosing the correct size (heating and/or cooling output) is critical not only in getting the best acoustic efficiency but also comfort, and lowest maintenance and operating costs over the life of the new system.

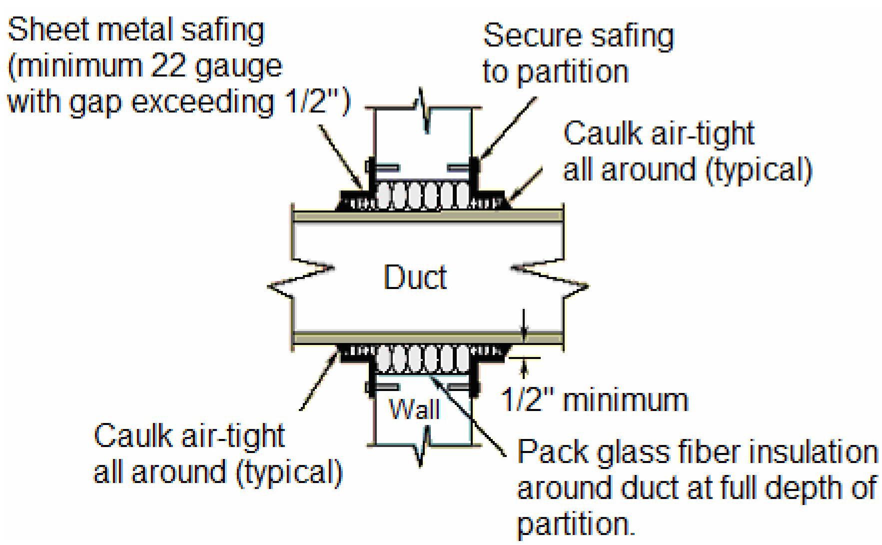
Further, the acoustical capabilities of the mechanical equipment should match the acoustical capabilities of the MER wall construction. For example, if a standard centrifugal fan system is selected for the project, and the acoustical engineer projects noise levels approximating NC 45 in the occupied space directly adjacent, the requirements for the wall and door should be in line with the known sound spectrum within the equipment room and projected noise levels outside the equipment room. A different MER wall may be selected for a mixed flow air handler and NC 35 projections.

On average, quieter equipment may generally be more expensive. However, it is almost always more economical in the long run to buy quieter equipment than to reduce noise by modification after purchase. Most equipment has a range of readily available noise control devices that are able to deal with the noise problems. It is advisable that noise levels specification is included when ordering new equipment. This allows the equipment suppliers to select appropriate equipment and optional noise control devices to suit the acoustic requirements.

MER Duct penetrations

All penetrations of MER walls must be sealed airtight. Sound, like air and water, will get through any small gap. All wall constructions must extend and sealed up to the floor construction above. If the wall is located under a beam, the space between the top of the beam and the deck must also be sealed.

The supply duct penetration must also remain resilient, avoiding rigid contact between the duct and the wall. The space between the duct and the wall should be packed with glass fiber insulation and be closed to a 1/2” wide gap. This gap should then be sealed with a permanently resilient sealant such as silicone caulk or acoustical sealant.



Duct penetration detail at wall

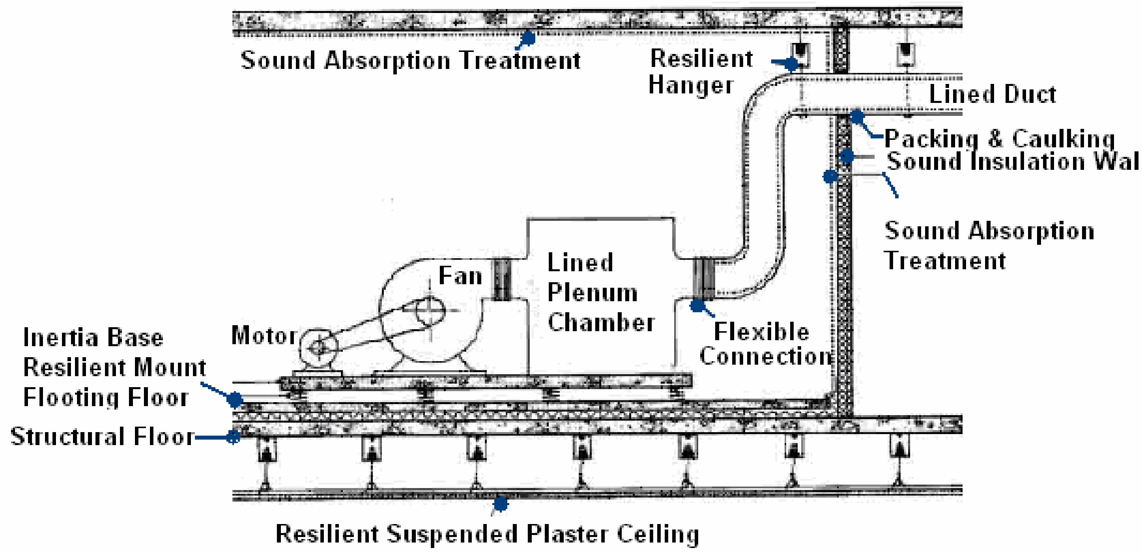
The figure above illustrates a recommended means of sealing the duct at the MER wall. The key to success is to allow no direct contact of the duct to the equipment room wall and to leave no voids between the ductwork and the wall.

