ASHRAE Research

Controlling HVAC system noise and vibration

A new ASHRAE special publication can help designers minimize the number and severity of HVAC system noise and vibration problems

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Today's practicing mechanical engineer has many sources of information to assist him or her in designing HVAC systems with appropriate levels of noise and vibration. These sources include texts,[1] journals,[2] industry periodicals,[3] manufacturers' applications bulletins[4] and reports on government- and ASHRAE-sponsored research projects.[5]

Many of these sources (such as the *ASHRAE Handbook—Fundamentals*[6] and *ASHRAE Handbook—HVAC Applications*[7]) describe the phenomena of noise and vibration in HVAC systems, and also present data and calculation methods that can be used to predict the noise levels near the various parts of an HVAC system.

Although many sources give guidelines for the selection and application of noise and vibration control products, they are frequently very technical and difficult for the practicing engineer to use.

The members of ASHRAE Technical Committee 2.6 (Sound and Vibration Control) have found that, despite the availability of these information sources, the number of noise and vibration complaints has been increasing.

The TC members who routinely troubleshoot noise and vibration complaints found that there are three underlying causes for most complaints:

- The acoustical aspects of the HVAC system were never considered during the design process, or were addressed in a piecemeal manner as the building was being constructed.
- The system components may have been selected properly, but were not integrated into a quiet *system*.
- Post-design cost cutting resulted in a system that, although less expensive, generated more noise or vibration.

Responding to the prevalence of these three causes, TC 2.6 requested that ASHRAE fund a research project to develop a book of HVAC system acoustical guidelines that would help engineers, architects and contractors make design decisions to minimize both the number and severity of noise and vibration problems.

This book *A Practical Guide to Noise and Vibration Control for HVAC Systems*[8] has three major themes, one to address each of the underlying problem areas mentioned above. The themes are:

- HVAC system noise and vibration control should be a cooperative effort of the entire design team, should start at the beginning of a building's design process and should continue throughout all phases.
- The levels of noise and vibration transmitted from an HVAC system into the surrounding spaces depend on the proper selection of the system components and their integration into a *system* that permits each component to perform optimally.
- Cost cutting frequently results in noisier HVAC systems.

The guidelines in the book were developed from reviews of hundreds of publications, as well as project files of mechanical engineers, contractors and acoustical professionals.

In some cases, the guidelines give specific design and selection procedures to

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About the author

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follow. In other cases, a comparison of alternate choices is given.

The book's intended audience includes mechanical engineers, architects, contractors, draftspersons, building managers and anyone else who has the responsibility for either preventing or solving HVAC system noise and vibration problems.

Sketches, photographs and checklists are used extensively to provide guidelines for the selection and application of basic HVAC system components, as well as noise and vibration control products. The book also includes sections on troubleshooting problems, some basics of HVAC system acoustics and definitions of acoustical terms.

A cooperative effort

Too often, HVAC systems are designed with little concern for controlling noise and vibration. Design team members may ask equipment vendors for their opinions during the design process, or an acoustical consultant may be retained just before the drawings are released for bids to check things over and make last-minute recommendations.

In such instances, the site plan, space plan, equipment selections, duct and pipe routing, and structural design are all complete and are unlikely to be changed.

On the other hand, if the project's acoustical aspects are given adequate priority during the early design phases, the design team has the necessary flexibility to select and locate HVAC equipment for proper operation and effective noise and vibration control.

In the early design phases, this is done by effective site planning, space planning, equipment selection and equipment room sizing. Proper consideration of acoustics early in the design may allow solutions to potential problems at little or no cost.

Site planning. This planning issue is important in the placement of ground-based, outdoor HVAC equipment such as cooling towers, air cooled condensers and air cooled chillers.

Many cities and counties have ordinances that place limits on the permitted level of HVAC system noise at adjacent property lines. Complying with a noise ordinance may mean locating the noisy equipment away from the property line and, thereby, bringing the equipment closer to the building that it serves.

This planning option must consider whether or not the equipment's proximity to the building may cause interior noise problems from sound penetration through the building's windows, doors or ventilation openings.

