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Understanding the Problem

Noise in the Classroom

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Member ASHRAE

Most of today's air-conditioned school classrooms are too noisy. Newer school classrooms all too often are built with HVAC units that are selected on the basis of lowest first cost with insufficient regard to overall system quality, durability, optimum air distribution, and acceptable background noise levels. When noise levels are too high, the result is reduced speech intelligibility and a reduction in the overall learning capacity of the students. The problem is not one of technical capability; it is one of awareness, understanding and priorities.

Currently, a national task force of approximately 50 educators, architects, acoustical consultants and audiologists is preparing a draft standard that will specify minimum acoustical requirements for all classrooms in the United States. This proposed standard addresses all acoustical issues affecting speech intelligibility in the classroom including background noise, reverberation, and sound isolation from other interior and exterior spaces. Although the new standard is not yet finalized, it is likely to have a significant impact on the design of all new and remodeled classrooms in the near future. This article presents guidelines for designing classroom HVAC systems that will be able to achieve the lower background noise levels required by this standard.

Noise Criteria

The background noise criteria that are being considered by the committee developing the new standards for school classrooms are very close to NC-30. The *1999 ASHRAE Handbook* suggests that higher background noise levels are acceptable, but that is likely to conflict with the new national standard for classrooms. The NC-30 criteria should be applied to all school classrooms, regardless of student age and course content. The only exception would be for special purpose classrooms that are used to instruct hearing-impaired students, students who do not speak the native language, and foreign language classrooms. Because of the difficulties of distinguishing subtle differences in language, these special purpose classrooms should be designed to meet lower background noise criteria (approximately NC-25).

Other schoolrooms may have higher background noise levels. For example, offices, libraries, assembly spaces, and cafeterias usually can tolerate background noise levels as high as NC-35. Background noise levels in corridors and lobbies can be around NC-40. Additional detailed information concerning background noise criteria for HVAC systems can be found in Chapter 46 of the *1999 ASHRAE Handbook*.

Because of the recently emphasized need for low noise levels in school classrooms, HVAC system designers need to reassess how they approach system design for these projects. If we are to succeed in achieving the recommended acoustical criteria we must consider noise from the beginning of the design process. The goal should no longer be lowest first cost. We should design for overall system quality, while considering the life-cycle cost, including the less tangible (but extremely important) cost of the educational impact of the students in the classroom.

System Design Guidelines

Basically, two general HVAC system types exist that can achieve the recommended noise criteria. One type is a central system where a single air-handling unit serves many classrooms from a central supply duct system, and the other type uses a dedicated air-handling unit for each classroom. The central system often is the most economical choice, because a single air-handling unit can be used for the entire system and because the fan, motor, and compressor (e.g., the noisy equipment) can be located far from the classrooms, making noise control more manageable.

Although a dedicated unit is much smaller and generates less noise at the fan, the fact that it must be located in or next to the classroom makes noise control more difficult. The following paragraphs present some general design guidelines for achieving acceptable background noise levels in classrooms.

HVAC systems that should be avoided in school classroom applications include:

About the Author

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3) Water source heat pumps above the classroom ceiling.

4) Any unit mounted in a window or wall.

These system and unit types should be avoided because they are inherently noisy, and cannot achieve the recommended NC-30 noise criteria with current technology.

The classroom air distribution system should be a low velocity system to minimize flow-generated noise and to minimize static pressure requirements on the supply fan. The system fans should be selected for maximum efficiency, which generally yields minimum noise generation.

Improper fan selection is one of the most common design errors that result in noisy HVAC systems. To correctly select a fan, the designer must have an accurate estimate of the total system static pressure at the design airflow rate. If the duty point is too far left of peak efficiency for a given fan (e.g., fan is too large), then the fan may go into surge, becoming unstable and extremely noisy with excessive vibration. This is especially true with forward curved centrifugal fans. If the duty point is too far right of peak efficiency (fan too small), the fan usually generates much higher levels of noise. This effect occurs with all types of centrifugal fans. As a result, simply overestimating the total system static pressure (as a conservative method to ensure adequate airflow) generally is not a good idea. Computer software programs should be used to accurately assess the system requirements prior to fan selection.