VIBRATION ISOLATION

Rotating or motor-driven machinery generates lot of vibration that can travel through a building's structure and radiate from the walls, floors and ceilings in the form of airborne noise. It is therefore necessary to isolate any vibrating equipment from the surrounding structure. This can be accomplished by:

1. Balancing the machines to reduce the forces at the source; a well-balanced motor and fan impeller at as low a RPM as possible shall result in lower vibrations;
2. Using resilient, anti-vibration mountings between the machine and the supporting structure. Common materials used as vibration isolators are rubber, cork, various types of steel springs, and glass fiber pads;
3. Placing the rotating equipment on grade, in the basement, or in the sub-basement. Most pumps need isolators even in these desirable locations;
4. Using inertia blocks at the base of the equipment to reduce motion, lower the center of gravity, minimize the effect of unequal weight distribution of the support equipment, and stabilize the entire vibration isolation system. Generally an inertia block should be at least 6” thick and very stiff and rigid to avoid significant flexure in any direction;
5. Using flexible connectors on fans at each duct connection. These connectors should not be pulled taut, but should be long enough to provide folds or flexibility when the fan is off;
6. Considering floating floors particularly if the mechanical room is located on a different floor.

The figure below shows a source (air-handling unit) placed on a resilient support inside the mechanical room.



NOISE FROM FAN SYSTEMS

The most dominating source of noise in HVAC systems is because of the fans and blowers of the air handling units. The noise generated by fan is transmitted through a building in different ways: via walls, floors and leakage points to adjacent rooms and via the supply and extract ductwork to the rooms connected to the ducting.

Types of Fans

The noise generated by a fan depends on the fan type, fan speed, air flow rate, pressure and the intake/discharge arrangement. HVAC fans are mostly of the centrifugal type or the axial flow type. The primary selection criterion for a fan is based NOT on its acoustical characteristics but on its ability to move the required amount of air against the required pressure. In most cases it is not practical to substitute a fan which generates less noise, since a quieter design of the same type probably will not meet the other operating specification for the fan.

Axial-flow fans impart energy to the air by giving it a twisting motion. Axial fans generate a higher proportion of high frequency noise but less low frequency noise than centrifugal fans of similar duty. Three types are common:

- Vane-axial fans generally have the lowest amplitudes of sound at low frequency of any fan. For this reason they are often used in applications where the higher frequency noise can be managed with attenuation devices. In the useful operating range, the noise from vane-axial fans is a strong function of the inlet airflow symmetry and blade tip speed.

- The tube-axial fan generates a somewhat higher noise level than the vane-axial fan; its spectrum contains a very strong blade frequency component.
- The noise levels of the propeller fan are only slightly higher than those of the tubeaxial and vaneaxial fans, but such of the noise is at low frequencies and therefore is difficult to attenuate. Propeller fans are most commonly used on condensers and for power exhausts.

Centrifugal fans move air by centrifugal action. The centrifugal forces are created by a rotational air column which is enclosed between the blades of the fans. These produce most of their noise in the low frequencies, but in general are quieter than axial fans. Centrifugal fans may be further characterized by the type of blade used. Two common types of centrifugal fans frequently encountered in HVAC applications are forward curved and backward curved blades.