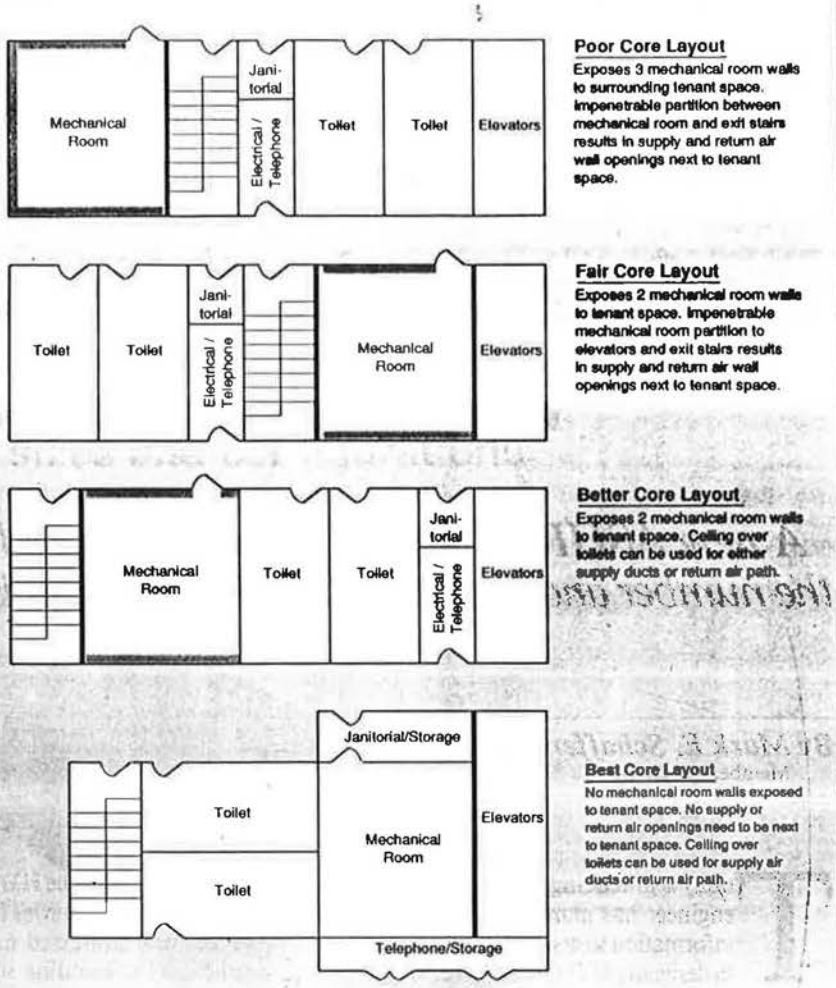

Figure 1. Acoustical comparison of various building core area layouts.

Space planning. The most effective noise control step is to locate noisy equipment and its related services as far as possible from noise-sensitive areas.

Figure 1 shows how non-sensitive areas (such as corridors, storage rooms, toilets, shafts, etc.) can be used effectively as buffer zones to shield noise-sensitive areas from mechanical equipment rooms in a typical multi-story office building core area.

Because the mechanical room placement is duplicated on every floor of this building type, the number of potential complaints caused by a single space planning error can be as many as the number of floors in the building.

Figure 1 compares several possible core area layouts, and promotes two concepts:

- The mechanical room should be located such that a minimum number of walls are exposed to noise-sensitive areas.
- Optimal mechanical room placement relative to other core areas permits the routing of the return air path and the supply air trunk ducts over areas with low acoustical sensitivity (such as restrooms).

Preliminary equipment selections and their structural implications. The mechanical engineer should make tentative equipment selections as early as possible to allow for a preliminary noise analysis and to determine the probable sizes of the mechanical rooms.

The primary acoustical design guideline is to select the quietest equipment possible. This usually means selecting equipment that will perform at its most efficient operating point. For fan-based equipment, select a fan with the lowest practical rpm, while avoiding proximity to the fan's stall region for all expected operating conditions.

After the equipment locations have been determined and the tentative selections have been made, the equipment loca-

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tions and operating weights should be given to the structural engineer.

