engineers newsletter

volume 38–2 • providing insights for today's hvac system designer

acoustical considerations for
Large Rooftop Units

from the editor …
While large rooftop HVAC units provide many advantages for the designer and building owner, extra consideration must be given to the acoustics of these units. In this newsletter, we discuss the specific acoustical challenges larger units pose, and how to address these issues to meet the sound goals of the project.

Introduction. Rooftop HVAC equipment provides enticing features for the design engineer and cost advantages for the owner. Fans, ventilation equipment, a heat source, compressors, condenser, and controls are assembled in a compact unit ready for installation on a roof curb. Manufacturers assemble, test, and rate the entire package as a system. The advantage of locating the unit on the roof frees up floor space in the building.

The convenience of packaged equipment has driven a demand for increasingly larger units. Packaged rooftop equipment is now available from several manufacturers in sizes up to and beyond 150 tons. The larger units' design has also been updated to meet industry demand for improved efficiency and indoor air quality. Greater flexibility in fan choices, equipment options, and unit configuration is also becoming available.

With these larger units, many factors need to be considered in the design of the building, such as increased structural support, larger electrical service, etc. Unfortunately, the increased sound levels produced by these units are sometimes overlooked. Following a fixed set of acoustical practices used with smaller units may not sufficiently attenuate the increased sound levels of the new larger units.

Large packaged rooftop units can be installed without creating noise problems in the occupied spaces, but not without appropriate consideration. An acoustical review using the source-path-receiver acoustical model (see sidebar, p. 3 "Defining an Acoustical Model") early in the design process is critical to achieving the desired sound levels.

The discussion that follows:

- Illustrates how an acoustical analysis affects design decisions and helps the installation succeed in terms of first cost and occupant satisfaction.
- Outlines general and specific acoustical considerations for very large rooftop units.

Acoustical Analysis, Step by Step

An acoustical analysis consists of five basic steps:

Step 1: Set acoustical goals for the finished space. It is critical to establish the acoustical goals for the finished space at the outset of any HVAC project. There are always implicit, often subjective, expectations for the background sound level in occupied spaces. It is much easier to produce a successful installation if you understand these expectations before designing the installation. The risk involved in waiting until the unit is installed is considerable because the cost of quieting an installed unit always exceeds the cost of applying the same treatment during installation.

Also be aware that once a unit is installed, some changes, e.g., switching to a different fan size, will not only be expensive but could affect the unit's UL rating.

Remember these three points when defining desired sound levels:

1. As a general rule, lower sound levels cost more to achieve.

2. All spaces in the building do not have the same sound requirement; a low-cost, quiet installation takes advantage of this point.

3. Successful acoustics requires a team effort. The team should include the owner, engineer, architect, equipment manufacturer, and contractor.

Sound goals will vary depending on how the space is used. Once the sound goals are understood, state them using an appropriate descriptor such as NC (Noise Criteria) or RC (Room Criteria).

Step 2: Identify each sound path and its elements. Large rooftop HVAC installations have four types of paths (Figure 1, p. 2):

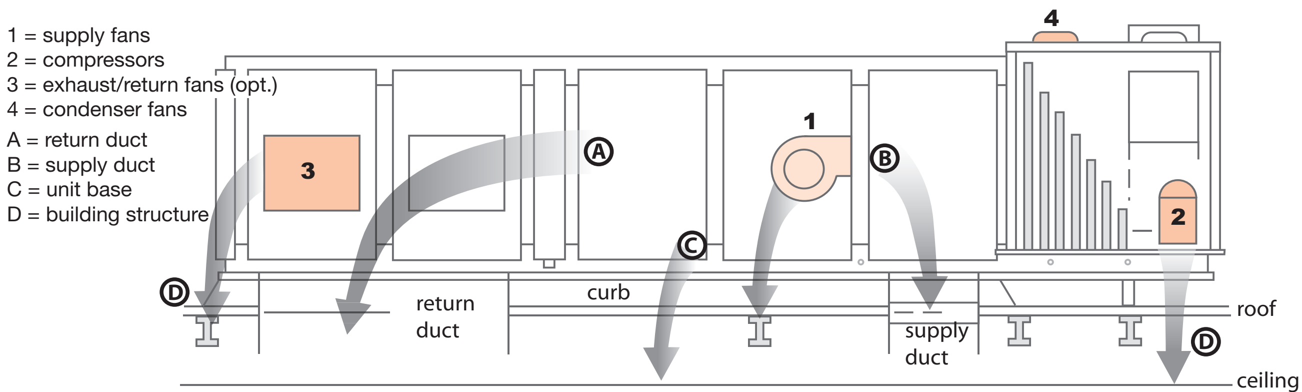
1. Airborne sound follows the airflow path. Supply airborne sound travels the same direction as the supply air. Return airborne sound travels against the airflow direction. Airborne sound also includes sound generated by the ductwork and diffusers.

