# Achieving Acoustical Standards in the Classroom

## Study of HVAC systems and classroom acoustics

# Introduction

The link between improved scholastic achievement and lower classroom sound is well documented. Research shows that excessive background noise or reverberation in classrooms interferes with speech communication and thus impedes learning. The noise from the HVAC system can be a significant contributor to the background sound levels in a classroom or other learning space.

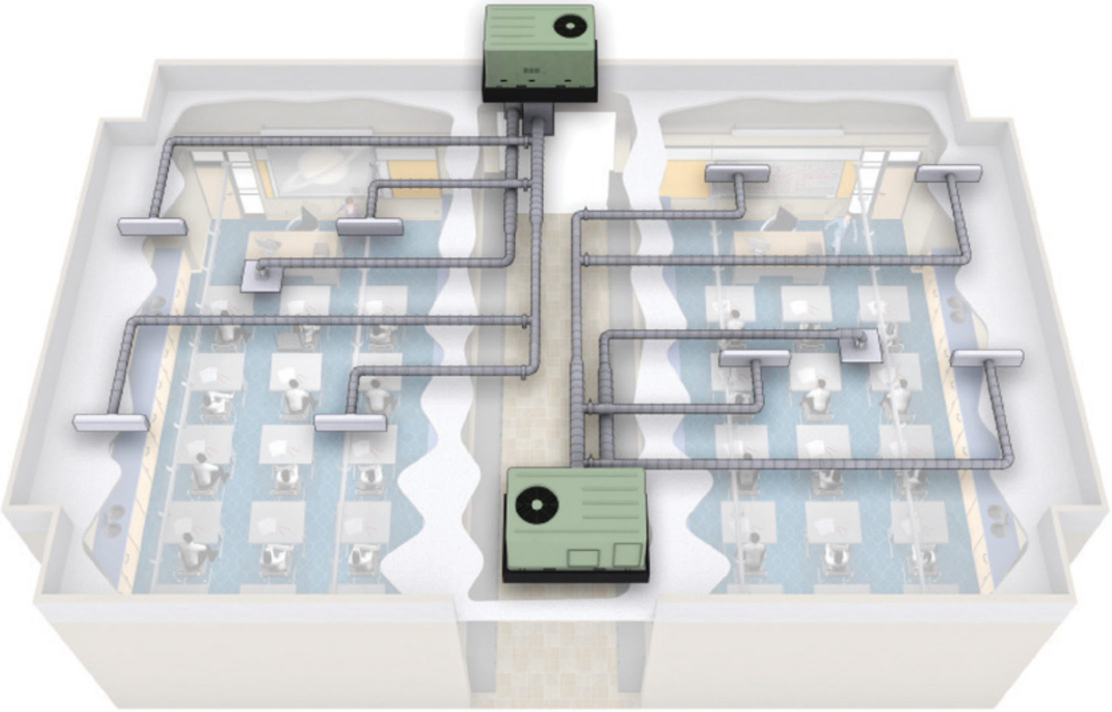
In 2002, the Acoustical Society of America (ASA) used the available research to create a standard entitled Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools (ANSI/ ASA S12.60-2002) to provide a minimum set of requirements to help school planners and designers “provide good acoustical characteristics for classrooms and other learning spaces in which speech communication is an important part of the learning process.” In 2010, several details were refined and the language was revised for use in building codes.

Despite the obvious benefits of quieter classrooms, incorporating the standard into building codes has been met with resistance. A common perception is that in order to meet the standard’s requirements, specialized HVAC equipment and installation methods would be necessary, resulting in an installed cost beyond what most schools can afford.

Acoustical prediction tools, such as Trane Acoustics Program1 (TAP™), indicate that the requirements of S12.60 can be met using standard HVAC equipment and installation methods. To verify the predictions, Trane built a classroom in its mock-up facility and tested a single-zone air handling unit, a high-efficiency watersource heat pump, and a packaged rooftop unit. The selected products were standard catalog offerings, without any special attenuation features, that were operated at typical airflow and static pressures.

This paper describes those tests, the conclusion, and the resulting recommendations.

**Figure 1. Example of a traditional HVAC system for a classroom**



# The design process

## Goal

ANSI/ASA S12.60-2010 consists of two parts: Part 1 covers the requirements for permanent classrooms; Part 2 covers relocatable classrooms. Complete copies of both parts can be downloaded for free from the ASA website (www.asastore.aip.org). Part 1 was referenced for this study.

The classroom acoustical requirements are based on room size and include maximum background sound levels for A- and C-weighted sound pressure levels (dBA and dBC) and reverberation time. The background sound and reverberation limits for permanent classrooms are summarized in Table 1.

## Acoustical model

Early in the design process, an acoustical model should be created. Each potential sound path from the HVAC equipment to the room should be modeled individually. All potential paths are added together to determine the total predicted sound in the classroom. The model allows the designer to adjust the configuration to provide the attenuation needed to meet the sound levels shown in Table 1.