This engineer should also be advised that the equipment operating load at any building attachment point (typically, a roof beam) should deflect that point no more than 0.33 in. (8 mm) for cooling towers or 0.25 in. (6 mm) for all other equipment types.

The structural engineer will use the information to help select beam sizes and column spacing, aspects of the design that are very difficult to change later.

Equipment room sizing. Economic pressure to maximize a building's rentable floor area has resulted in less space being available for the HVAC system and other building services.

This trend often forces the mechanical engineer to specify small, inefficient equipment or to shoehorn properly-sized equipment into a restricted space. Both options can lead to excessive noise in neighboring spaces, which may then become non-rentable.

To minimize the chances of noise problems, fan and air handling unit rooms should have floor areas of at least 10 to 15 ft^2 for each 1,000 cfm (6.7 to 10 m^2 per 1000 L/s) of equipment air flow. This usually allows adequate space for proper air flow into the fan, low-noise supply and return air duct fittings and duct silencers, if required.

To minimize the acoustical coupling between equipment housings and equipment room walls, all HVAC equipment rooms should have a floor area large enough to allow a clearance of at least 2 ft (600 mm) around all equipment. In some cases, electrical codes mandate even larger clearances.

Acoustical system effects

Mechanical engineers are familiar with the term *system effect* as it applies to fan performance for a given set of intake and discharge air flow conditions. An excessively turbulent air path on either side of a fan can dramatically decrease its performance and can even cause it to stall or surge.

These same aerodynamic conditions can also cause an *acoustical system effect*, whereby excessive intake or discharge turbulence can increase the fan's noise output when compared with its acoustical performance at optimal air flow conditions.

While the traditional system effect is well documented, the acoustical system effect is not reported as such in either the acoustical or HVAC literature. Accordingly, this effect is not commonly known among engineers.

Acoustical system effect occurs when a poor duct system design causes excessive static pressure that must be overcome by increasing the fan's rpm. The effect may also occur when air flow obstructions or distortions cause the fan to stall and deliver the air in "gulps" instead of a steady stream.

Acoustical system effect can cause sound level increases as high as 10 to 20 decibels in the lower frequency ranges. Engineers frequently (and mistakenly) attribute these low frequency noise problems to ineffective sound trap or duct liner performance without considering that the system's design or installation might be the problem.

A recent international symposium on fan noise contained several papers discussing this phenomenon.[9]

Figure 2 compares some examples of good and bad air flow conditions for vaneaxial fans. This fan type produces a strong blade passage tone that can be very annoying if not controlled.

Figure 3 shows a fan/duct installation with a very poor fan discharge condition. This installation has a large system effect, as well as a large acoustical system effect.

Expanding the system concept to other areas of HVAC noise control, consider sound trap placement in a mechanical