2. Breakout sound passes through duct walls into the plenum space, then through the ceiling and into the room.

3. Roof transmission sound passes through the roof deck (both within and outside the roof curb), plenum space, and ceiling into the room.

4. Structure-borne sound differs from the other sound paths in that it is vibrational energy transmitted through the framework of the building. This energy may come directly from the vibration of the sound source or from

Figure 1. Large rooftop: Four types of sound paths



airborne sound energy transferred to the structure.

Step 3: Perform a path-by-path analysis. Once each path has been identified, individual elements can be analyzed for their contribution. For example, the supply airborne path includes various duct elements (e.g., elbows, straight duct, junctions, diffusers) and a room-correction factor. Algorithms available from ASHRAE can calculate the acoustical effect of each duct element. The effect of changing an element (e.g., removing the lining from a section of ductwork) can be examined. A software tool like the Trane Acoustics Program™ (TAP) simplifies this process.

This step typically entails at least two iterations for each path. The first pass establishes the acoustical performance of the initial design. Subsequent passes determine the effect of adding various acoustical treatments.

Step 4: Sum the results to determine the acoustical performance of the installation. The sound level at a receiver location is the sum of all the sound paths for that location, both from the rooftop unit and from other sound sources. After the contributions of the individual paths are calculated, add them together to determine the sound level at the receiver location. If the sum exceeds the goal, another round of path attenuation calculations is required.

Step 5: Compare the summations with the acoustical goals in the context of the project budget. Once a design meets the acoustical goals for the project, everyone on the team must understand the work and costs required to implement the design. It may also be prudent to review the cost of meeting the acoustical goals and reconsider equipment options that were initially rejected due to cost.

Additional guidance on creating a rooftop sound analysis can be found in the Trane application manual and ASHRAE Journal article listed in the reference section.

Specific Considerations for Very Large Rooftops

As rooftop unit size increases, building and duct construction details play a key role in determining the sound levels in the occupied space. Review of generalized acoustical models for large rooftop applications indicate that the three critical sound paths are *return airborne*, *return breakout*, and *supply breakout*. The models also show that if acoustics are not considered, an application can have sound levels that are too high. However, acceptable sound levels in the occupied space can be achieved with proper attention to unit selection and application details.

This section uses a generalized acoustical model to show how both unit and application choices impact the potential NC in an occupied space. As described in the previous section, an accurate estimate of sound pressure in the occupied space requires a unique acoustical analysis for each application. The NC values in this section are based on a generalized model and do not indicate what the sound will be in any particular application.

Quiet the Source. One way to lower the sound level in the occupied space is to reduce the sound produced by the rooftop unit. Operating conditions, fan selection, optional equipment, and cabinet choices all have an impact on the amount of sound produced by the rooftop unit.

Solid Surfaces . Some rooftops come standard with solid double-wall construction throughout. This helps prevent dirt and moisture from adhering to the surfaces but makes the surfaces less absorptive to sound.

For applications that do not require all solid surfaces in the airstream, one or more sections of the unit may be available with a sound absorbing lining (either with or without a perforated plate) and a moisture barrier to separate the lining from the airstream. Units rated following ARI 260 test methods indicate that the addition of lining can result in a sound reduction on the order of 4 to 6 dB in the critical 125 Hz octave band.

Fan Configuration. Units may be configured with supply fan only, supply and exhaust fan, or supply and return fan. Although unit configuration isn't generally based on acoustical considerations, each choice has a unique impact on sound produced by the unit. If design flexibility allows, check all available configurations to find the one that is best for the application.

Supply Fan Only. This configuration will have higher sound levels at the discharge opening but relatively low levels at the return. A supply fan only configuration tends to perform well overall because of the plenum attenuation created by the heat and coil sections on the discharge side, and mixing and return sections on the inlet side of the fan (see Figure 2).

The supply fan is the dominant sound source in rooftop units. To help attenuate the supply fan discharge sound, consider using the largest supply fan available in each tonnage size. Larger fans run at a lower speed and are typically quieter. Unit selections have shown a 10 dB reduction in the 250 and 500 Hz octave bands at 32,000 cfm and 5" of fan static for some fans. (Of course, unit sound data is dependent both on fan type and operating point, so check all available fan selections for a particular operating point.)