The same classroom air distribution system should be used for both the central and dedicated systems. The recommended classroom supply air distribution system is an array of ceiling diffusers as shown in *Figure 1*. For classrooms less than 1,000 ft^2 (93 m^2) (floor area) a total of four 4-way ceiling diffusers is recommended. If fewer than four diffusers are used, it is likely that there will be excessive diffuser noise in the room. In essence, the throw requirements will be too severe to meet the air distribution needs without exceeding the noise criteria.

Because of the additive effects of multiple diffusers and because of the need to accommodate noise from other HVAC system components (VAV boxes, duct breakout, etc.), the designer should not select diffusers to exactly match the design criteria. Supply diffuser NC ratings are based on the assumption that only one diffuser is in the room, the listener is not close to the diffuser, and no other sources of noise exist. If only one diffuser is in a room, size that diffuser for at least 3 NC points less than the NC criteria. This will help to compensate for other noise sources and listener locations relatively close to the diffuser. If there are two diffusers in a room, size each diffuser for 6 NC points less than the NC criteria. If there are four diffusers, size the diffusers at 9 NC points less than the criteria.

Each time the number of diffusers is doubled, the NC rating of each diffuser should be reduced by 3 NC points. Therefore, to meet NC-30 in a classroom with four diffusers, size each diffuser for NC-21. To ensure the desired acoustical performance from the diffuser, the designer must also make sure that the volume damper is not located at the diffuser inlet. This damper should be located at the flex duct connection to the low pressure duct above the ceiling—at least 6 ft (1.8 m) from the diffuser. In addition, provide at least 3 diameters of straight flex duct at the diffuser inlet. If an elbow or bend is in the flex duct near the diffuser inlet, the air velocity distribution at the inlet of the diffuser will not be uniform and the diffuser will be noisier than its catalog rating.

This effect can increase noise as much as 10 to 15 dB, depending upon the angle and location of the bend. This important detail must be checked during construction. If there is not adequate space to ensure a minimum of three duct diameters of straight flex prior to the diffuser inlet, the diffuser should be oversized to help compensate for the noise level increase cause by uneven flow distribution at the diffuser inlet.

The low-pressure ductwork above the classroom ceiling should be internally lined sheet metal ductwork sized for a velocity of 800 to 1,000 fpm (4 to 5 m/s). Lower velocities are not necessary, nor are they recommended because they will result in larger ducts with a greater surface area resulting in greater breakout

Definition of Acoustical Terms

Acoustic Frequency: number of acoustic pressure oscillations per second, expressed in Hertz (Hz). The human ear is most sensitive at frequencies near 2,000 Hz, but most people with good hearing can hear sounds as low as 20 Hz and as high as 16,000 Hz.

Breakout: noise radiation from the exterior surfaces of HVAC ductwork.

Noise: unwanted sound. Noise is usually distributed (though not uniformly) over a wide range of acoustic frequencies.

NC: background noise rating system based on the octave band sound pressure levels in the occupied space with all HVAC equipment operating. Higher values represent higher background noise levels.

Octave Band: range of acoustic frequencies, extending from 0.707 times the center frequency to 1.414 times the center frequency. The 10 standard octave band center frequencies covering the range of human hearing are: 16, 31.5, 63, 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz.

Octave Band Noise Level: the total acoustic pressure in an octave band, expressed in decibels (dB). Higher decibel levels generally represent an increase in loudness if compared within the same octave band.

Sound Pressure Level: a measure of the intensity or loudness of a sound, expressed in dB. In general, the sound pressure level decreases with distance from the source because the acoustic energy is distributed over a broader area.

Sound Power Level: a measure of the total acoustic power radiated by a source in all directions, expressed in dB (ref. 1 picowatt). Unlike the sound pressure level, the sound power level cannot be measured directly, and is generally unaffected by the acoustic environment.

noise problems, not to mention the higher construction costs and problems with space limitations. The duct liner should be 2 in. (50 mm) thick and extend at least for the first 10 ft (3 m) of ductwork above the ceiling. If acoustical duct lining is not desired in the low-pressure duct system, it can be replaced by a sound attenuator at the beginning of the low-presssure duct. The sound attenuator should provide a minimum insertion loss of 10 dB in the 125 Hz octave band.

