The Challenge

Building design and construction must include engineering controls for HVAC equipment to limit objectionable noise and vibration levels. Meeting the acoustical expectations of building owners and occupants has become increasingly difficult with today's lightweight construction methods and with HVAC systems that are located in close proximity to occupied spaces and listener critical environments.

Proper design and effective use of noise and vibration control materials are required to avoid system problems. BRD has the practical experience using proven and tested materials to quiet mechanical systems in new design and remedial construction projects. There is no cost or obligation to consult with us on your next project.

HVAC System Problems

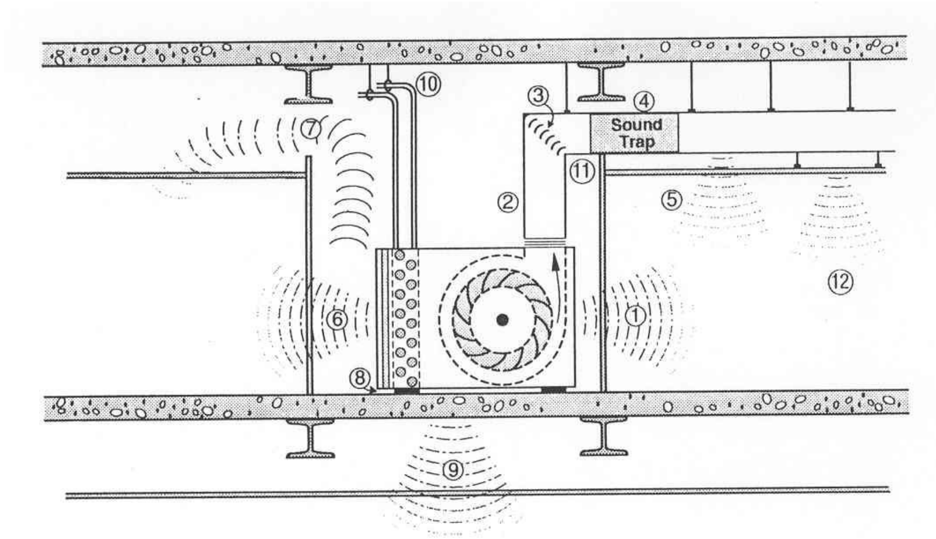
Noise and vibration problems in HVAC applications are rarely caused solely by the ventilation equipment. Most such complaints are system problems relating to the lack of integration of all system components.

Improper selection, design or installation can result in system problems despite the use of duct silencers, sound absorptive duct liners and other common noise and vibration treatments.

Correction Vs. Prevention

Correcting a noise or vibration problem after start-up of the HVAC system costs much more than addressing the potential problems at the design stage. Short cuts to save on construction costs may result in real costs far exceeding the monetary cost in direct payments to the retrofitting contractors. The opportunity costs of time lost in the investigation, analysis and implementation of a solution and the loss of goodwill from the building owner and/or tenants are also part of the real costs. The cost of prevention to incorporate sufficient noise controls and integrate all of the system components into a quiet design has been estimated at as little as 1% of total HVAC system costs. The benefits of prevention more than justify this small incremental increase in project costs.