Acoustic Stall

Fans enter a region of acoustical stall prior to entering aerodynamic stall. When operating in acoustical stall, the fan will reliably move air; however, the fan sound modulates, making it impossible to provide accurate acoustical data. In addition, when the fan is operating in the acoustical stall region, the low frequency sound generated by the fan will increase quickly with even a small reduction in airflow.

Fans should not be selected in the acoustical stall region when acoustics are an important application consideration. It should also be noted that a fan selected above the acoustical stall region could unload into the stall region; check the selection at part load conditions to avoid this problem.

In general, moving to a larger fan will lower the sound level for a given flow and pressure drop. However, moving to a larger fan may also move the fan closer to a region where "acoustical stall" occurs (see the sidebar "Acoustic Stall").

The cost implication of changing the fan type should also be considered. It may be more cost effective to quiet the unit/installation by another method.

Return/Exhaust Fan. In some cases the addition of a return fan will lower the discharge sound level; however, return and exhaust fans increase sound levels at the return opening. The model shows that switching from a supply fan only to a supply and exhaust fan configuration increases the sound in the occupied area below the rooftop by 3 NC. Switching to a supply and return fan may result in an 11 NC increase over the supply fan only unit. The change in supply sound depends on both the type and operating point of the return/exhaust fan used.

Sound radiated from the return opening comes from the inlet of the supply fan plus the exhaust or return fan. Adding a return fan may cause the return airborne and breakout sound paths to set the sound levels in the occupied space. Return fans generally result in higher sound levels in a space than exhaust fans when the inlet to the return fan is mounted directly above the return ductwork. Sound from a sidewall-mounted exhaust fan is attenuated by the plenum effect of the return section. Also, different fan types and operating points may be used for the two fans so the sound created will be unique to each fan at each operating point.

To lower the sound being transmitted through the return air opening, consider the following:

1. Review the sound data for return vs. exhaust fan for your conditions to determine which configuration results in the lowest sound levels. Also look at all fan options for each configuration. Changing to a larger

Defining an Acoustical Model
Understanding acoustic fundamentals is a prerequisite to making sound decisions for any type of HVAC installation. A simple acoustical model starts with identifying the following:

Source: Object from which the sound originates.

Receiver: Location where the sound will be measured.

Path: The route the sound travels from the source to the receiver.

Source: Large rooftop units contain a number of sound sources, including compressors, condenser fans, supply fans, return fans, and exhaust fans. Each source has a unique sound quality and level. All play a role in determining the sound the receiver hears.

An accurate building application acoustical analysis depends on accurate sound data for the rooftop equipment. Ducted sound power levels, such as "ducted discharge" for the supply duct and "ducted inlet" for the return duct, should be measured in accordance with ARI Standard 260, Sound Rating of Ducted Air Moving and Conditioning Equipment. This test standard assures that the ducted sound data for the rooftop accurately reflects the contributions of all the internal unit sound sources, including the effects of the cabinet, at the specified operating conditions.

Receiver: The receiver is simply the location where you are concerned about the sound. This could be the conference room, an open office area, a theater, or, for outdoor sound, the property lot line. A given sound source may have several receiver locations.

Path: Most acoustical variability lies in the path. For that reason, it deserves particular attention. Sound from a single source may take more than one path to the receiver location. For example, sound from the supply fan follows the ductwork and enters the room through the diffuser. Sound also "breaks out" through the wall of the supply duct and enters the room through the ceiling tile.

Path analysis stresses the importance of unit location. The sound at a receiver location diminishes as the distance between the source and receiver increases. Increased path length allows for the attenuation of sound by absorption, transmission loss, or spreading. The individual elements of the sound path show these effects. When path lengths are short—for example, a rooftop placed over occupied space—it can be difficult to attain sufficient reduction in the sound before it reaches the receiver.

supply and return fan size can have a significant effect. A typical selection showed switching to the larger return fan at 27,000 cfm and 2" of fan static will reduce the 250 and 500 Hz bands by 4 and 5 dB respectively.

2. Consider using a horizontal connection (if available) for the unit return and running the return duct over the roof before penetrating the building. Running the return duct over the roof has several advantages:
   - Low frequency sound will break out of the duct walls to the outdoors, thereby reducing the sound entering the building.
   - Lining the duct run on the roof will provide attenuation at the mid and upper frequencies.
   - The duct penetration can be moved to a non-sound sensitive area of the building.

Quiet the Sound Paths. Quieting the unit helps, but the greatest acoustical benefits come from looking at how the unit is integrated with the building. Changing the installation to attenuate the critical sound path(s) can have a dramatic effect on sound levels in the occupied space.