Central System: Design Guidelines

With a central system the main (medium pressure) supply duct should be located above the corridor, not above the classrooms. The branch duct fittings to each classroom should be low-pressure drop conical tee fittings to minimize self-generated noise at the fitting. If VAV boxes are used to regulate airflow to each classroom, they must be selected for low noise. Fan powered VAV boxes are too noisy to be located above classrooms, but they can be located above the corridor if there is room.

Standard VAV boxes can be located above the classroom ceiling if the VAV box is selected properly. To meet the recommended NC-30 design criteria, the *radiated* sound power level of the VAV box in the 125 Hz octave band must be 65 dB (ref. 1 picowatt) or less. Octave band sound power level ratings for VAV boxes are generally available from the manufacturer. The reader should be cautioned about using the VAV box NC ratings for selection purposes because these ratings are based on assumptions that are not always valid for the intended installation. It is best to use the octave band sound power levels for selection purposes.

The *discharge* sound power level of the VAV box in the 125 Hz octave band should be 70 dB or less if the discharge duct is acoustically lined or if a sound attenuator is provided on the discharge duct. If the discharge sound power level exceeds 70 dB in the 125 Hz octave band, an improved sound attenuator should be provided to the low pressure ductwork to compensate. Unfortunately, sound attenuators cannot be used to compensate for excessive radiated sound power if the VAV box is located above the classroom. VAV boxes are available to meet these criteria, provided they are properly sized and the inlet static pressure to the VAV box is not too high. If the inlet static pressure is above 1 in. of water (249 Pa), the sound power levels will likely be too high to meet the recommended criteria. Therefore, it may be necessary to add a manual volume damper in the branch duct upstream of the VAV box to reduce the inlet static pressure to 1 in. (249 Pa) or less.

The inlet duct to the VAV box should be round spiral pipe, not flex duct. Flex duct is nearly transparent to noise, so the VAV box inlet damper noise could radiate into the classroom if flex duct is used at the VAV box inlet. Of course, if the VAV box can be located entirely above the corridor, this would not be as great a concern since the corridor noise criteria is about 10 dB higher than the classroom.

In general, round ductwork is preferred over rectangular because it eliminates the problem of low frequency breakout that is so typical of rectangular ductwork. Main duct velocities should be less than 1,800 fpm (9 m/s) for rectangular main ducts. Main ducts constructed from spiral round pipe can support flow velocities as high as 2,500 fpm (13 m/s) if low-pressure drop fittings

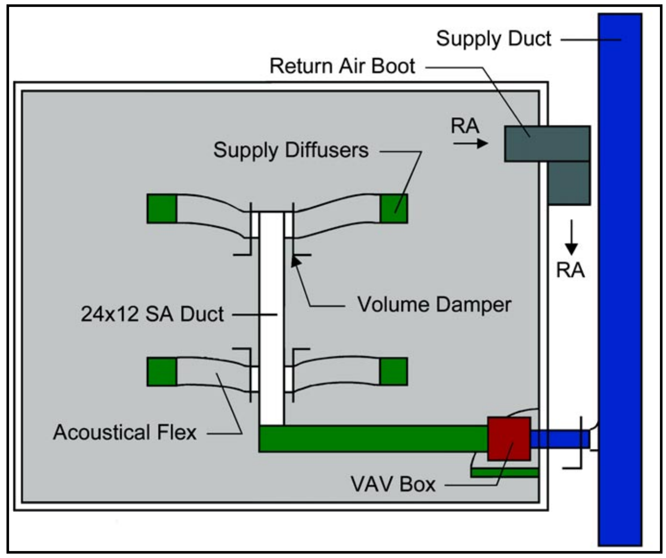

Figure 1: Typical layout of central HVAC system serving classroom.