- The forward-curved fan is used primarily for HVAC work where high volume flow rates and low-pressure characteristics are required. Forward curved fans are commonly used in self-contained package units where space is at a premium. The most distinguishing acoustical concern of FC fans is the prevalent occurrence of low-frequency rumble. Forward curved blades will deliver more air than backward curved blades at a given speed, with increased noise, and if the resistance is reduced will deliver still more air and may overload the driving mechanism.
- Backward curved (BC) fans are generally much more energy efficient than FC fans at higher pressures and airflow. They require higher speed for the same air delivery and resistance as forward curved blades, but are less noisy and may be so designed as never to over load when the resistance is reduced. If the fan is close to a critical space, consider a backward curved (airfoil type) fan and silencers since the low rumble of forward-curved fans can be difficult to silence.

Many other designs fall between these two options.

Fan Characteristics

Maximum fan efficiency coincides precisely with minimum noise. Select fans that operate as near as possible to their rated peak efficiency when handling normal airflow and static pressure. This may seem obvious, but is often overlooked. Using an oversized or undersized fan can lead to higher equipment noise levels. The resulting variations in fan RPMs can also lead to airflow fluctuations and duct rumble.

Typical Sound Power Levels of Fans

Volumetric Flowrate (CFM)	Sound Power Level, dB (A) at Static Pressure	
	0.5 inch wg	3 inch wg
1000	79	95
5000	83	99
10000	85	101
20000	89	105
25000	90	107
50000	93	110

The sound power generated by fan performing a given duty is best obtained from manufacturer's test data taken under approved (ASHRAE Standard 68- 1986; also AMCA Standard 300-1986). However, if such data are not readily available, the octave-band sound power levels for various fans can be estimated by the empirical formulae described here.

$SWL = 77 + 10 \log kW + 10 \log P$

$SWL = 25 + 10 \log Q + 20 \log P$

$SWL = 130 + 20 \log kW - 10 \log Q$

Where:

- SWL = overall fan sound power level, dB
- kW = rated motor power, kW

- P = static pressure developed by fan, mm w.g.
- Q = volume flow delivered, m3/h

Octave band sound power levels are then found by subtracting correction factors from the overall sound power level calculated by any one of the above formulae.

Choice of Fan

A low self-noise level is an important criterion when specifying and choosing equipment. Fans should be chosen so they can operate at high levels of efficiency within their normal operating ranges. Fans that are made to run at unsuitable operating points, with subsequent poorer efficiencies, are often noisier than those that have been chosen correctly.

In CAV (constant flow) systems, fan should be chosen so that their maximum efficiencies are at the design air flows and static pressure. Operating the fan well off its duty point will create extra noise. Choosing a high-pressure air mover in a low pressure application will result in significantly greater noise. Conversely, a low-pressure air mover heavily loaded in a high-pressure application will also increase noise.

In VAV (variable flow) systems, fans should be chosen so that they can operate with optimal efficiencies and stability in the most frequently used working ranges. For example, a fan selected for peak efficiency at full output may aerodynamically stall at an operating point of 50% of full output resulting in significantly increased low frequency noise. Similarly, a fan selected to operate at the 50% output point may be very inefficient at full output, resulting in substantially increased fan noise at all frequencies. The fan for VAV applications should be selected for peak efficiency at an operating point of around 70 to 80% of the maximum required system capacity. This usually means selecting a fan that is one size smaller than that required for peak efficiency at 100% of maximum required system capacity. When the smaller fan is operated at higher capacities, it will produce up to 5 dB more noise. This occasional increase in sound level is usually more tolerable than the stall-related sound problems that can occur with a larger fan operating at less than 100% design capacity most of the time.

A correctly chosen and installed fan reduces the need for noise attenuation in the ducting system. The following points should be kept in mind:

- Design the systems: the ducts, terminal devices and components for low pressure drop;
- Compare sound data for different types of fans and from different manufactures and chose the quietest;
- Choose variable speed control for air flows rather than damper control.

Fan Speed

You need to know two things:

1. Fans are designed to push air: the faster the fan, the more air it pushes
2. Fans produce noise: the faster the fan, the more noise it produces

For our purposes, the best fan is the one that pushes the most air for the least noise.