Location. Locating a large rooftop unit over a sound-sensitive area will either result in unacceptably high sound levels in the occupied area or add considerable cost to prevent the sound produced by the unit from reaching the occupants. Consider locating the unit over a non-sound sensitive area, even if it means running the supply and return ducts over the roof. External runs of duct can provide attenuation of the supply and return airborne sound before the roof penetration is made.

Roof Structure. Supply duct breakout has commonly been the critical sound path for rooftop units, but problems with roof transmission are on the rise. This is perhaps due to an increased awareness and attention to attenuating the discharge path, but it may also be due to the increased use of lightweight roof structures.

Sound radiated from the compressors, condenser fans, exhaust fans, and the casing of the unit will impinge on the roof surface surrounding the unit. A lightweight roof (metal deck with insulation and ballast) provides minimal resistance to the transmission of sound.

The poor transmission loss characteristic of roofs often becomes apparent when taking sound readings on problem jobs. With all sound producing equipment off, place a radio at moderate volume on the roof near the unit and go inside and listen. If you can hear the radio, roof sound transmission is likely to be a problem.

Increasing the transmission loss of the roof generally means adding mass to the roof--typically a concrete slab--around the unit. Thickness and area of the slab are dependent on how much transmission loss is required to meet the sound goals for the job.

Also avoid unit placement on a flexible roof structure that will transform vibration from the unit into sound that radiates into the building. As with all rooftop units, placing the unit in a location over a column or other rigid support element will minimize this problem. Proper support is especially important for larger units because of the increased mass and vibration energy due to larger compressors and fans, and high airflow.

Duct Chase. When a large rooftop unit serves several floors of a building via a duct chase, properly positioning the unit over the chase will have a dramatic effect on the sound levels in the occupied areas near the unit.

Figure 2 shows a construction that will provide a high level of path attenuation. A special curb is used that provides unit attenuation and brings the supply and return openings closer so they can be matched up with the chase opening. Notice that a short run (height of one floor) of return duct is installed inside the chase; this provides some additional return breakout transmission loss that lowers the sound levels in the chase.

Return air openings at the floors are supplied with a silencer and a short run of lined return duct to provide additional attenuation and move the return airborne sound away from the shaft wall. Round duct is used for the supply to reduce duct breakout near the chase wall. The generalized model shows that removing the short run of return duct from the configuration shown in Figure 2 results in an increase of 10 NC for the supply fan only unit and 12 NC for the supply and exhaust fan unit.

Figure 2. High level of path attenuation

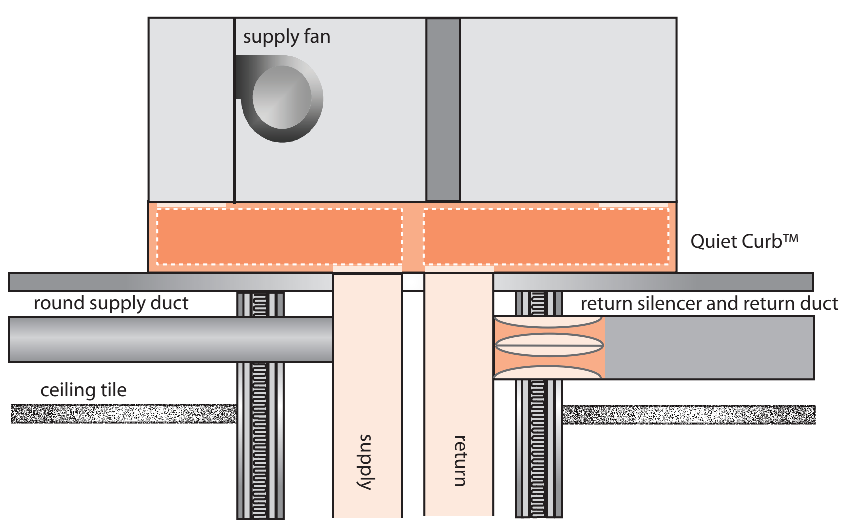
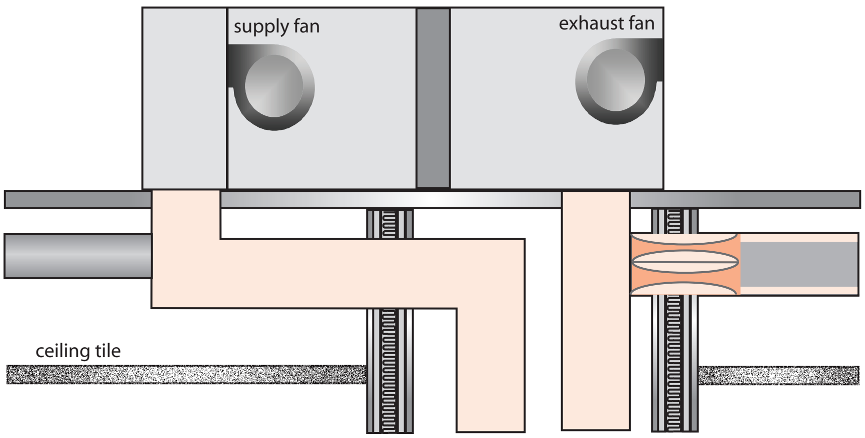