Technical Discussion

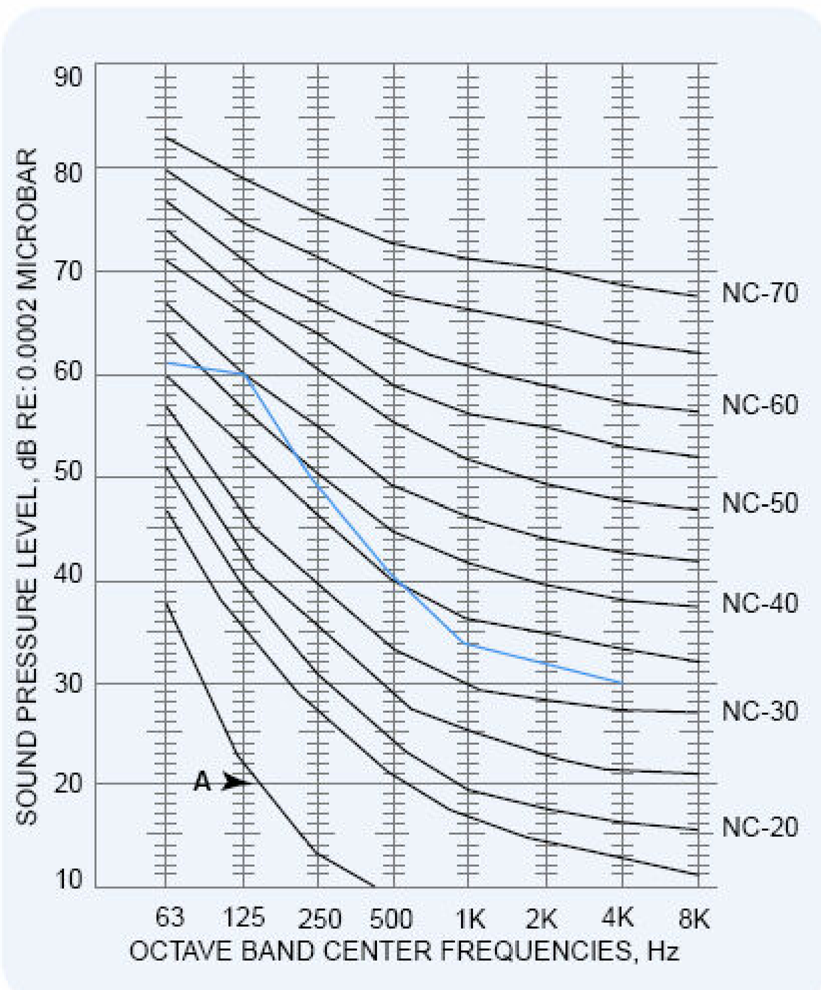


Typical "System" Problems For A Common Air Handling Application Are Shown Above And Described In More Detail Below

1. AHU panel vibration "couples" to the lightweight, flexible gypsum wall just a few inches away. This coupling lets low frequency noise pass easily through the wall.
2. The counterclockwise rotation of the fan's discharge air is forced to change direction at the downstream elbow. The change in the direction at the elbow causes turbulence resulting in excessive low frequency noise, duct rumble and pressure drop.
3. Problem 2 is aggravated if the elbow's turning vanes do not have long trailing edges to straighten the air flow and control the turbulence.
4. The sound trap is too close to the elbow. This compounds the turbulence problem.
5. Rectangular ductwork and sound traps do not control the rumble produced by turbulent air flow.
6. The AHU's air inlet is too close to the wall. This causes two acoustical problems: unstable fan operation leading to surge and rumble, and direct exposure of the inlet noise to the mechanical room wall.
7. The lack of a sound trap in a mechanical room return air opening allows fan noise to travel into the ceiling cavity, then through the lightweight acoustical ceiling into the occupied space.
8. The unit is resting on thin cork/neoprene isolation pads that are too stiff to adequately isolate the fan vibration.
9. The poorly isolated unit is resting on a relatively flexible floor slab without sufficient structural support. This arrangement allows unit vibration to enter the slab.
10. The chilled water piping is rigidly attached to the slab above, thereby letting unit vibration enter the slab.
11. Duct wall vibration in the sound trap (or any other part of the trunk duct system) touching the drywall partition can cause the partition to act as a sounding board and radiate low frequency noise into the occupied space.
12. Suspending the ceiling from the supply duct causes it to be a sound radiator.