Creating a useful model requires reliable and accurate information about the sound power levels that will be produced by the selected equipment. The sound emitted from the equipment is dependent on the actual operating conditions for the equipment and how the sound leaves the unit, e.g., ducted discharge, ducted inlet, or casing radiated. To acquire accurate sound data, the supplier of the HVAC equipment needs to follow the appropriate rating standards, such as the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Standard 260 for ducted equipment, AHRI 350 for unducted equipment, or AHRI 270 for outdoor equipment.

When accurate sound power levels are available, predictive tools, such as TAP™, can be used to model the various paths that the sound travels from the equipment to the classroom. Predictive tools rely on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) acoustical algorithms to evaluate the attenuation present along these paths, estimate the noise generated as the air travels through the ductwork, account for room effects, and add the contributions of each path to predict the overall sound level in the classroom.

**Table 1. Limits on A- and C-weighted sound levels of background noise and reverberation times in unoccupied furnished learning spaces**

| Learning space[a] | Greatest one-hour average A- and C-weighted sound level of exterior source background noise[b,f,] (dB) | Greatest one-hour average A- and C-weighted sound level of interior source background noise[c,f,] (dB) | Maximum permitted reverberation times for sound pressure levels in octave bands with midband frequencies of 500, 100 and 200 Hz(s) |
|---|---|---|---|
| Core learning space with enclosed volume < 283 $m^3$ (<10,000 $ft^3$) | 35/55 | 35/55 | 0.6 s[e] |
| Core learning space with enclosed volume > 283 $m^3$ and < 566 m3 (>10,000 $ft^3$ and < 20,000 $ft^3$) | 35/55 | 35/55 | 0.7s |
| Core learning space with enclosed volume > 566 $m^3$ (>20,000 $ft^3$) and all ancillary learning spaces | 40/60[d] | 40/60[d] | no requirement |

[a] See 3.1.1.1 and 3.1.1.2 for definitions of core and ancillary learning spaces.

[b] The greatest one-hour average A- and C-weighted interior-source and the greatest one-hour average A- and C-weighted exterior-source background noise levels are evaluated independently and will normally occur at different locations in the room and at different times of day.

[c] See 5.2.2 for other limits on interior-source background noise level.

[d] See 5.2.3 for limits in corridors adjacent to classrooms.

[e] See 5.3.2 for requirement that core learning spaces < 283 $m^3$ ( < 10,000 $ft^3$) shall be readily adaptable to allow reduction in reverberation time to 0.3 s.

[f] The design location shall be at a height of 1 m above the floor and no closer than 1 m from a wall, window, or fixed object such as HVAC equipment or supply or return opening. See A.1.3 for measurement location.

## Overview of the classroom

### Classroom size and design airflow

The tests were performed in an existing 500 ft$^2$ room in Trane's mock-up facility. To accurately reflect typical classroom HVAC sizes, the units were selected and operated to accommodate a 900 ft$^2$ room. This resulted in a design airflow of 1280 cfm.

The 8-ft ceiling height of the test room is at the low end of the typical range for classrooms, putting the mock-up room at a slight disadvantage over rooms with higher ceilings because diffusers (a significant source of sound in the room) are closer to the listener's ear.

### HVAC equipment tested

A single-zone air handling unit[2], a packaged rooftop unit[3], and a water-source heat pump unit[4] were tested. The selected products were standard catalog offerings, without any special attenuation features, that were operated at typical airflow and static pressures. Per recommended practice, the units were located above a corridor immediately adjacent to the classroom.

### Reverberation

The reverberation time of the room was measured following the procedures in Annex A of ANSI/ASA Standard S12.60. Absorption (in the form of fiberglass batts) was added to the room until the reverberation time was less than 0.5 seconds at 1000 Hz. At 500 Hz, the room was slightly more reverberant than permitted by the standard; reducing the 500 Hz reverberation time should slightly lower the measured sound pressure levels.

ANSI/ASA S12.60 requires specific sound transmission class (STC) ratings for the walls, floor, and ceiling surrounding the classroom. The wall in the mock-up classroom did not meet the transmission loss (TL) requirements of the standard but should be adequate to control the radiated sound path. It is possible that a higher TL wall would have lowered the sound in the classroom by reducing the wall transmission sound.

## Acoustical analysis results for the mock-up classroom

Once a rough design was laid out, an acoustical analysis was conducted to determine the extent of acoustic controls needed to meet the goal. For the analysis, three acoustic paths were considered: supply airborne, return airborne, and casing radiated. The model indicated that the target sound levels could not be met by the units without additional acoustical control.

### General acoustical controls

To achieve the target room sound level, the TAP model indicated that it would be necessary to:

1. Line the supply and return ducts with 2 inches of absorptive material
2. Add a lined plenum to the supply duct
3. Select quiet diffusers
4. Add an elbow to the return duct
5. Isolate the corridor from the classroom with continuous floor-to-roof deck walls

### Specific unit details

Variations in inlet and outlet configuration resulted in each setup being slightly different. Specific installation details for each unit are described in the following sections along with the test procedure and measurement results.