Figure 3. Low level of path attenuation



Locating either the supply or return opening over the chase and then ducting the other opening to the chase is not recommended (see Figure 3 and Figure 4), except for jobs using a poured concrete roof curb. Poured concrete roof curbs are typically used in conjunction with a concrete roof slab to minimize roof transmission. With the concrete curb, the supply opening should be located over the shaft, as in Figure 4, with the return duct run inside the concrete curb to the shaft.

In all chase applications, it is important that the chase is run all the way to the roof deck and is sealed with acoustical mastic to the roof deck. Supply and return air duct penetrations though the shaft wall must also be sealed to prevent sound from leaking out of the shaft.

General Considerations.

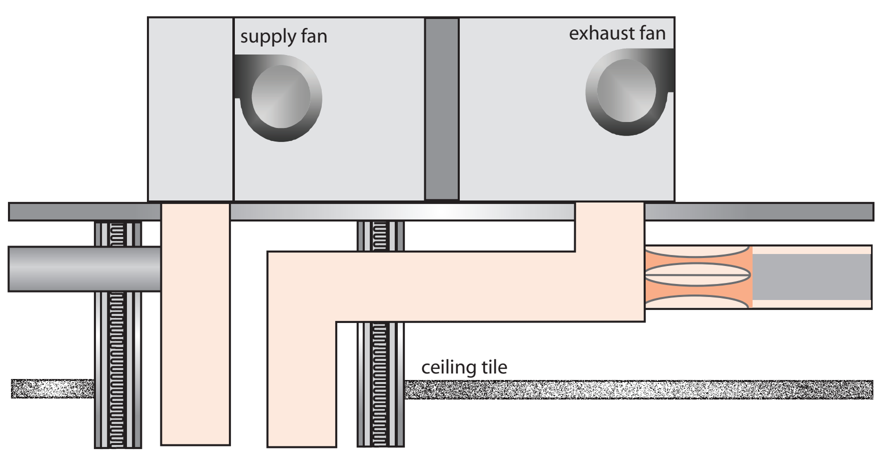
Operate the Unit as Designed. It is quite common to overestimate the system static pressure required to achieve design airflow. This results in the installation of larger motors and/or higher fan rpm than required to overcome the actual static pressure. To compensate for the additional static, the air terminal device balancing dampers are more restricted than necessary. These "over-aired" systems waste energy and force the units to generate excess sound.

To minimize noise, operate the rooftop at the lowest possible pressure in the duct. After installing the rooftop unit and its associated air distribution system, it must be properly air balanced by qualified air balancing technicians using calibrated air measuring devices. The airside system should be balanced to achieve the desired airflow at all terminal outlets while maintaining the lowest possible fan rpm and system static pressure. Utilizing the fan pressure optimization control strategy is an excellent way to achieve this on VAV systems. (See "Energy Saving Strategies for Rooftop VAV Systems", Engineers Newsletter vol. 35--4, 2006.)

Proper Duct Design. The fans in the rooftop unit are not the only sound source in the HVAC system. Aerodynamic noise is generated at duct fittings, e.g., junctions, elbows, diffusers, dampers, and take-offs. The sound power levels generated at these fittings are dependent on airflow turbulence, fitting geometry, and airflow velocity. Meeting the acoustical goals for the job requires all sources of sound to be considered.

Several guidelines for minimizing the generation of aerodynamic noise are available. The ASHRAE book, "*A Practical Guide to Noise and Vibration Control for HVAC Systems*" is a good reference source for designing quiet HVAC systems as are the ASHRAE Handbooks. Careful duct design is especially important at the discharge of the rooftop unit. Air leaving a rooftop unit tends to be turbulent; as a result, pressure drop and generated sound will exceed what is normally predicted for fittings near the unit.

Figure 4. Low level of path attenuation



Closing Thoughts

Don't let noise ruin the advantages and convenience of large rooftop units. Review the acoustical goals for the occupied space during the building design process. Use an acoustical analysis to identify and attenuate the critical sound paths so the sound goals for the job can be achieved. Yes, this adds cost and takes time but not nearly as much time and money as fixing a problem job.

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