Acoustical Rating Systems And Criteria

Many single number rating systems and criteria have been developed to quantify and describe HVAC system noise in buildings and occupied spaces. Examples of these rating systems include A-weighted decibels (dBA), loudness levels (Sones), room criteria (RC) and noise criteria (NC). Most commonly, engineers and consultants today are using the NC rating system in specifications and when evaluating noise situations. The NC curves and rating system are described in more detail below. They were derived from equal loudness curves consistent with human hearing frequency response. The NC system, like any rating criteria, has its own set of assumptions and limiting conditions. Building occupants agree that the NC curves have a spectrum shape that sounds too rumbly and hissy. Momentum is gathering in the engineering community to adopt the NCB (Noise Criteria Balanced) system, but standard NC methods remain the single most widely accepted rating system.



Noise Criteria (NC) Curves

Standardized NC curves are plotted at left along with frequency spectrum data for a particular room application. The NC-45 rating for the example, at left, is determined by comparing the plotted data to the standardized curves and finding the highest penetration which in this case is the tangent point on the NC-45 curve at 125 Hz (60 dB). The A curve represents the approximate threshold of hearing for continuous noise. The NC rating system should be used with caution in evaluating environments with dominant low frequency levels as the standardized curves do not extend down into the 16 Hz and 31.5 Hz octave bands.

Another caution/limitation of this system is the inability to differentiate the subjective quality of the noise for equivalent rating values.

Recommended NC Levels For Various Activities

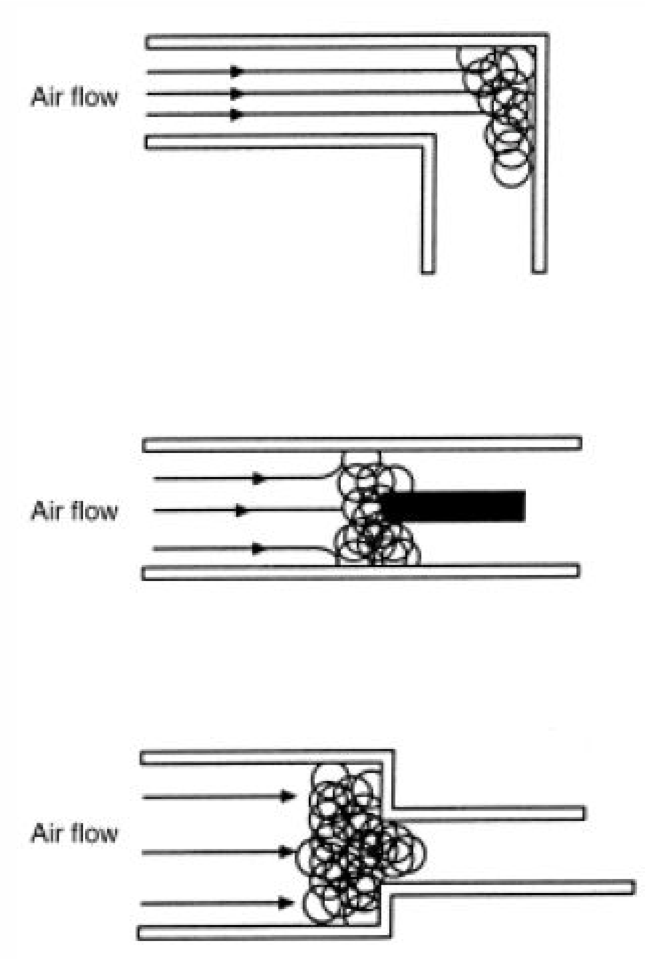
Broadcast studios (distant microphone pickup used)	10	Office buildings:	
Concert halls, opera houses, and recital halls		Offices	
(listening to faint musical sounds)	15-18	executive	25-35
Small auditoriums	25-30	small, private	35-40
Large auditoriums, large drama theatres, and large		larger, with conference tables	30-35
churches (for very good speech articulation)	20-25	Conference rooms	
TV and broadcast studios		large	25-30
(close microphone pickup only)	15-20	small	30-35
Legitimate theatres	20-25	General secretarial areas	40-45
Private residences:		Open-plan areas	35-40
Bedrooms	25-30	Business machines/computers	40-45
Apartments	30-40	Public circulation	40-50
Family rooms and living rooms	30-40	Hospitals and clinics:	
Schools:		Private rooms	25-30
Lecture and classrooms		Wards	30-35
with areas less than 70 sq. m.	35-40	Operating rooms	25-35
with areas greater than 70 sq. m.	30-35	Laboratories	35-45
Open-plan classrooms	35-40	Corridors	35-45
Hotels/motels:		Public areas	40-45
Individual rooms or suites	30-35	Movie theatres	30-40
Meeting/banquet rooms	25-35	Courtrooms	30-35
Service support areas	40-50	Libraries	35-40
Churches, small	30-35	Restaurants	40-45