Acoustical Duct Lining

During the past 10 to 15 years, there has been much discussion regarding the environmental impact of placing fiberglass duct liner in HVAC ductwork. Most of this discussion has centered on the concerns that the fibers may be carcinogenic and/or that duct liners may promote microbial growth. ASHRAE Technical Committee 2.6, Sound and Vibration Control has reviewed the available scientific information in this regard and has adopted the position that acoustical duct lining is both a reasonable and cost-effective noise control alternative in many HVAC systems (including educational facilities), provided that it is properly installed. For additional details, see Page 46.17 of the *1999 ASHRAE Handbook—HVAC Applications*.

are used throughout. Acoustical duct lining generally is not required in the main supply duct, provided that the fan noise control is taken care of at the central unit.

It is extremely important to locate the central air-handling unit away from the classrooms and other noise sensitive spaces. The most popular location is on the roof of the building. This is fine if the equipment is positioned above non-sensitive areas like storage rooms, restrooms, locker rooms, and entry vestibules. The roof structure should be stiff and massive to provide a solid foundation for the unit and minimize the possibility of excessive building vibration.

The supply fan in the central air-handling unit should be selected for maximum efficiency and minimum noise generation. There are lots of different fan types (forward curved, airfoil, plenum fan, etc.) that should be carefully evaluated prior to making a final decision regarding fan selection. This step is critical. All too often a fan is selected for an application without careful evaluation of the impact of the fan selection on the system. The result is often too much noise in the conditioned space, or excessive noise control is needed to achieve the required sound level. Also, when making this evaluation, be sure

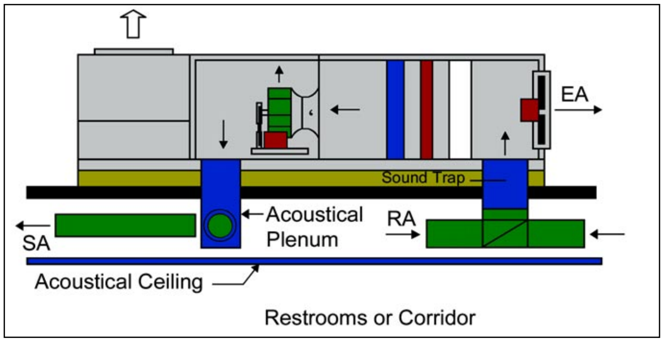

Figure 2: Rooftop air-handling unit with noise and vibration control.

to consider impacts of noise transmission via the return air path as well as casing radiated noise. The supply air path is the most obvious, but oftentimes the other transmission paths will control the optimum fan selection.

No matter which fan type is used, provide internal spring vibration isolators on the fan/motor assembly (with a flex connection at the fan intake/discharge) in air-handling units (e.g., units without compressors and condenser fans). Self-contained package units should be externally vibration isolated with spring isolators (e.g., a spring isolation curb if roof-mounted) because vibration from the compressors, refrigerant piping, and condenser fans cannot be effectively isolated within the unit.

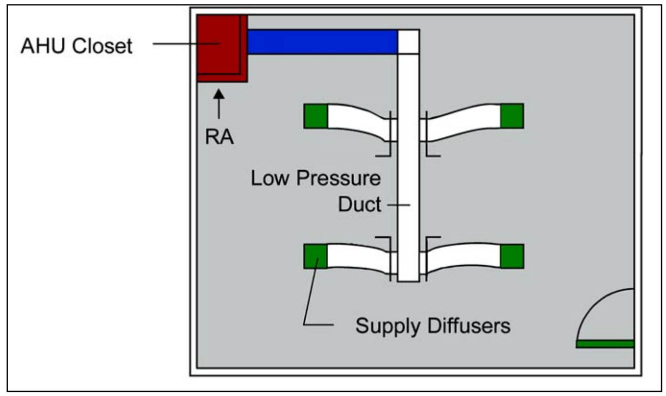

Figure 3: Typical layout of dedicated HVAC system serving classroom.

In most cases even the quietest central supply fan will be too noisy to meet the classroom noise criteria without an additional sound attenuator and/or acoustical duct lining somewhere in the main supply duct system. It is best if the sound attenuator can be installed inside the air-handling unit. This is often possible with custom equipment, but generally is not feasible with less expensive production units.