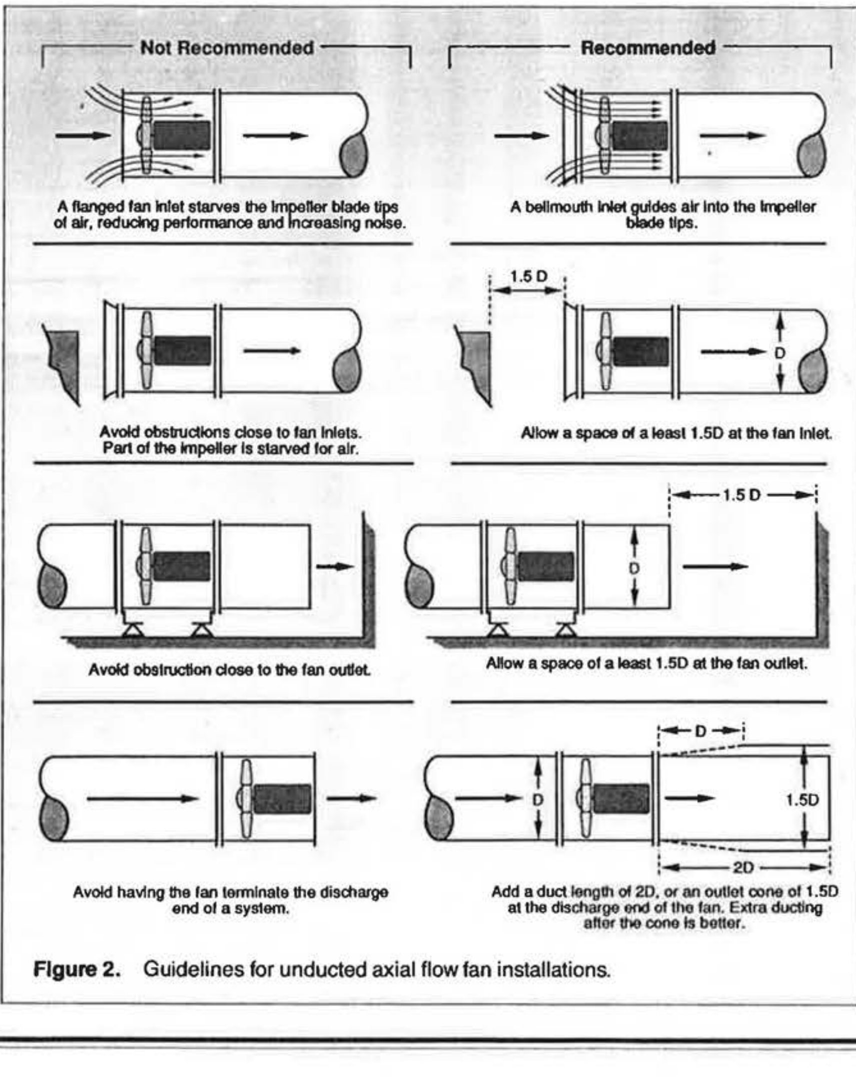

Figure 2. Guidelines for unducted axial flow fan installations.

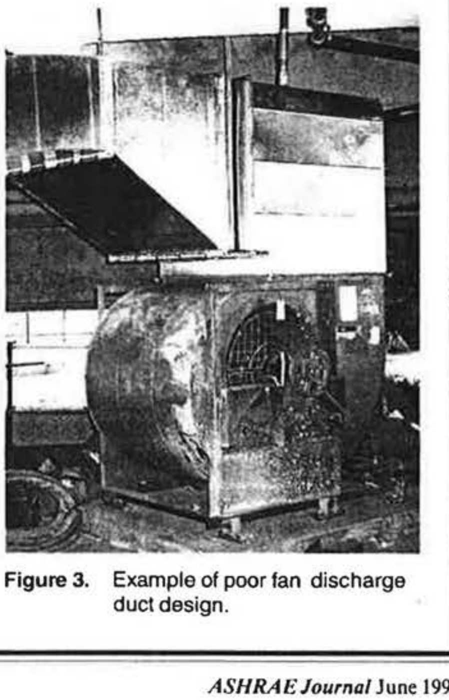

Figure 3. Example of poor fan discharge duct design.

room that is near a noise-sensitive area. The sound trap will provide the greatest benefit when it is integrated properly into a building's mechanical and architectural systems.

Figure 4 shows several possible placements of a sound trap relative to a mechanical room wall. Notice that the optimal placement has the sound trap straddling the wall. In this case, equipment room noise that leaks through the duct walls must travel at least a few feet through the trap before it can enter the downstream duct and break out through the duct walls.

The least effective placement puts the trap completely outside the mechanical room. This placement exposes the noise-sensitive area to noise from inside the duct sensitive area to noise from inside the duct before it has been reduced by the sound trap. In this case, the sound trap provides no benefit to this particular noise-sensitive area.

Another acoustical system to consider is that of vibrating equipment, its vibration isolators and the building structure that supports the equipment. The primary design goal is to mount the equipment on resilient isolators that are attached to very stiff, massive parts of the building structure.

Figure 5 compares various mounting concepts. It shows that the stiffest, most massive support locations are superior to the more flexible, lighter-weight ones.