Calculation	Source	Octave Band/Center Frequency (Hz)							
		1/63	2/125	3/250	4/500	5/1K	6/2K	7/4K	8/8K
1. Room design goal NC.									
2. Room attenuation.									
3. Multiple outlet effect.									
4. End reflection attenuation.									
5. Branch power division.									
6. Elbow attenuation, noise source to outlet. 7. Duct attenuation, noise source to outlet.									
8. Terminal unit correction.		-3	-3	-3	-3	-3	-3	-3	
9. Allowable PWL at fan discharge.	Total Lines 1-8								
10. Actual PWL at fan discharge.	Fan Mfr's Data								
11. Dynamic insertion loss (DIL) required.	Subtract Line 9 from Line 10								
12. DIL of selected silencer. HUSH DUCT™ MODEL______ Face velocity_____fpm.	HUSH DUCT™ Performance Tables								
13. Silencer air flow generated noise PWL at___fpm. Include air flow generated noise correction factor where required.	HUSH DUCT™ Performance Tables								
14. Attenuated fan PWL at silencer discharge.	Subtract Line 12 From Line 10								
15. Resultant PWL at silencer discharge (compare with Line 9).	Combine Lines 13 & 14.								

Simple form sample worksheet for system design calculations.

Detailed procedures for calculating HVAC system noise levels to meet a desired NC design goal are outlined in various trade reference guides and technical publications. Please refer to the chapters entitled "Sound and Vibration Fundamentals" in the ASHRAE Fundamentals Handbook and "Sound and Vibration Control" in the ASHRAE Systems and Applications Handbook for more details. The short form at left is available in full format upon request. Operating conditions and fan sound power levels