It is usually best to locate the sound attenuators as close as possible to the noise source, but the attenuator can also be too close to the fan, so be careful to observe the manufacturer's

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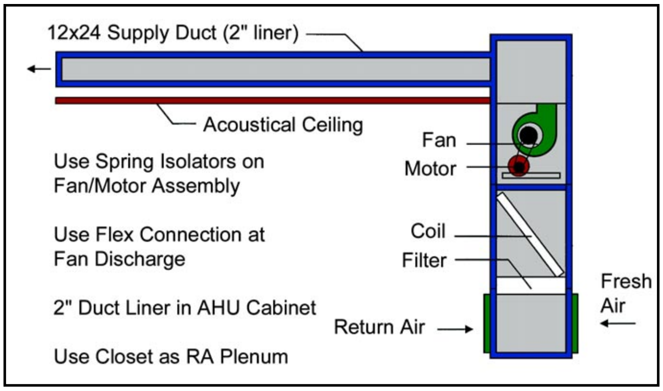

Figure 4A: Typical dedicated classroom HVAV unit with noise control.

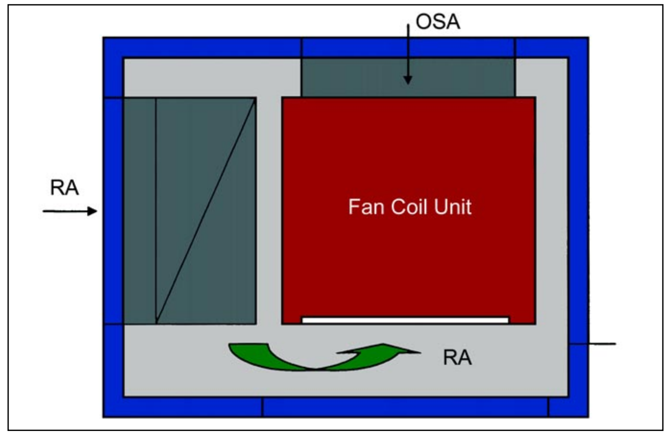

Figure 4B: Top section view of mechanical closet showing fan coil unit and RA duct.

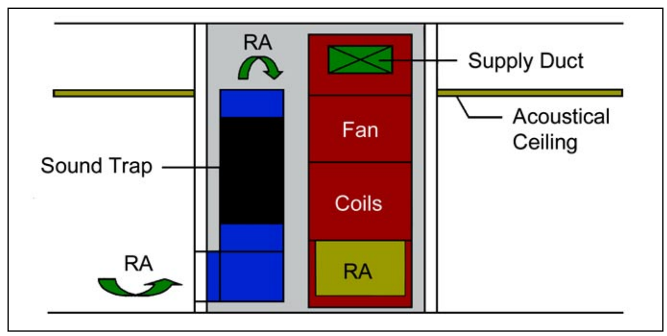

Figure 4C: Front elevation view of classroom HVAC unit in closet.

recommendations in this regard. *Figure 2* shows a section through a rooftop unit in a system designed for low background noise. Note that the supply air is discharged into an acoustical plenum (shown in blue) that penetrates the concrete roof deck (shown in black).

The yellow band above the roof and below the unit represents a spring isolation curb that controls structure-borne sound transmission from the compressors and condenser fans into the roof structure. Round supply air ducts are shown to eliminate low frequency breakout from the supply duct system. A sound attenuator also is shown in the return air opening through the roof (above the ceiling of the corridor or rest room). This particular drawing shows a plenum fan, but a standard centrifugal fan also could be used as well.

The sound attenuator and/or acoustical duct lining should be designed to reduce the remaining sound power level of the supply fan at the point the duct enters the classroom to no more than 80 dB at 63 Hz, 73 dB at 125 Hz, and 70 dB at 250 Hz. This is the maximum allowable sound power level entering the classroom supply duct that can achieve NC-30 with the recommended low pressure supply duct layout shown in *Figure 1*. Sound attenuators may also be required at the return air opening of the central unit (as shown in *Figure 1*), although this is oftentimes far enough removed that it may not impact the classroom noise level.