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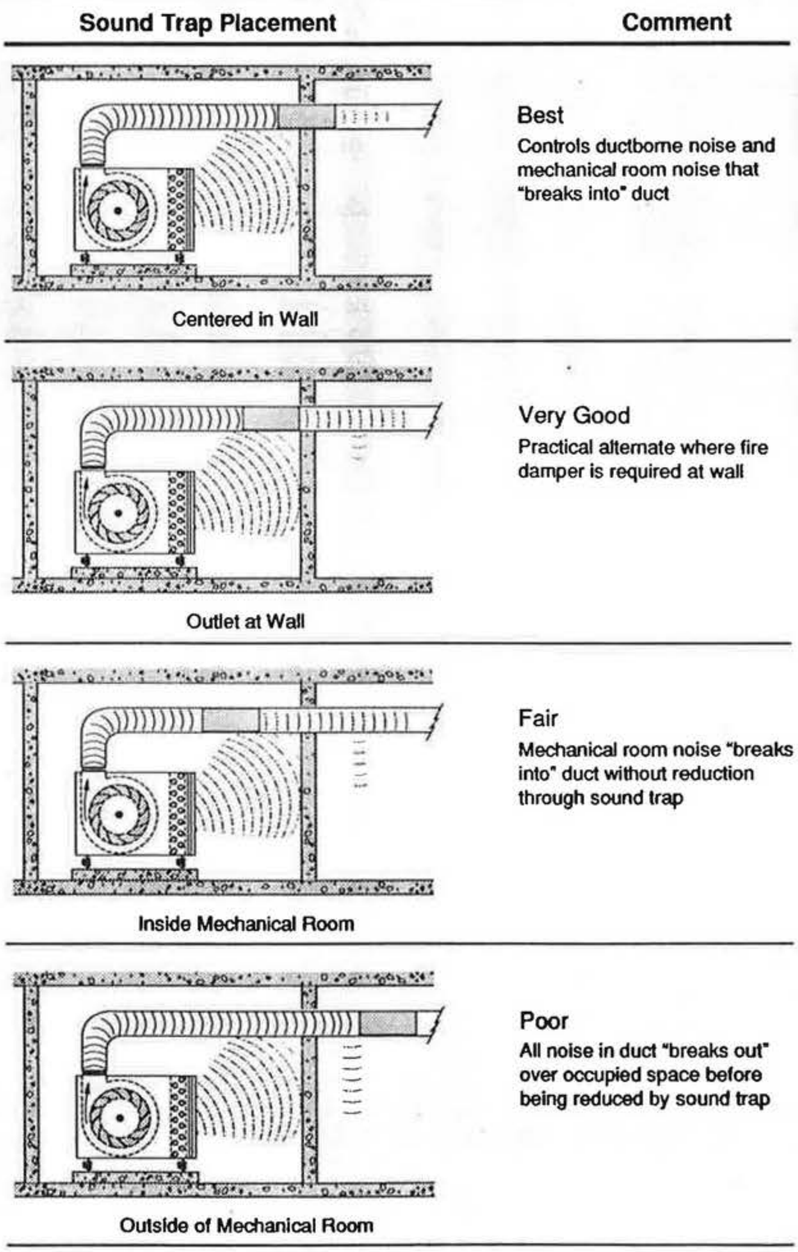

Figure 4. Sound trap placement near a mechanical room wall.