Regenerated Noise: HVAC Designer Enemy #1

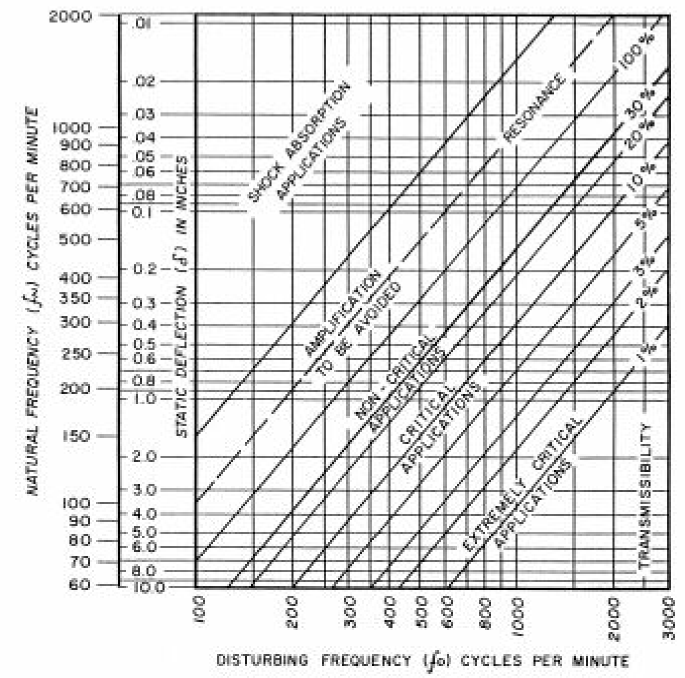


Medium and high velocity air flow impinging on any obstruction will cause disturbance of the air flow. The resultant turbulence produces regenerated noise. HVAC duct design components such as elbows, turning vanes, dampers, transitions, offsets, take-offs, tees, etc. are examples of such obstructions. The turbulence in most air flow systems is characterized by sharp changes in the air flow path, sharp bends, abrupt cross-sectional area changes, etc. in contrast to aerodynamic fan noise which manifests itself in a more tonal frequency spectrum at the fan blade passage frequency. Turbulence and regenerated noise are generally characterized by a broad band frequency spectrum. Turbulence increases noise levels and system operating costs. Regenerated noise can be minimized by ensuring smooth air flow conditions. SMACNA duct design and construction guidelines should be incorporated in all job specifications and drawings. The SMACNA guidelines also outline optimal duct silencer locations and guidelines for centrifugal fan installations (distances for placement of duct fittings).

The Design/Planning Phase

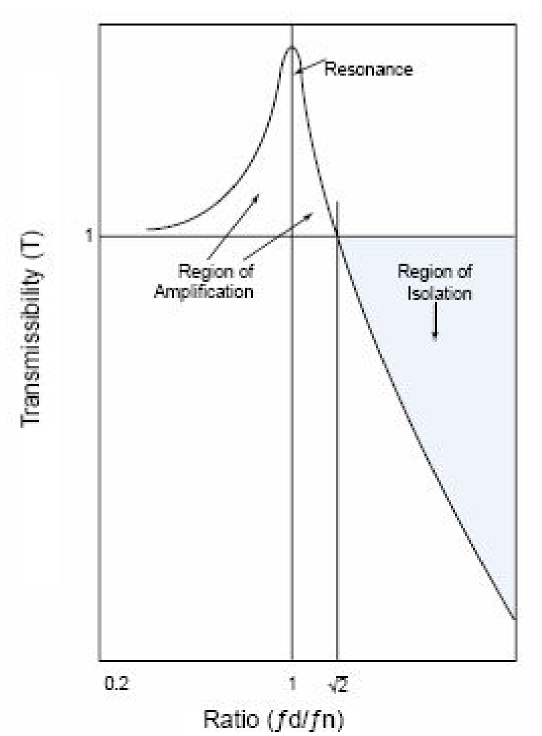
Postponing the acoustical design until the end of the working drawings phase does not allow for proper integration of all components to ensure the system design goals are met. The use of duct silencers, acoustical lining and insulation and vibration isolators if not integrated into the system or if improperly implemented can reduce the system performance (noise reduction) and in some cases cause additional noise or vibration problems. This explains why today, despite the increased use of acoustical equipment and materials, noise and vibration problems persist. Noise and vibration control design should start during the schematic and design development phases and continue throughout the entire design process.

About Vibration Isolation



The above chart graphically illustrates the static deflection required of a vibration isolation mounting to limit the transmission of vibration to a given percentage of the total vibratory force of the equipment. The chart also suggests the maximum permissible transmissibility for various conditions encountered in machinery/equipment installations. To use the chart, determine the lowest rotational speed of the equipment and consider this as the disturbing frequency. Move vertically to the slanted line corresponding to the % of transmissibility which can be tolerated. Then move horizontally to the left to determine the natural frequency and static deflection required of the isolators. Finally, refer to the HUSH MOUNT™ product section and select the isolator type with the corresponding static deflection. The efficiency chart models a single degree of freedom system. Other factors may affect the final selection. BRD sales engineers are ready to review your applications.