Dedicated System: Design Guidelines

A layout of the typical dedicated system is shown in *Figure 3*. The ceiling supply air-distribution system in the classroom is identical to the one recommended for the central system. A VAV box is not required because there is only one zone in this system. The closet enclosing the air-handling unit can be located in a corner of the classroom (as shown here) or it could be placed next to another mechanical or storage closet serving the adjacent classroom in a nested fashion. The dedicated unit should be a fan coil unit, not a self-contained package unit or a heat pump since these devices contain noisy compressors and condenser fans. Cooling should be provided from a remote central chiller with a chilled water distribution system.

As with the central system, the maximum allowable sound power level entering the supply duct above the ceiling should not exceed 80 dB at 63 Hz, 73 dB at 125 Hz, and 70 dB at 250 Hz. To meet these levels, the fan inside the dedicated AHU will probably have to be an airfoil or forward curve centrifugal fan selected for maximum efficiency and minimum noise. It is very important to keep the total system static pressure below 2 in. (500 Pa) if this goal is to be achieved.

In addition, a fan discharge plenum should be mounted to the top of the unit (internally lined with 2 in. [50 mm] acoustical duct liner) to provide additional fan noise control prior to the supply duct connection. If exposed duct liner is not desired in the discharge plenum, the insulation can be wrapped in 1 mil polyethylene (or equivalent material) and faced with perforated sheet metal.

Another alternative to the acoustical discharge plenum would be to use an elbow silencer. Custom designed elbow silencers are now available from several manufacturers. If the fan is properly selected, it should be possible to meet the recommended sound power levels without the use of an attenuator in the supply air system, but only if an acoustical discharge plenum is used in conjunction with duct lining. If the supply fan sound power levels exceed the recommended values, a duct silencer can be installed in the supply air duct positioned just above the mechanical closet wall.

The dedicated AHU casing should be minimum 18 gauge steel with 2 in. (50 mm) thick internal acoustical lining throughout. In addition, the fan/motor assembly must be internally isolated on spring isolators with a minimum design static deflection of one inch. The fan discharge should be vertical into an acoustically lined discharge plenum that extends above the classroom ceiling line. The AHU return air opening should be located near the floor inside the closet. The return air from the classroom must pass through a lined duct with a sound attenuator located next to the AHU in the closet as shown in the layout above to minimize noise radiation from the AHU casing and the AHU inlet opening.

This design requires a 60 in. (1.5 m) long sound attenuator sized for a face velocity of 500 fpm (2.5 m/s). The closet wall construction should be one layer of 5/8 in. (16 mm) gypsum board on each side of 3.5 in. (89 mm) (25 gauge) metal studs spaced 24 in. (60 cm) on center with fiberglass insulation filling the stud cavity. The closet door should be a minimum 1.75 in. (44 mm) thick solid core wood with perimeter acoustical seals and an automatic door bottom. The fan coil unit should be spaced away from the closet wall by at least 3 in. (76 mm).

Figure 4A illustrates the recommended noise control features of a typical dedicated classroom HVAC unit. Note the upward discharge of the supply fan into an acoustically lined plenum above the ceiling line. The closet walls are not shown for clarity. *Figures 4B* and *4C* show a top and front elevation view, respectively.

Summary

It is not difficult to design and build a school classroom HVAC system to achieve low background sound levels comparable to NC-30. This can be accomplished with conventional HVAC system components using either a central system or a dedicated air-handling unit located in a closet in or adjacent to the classroom. Simply follow the few simple design guidelines presented earlier. Engineers who would like additional assistance in specific system designs can find help from members of the National Council of Acoustical Consultants at www.ncac.com.

Acknowledgments

Appreciation should be given to those individuals who were first to recognize and promote the need for lower background noise levels in classrooms, and those who continue to champion the work toward the creation of a national standard. Specific recognition should be given to Robin M. "Buzz" Towne (a longtime ASHRAE member who died in August 1998) who started the ball rolling several years ago with Michael Nixon. In addition, Lou Sutherland and David Lubman are leading the current task force for the national classroom acoustical performance standard. ■

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