The effect of rotational speed on noise can best be seen through one of the fan laws:

dB1 = dB2 + 50 log10 (RPM1 / RPM2)

Speed is an obvious major contributor to fan noise. For instance, if the speed of a fan is reduced by 20%, the dB level will be reduced by 5 dB."

The following table provides a guide to the trade-off that can be expected.

Fan Speed Reduction	Noise Reduction
10%	2 dB
20%	5 dB
30%	8 dB
40%	11 dB
50%	15 dB

Fan Selection

While it is true that fan noise is roughly proportional to the 5th power of fan speed, it is often mistakenly assumed that the lowest RPM fan selection is always the best selection. Note that the undersized fans operating at higher shaft speeds will produce more noise, and oversized (larger diameter) fans operating at lower shaft speeds will create more low-frequency noise (63, 125 and 250 Hz octave bands), which is much more difficult to remove.

Therefore, when choosing between two different fans of same duty and at same sound power, the one with the **lower** sound output at the **lower** frequencies is preferred from acoustic point of view. Sound power in higher-frequency bands is easier to control than low-frequency sound.

Fan discharge velocities for quiet operation

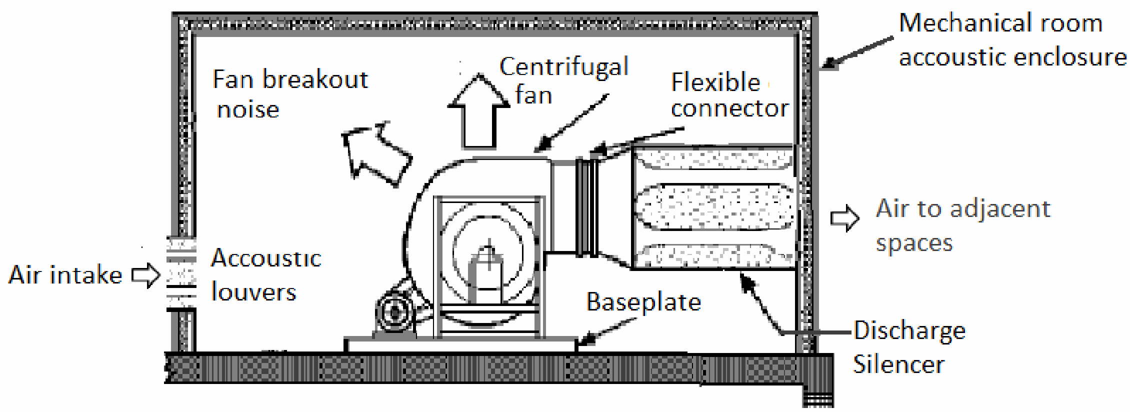
As conditioned air travels from a fan to an occupied room, it is subjected to acceleration, deceleration, changes in direction, division and a variety of surfaces and obstacles. Each of these effects disturbs the uniformity of the airflow and causes turbulence, which in turn creates noise. It is essential to limit the velocity of the airflow through all duct work systems in order to keep it from generating excessive noise. This is particularly true at the final branch ducts and the neck of the supply diffusers and return grilles where this regenerated noise is exposed directly into the occupied spaces.

Air-borne Noise from Fans

The air borne noise from fans mainly comes from the interaction of flow turbulence and solid surface of fan blades, and blade/fan vibration. The noise is transmitted upstream and downstream in the connecting ducts or to the atmosphere through the fan case.

Remedies

- Provide flexible connector at the fan discharge;
- Install a silencer at air discharge point of a fan so as to absorb noise generated from the fan;
- Install acoustic louvers at the fresh air intake;
- Acoustically insulate the mechanical room;
- Divert duct openings away from receivers for outdoor use;
- Provide acoustic enclosure to contain and absorb the noise energy for outdoor use, if required.



Centrifugal Fan serving the Indoor Spaces

Structure-borne Noise from Fans

Vibration from an operating fan may be transmitted to the interior of the building through building structure when the fan is directly mounted on a supporting structure without proper isolation. The vibration noise can be very annoying and must be tackled during design.

<u>Remedies</u>

- Provide an inertia block to support the fan so as to add rigidity and stability to the ventilation system;
- Provide vibration isolators to support the inertia block, thereby isolating it from the building structure;
- Provide flexible connectors between the fan and associated ducts, thereby isolating it from the ductwork.