The chart below helps define amplification, isolation and resonance. The vertical axis shows transmissibility while the horizontal axis shows the ratio of the disturbing frequency (fd) to the natural frequency of the isolator system (fn). Resonance results when sympathetic vibrations reinforce each other because the disturbing frequency is equal to the isolator natural frequency (the fd/fn ratio equals one). Below a ratio of one we are in the region of amplification. Above a ratio of one we are still in the region of amplification until the ratio equals the square root of two. Above this point we begin the region of isolation because less energy is coming out of the isolator compared to what is going in. As a rule of thumb a ratio of ten to one is desirable for effective vibration isolation. A ratio below three to one is not generally recommended.



Technical Discussion

What Are Seismic Loads?

Seismic Loads are the forces exerted on a structure during an earthquake. Every structure is designed for vertical, or gravity loads. In the case of ducts or pipes, gravity loads include the weight of the ducts or pipes and their contents, and the direction of the loading is downward. The ordinary supports designed for gravity loads generally take care of the vertical loads imposed during an earthquake. Therefore, the primary emphasis in seismic design is on lateral, or horizontal forces. However, since vertical loads contribute to any overturning, they are included in seismic analysis.

What Happens During An Earthquake?

A fault is a fracture in the earth's crust, and an earthquake results from slippage along the fault plane. Any structure straddling the fault line will probably suffer damage, no matter how well it has been designed. However, most effects of earthquakes are not directly on the fault line. This is because the movement caused by the slippage creates waves in the earth that travel away from the fault plane. These waves change throughout the duration of the earthquake, add to one another, and result in extremely complex wave motions and vibrations. The direction of forces on structures can be horizontal, vertical, or rotational. In terms of the way they may affect a given building, they are not only unpredictable in direction, they are also unpredictable in strength and duration. The structural load is proportional to the intensity of shaking and to the weight of the supported elements.

How To Resist Seismic Loads

The general principle in resisting seismic loads is that we want equipment, ducts, and piping to resist seismic forces by the strength of their attachment to the building's structure. Naturally, we must assume that the building has been designed to perform safely in response to earthquake motions. So that they remain intact and functioning, we want equipment, ducts and pipes to move with the building during an earthquake and not break away from their supports. Therefore, the restraints are sized to insure the chances of keeping these systems attached to the structure.

Kinds Of Bracing

Because we cannot predict the directionality of seismic forces, it is important to restrain equipment and brace piping and ductwork in several directions. Floor mounted equipment is typically restrained by use of a seismic isolator or restraint which keeps the equipment captive. If the equipment does not require vibration isolators, properly sized anchor bolts can be used to seismically restrain the unit. In order to restrain ducts and pipes against seismic forces, longitudinal (in the direction of their run) and transverse (perpendicular to their run) bracing together with their vertical support will resist lateral loads from any direction. All in-line equipment must be braced independently of the ducts or pipes.

Angle Bracing vs. Cable Restraints

When suspended equipment, piping or duct is hung using spring or rubber vibration isolators, cables are required for seismic restraint so as not to short circuit or bypass the isolators. Angle bracing can be used when piping and duct is hard mounted to the structure.

General Requirements For Seismically Restraining Ducts

Rectangular ducts with cross-sectional areas of 6 square feet and larger, and round ducts with diameters of 28 inches or larger generally require seismic restraint. No bracing is required if the duct is suspended by hangers 12 inches or less in length. Bracing of ductwork shall be at 30 foot intervals, at each turn and at each end of a duct run.

General Requirements For Seismically Restraining Pipe

All piping of 2.5 inches nominal diameter and larger requires seismic restraint. All piping located in boiler rooms, mechanical equipment rooms, and refrigeration mechanical rooms that have a nominal diameter of 1.25 inches and larger require restraints. Fuel oil piping and gas piping (fuel gas, medical gas, compressed air) of 1 inch nominal diameter and larger require seismic restraint. No bracing or restraint is required for piping suspended by individual hangers 12 inches or less.