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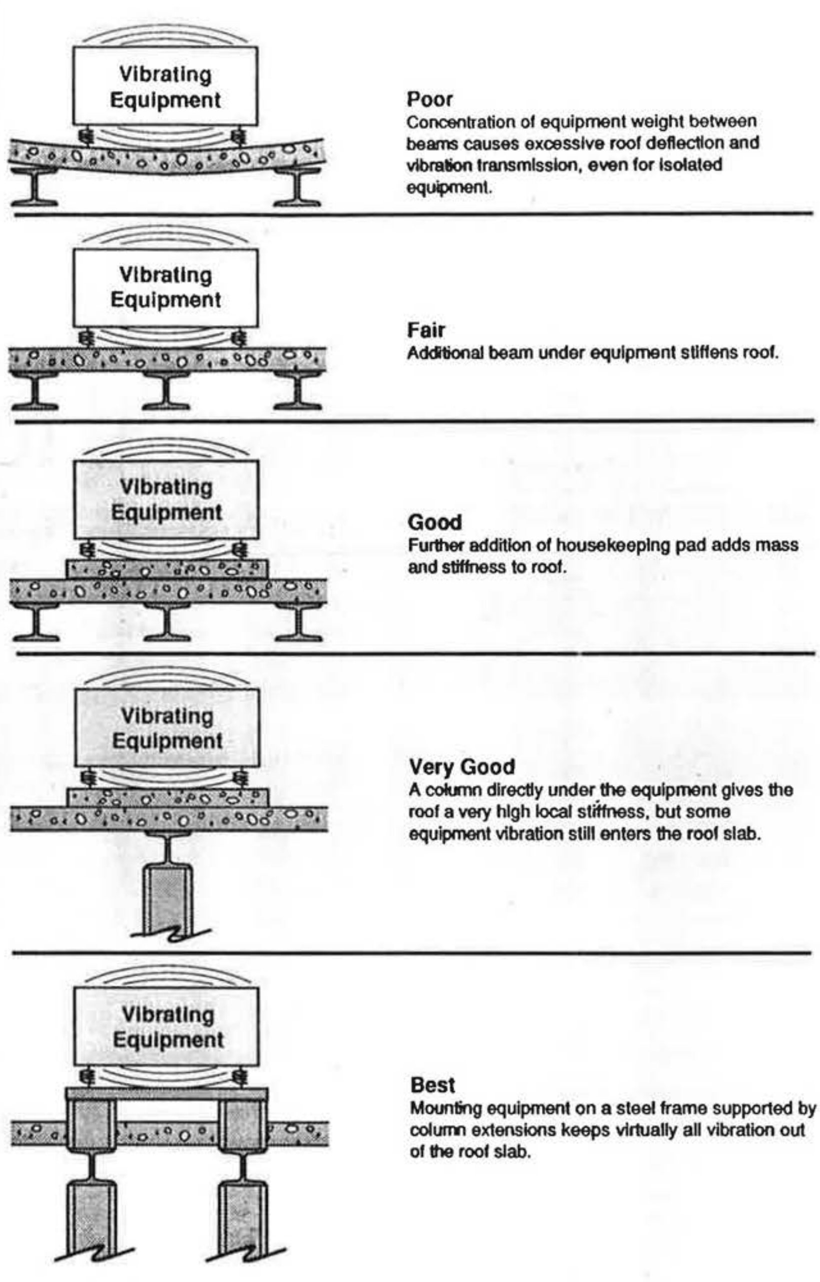

Figure 5. Structural support of rooftop equipment for vibration control.

Implications of cost cutting

Because a project's economic feasibility often determines whether or not it will be built, there is always an incentive for owners, developers and contractors to reduce construction costs whenever possible.

The HVAC system is never immune from such cost cutting. Unfortunately, reducing the cost of an HVAC system often leads to increased noise and vibration.

One example of a potential cost cutting problem is the reduction of a fan size from an efficient selection to one that is smaller and less expensive. This change requires that the smaller fan rotate faster such that it has a higher tip speed and no longer operates near peak efficiency. Unfortunately, the higher tip speed and deviation from peak efficiency result in two penalties: increased noise and higher energy cost.

Another example of a potential cost cutting problem is the reduction of duct sizes. If duct size is reduced while maintaining the same air flow, the duct velocity increases. This increase can cause additional regenerated air flow noise at duct fittings, oil-canning because of large-scale turbulence, and greater pressure drop.

If the building occupants can tolerate the additional noise and the building owner does not mind paying the extra energy cost to overcome the increased pressure drop, then higher duct velocities are acceptable. Otherwise, duct sizes should be kept as large as practical to minimize rumble, air flow noise and energy costs.

Conclusion

By following the guidelines in the new ASHRAE publication *A Practical Guide to Noise and Vibration Control for HVAC Systems*, HVAC designers and other building industry professionals can minimize the number and severity of HVAC system noise and vibration problems.

A building's design team can thereby prevent most potential noise and vibration complaints that are related to HVAC systems.

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