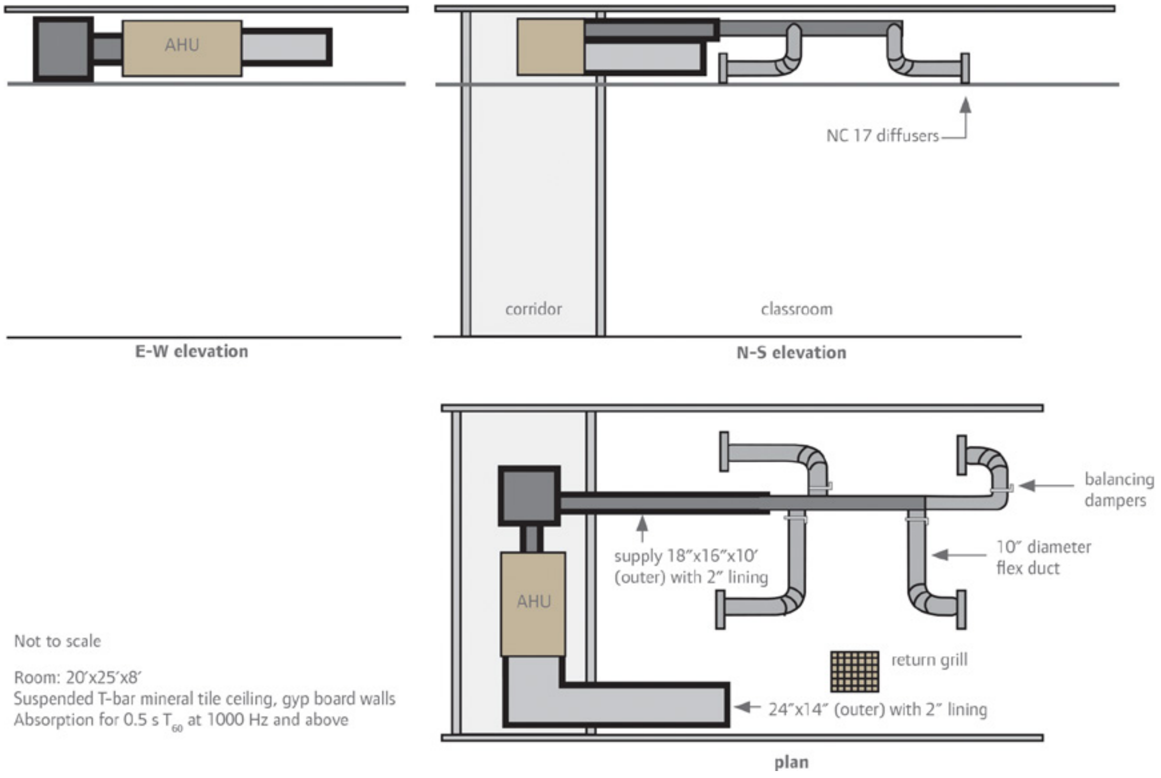
[2] Trane blower coil model no. BCHC

[3] Trane Precedent™ rooftop unit

[4] Trane Axiom™ high-efficiency water-source heat pump model EXHE

# Single-zone air handling unit installation details

**Figure 2. Mock-up classroom layout for zone-level air handler**



It was necessary to select NC 17 diffusers at the desired airflow to keep the effect of four diffusers plus duct-borne sound below the A-weighted sound pressure level limit of 35 dBA. The final room layout is shown in Figure 2.

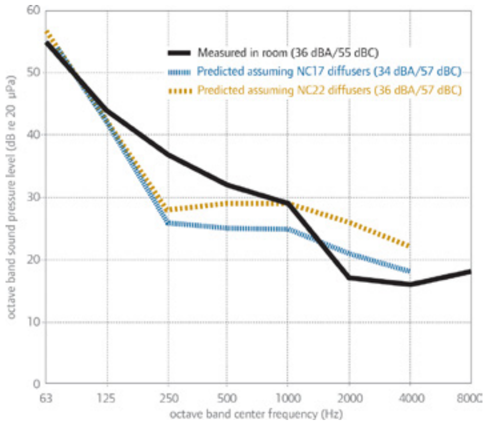
Prior to taking acoustic measurements, airflow was verified to match the design condition using a flow hood, and fan speed and static pressure across the fan and unit were measured. Sound pressure levels were measured directly underneath each diffuser at a height of 4 ft.

Background sound levels without the HVAC system operating were 25 dBA (26 dBC). With the unit running at design flow, the measured sound pressure level was 35 dBA (55 dBC) under two diffusers and 36 dBA (55 dBC) under the remaining two diffusers.

The prediction and measurement results are shown in Figure 3. The model predicted 34 dBA with NC 17 diffusers, as shown in blue. Measured sound levels from the microphone with the highest sound level are shown in black. The standard allows a 2 dB test tolerance so this level meets the stated requirement.

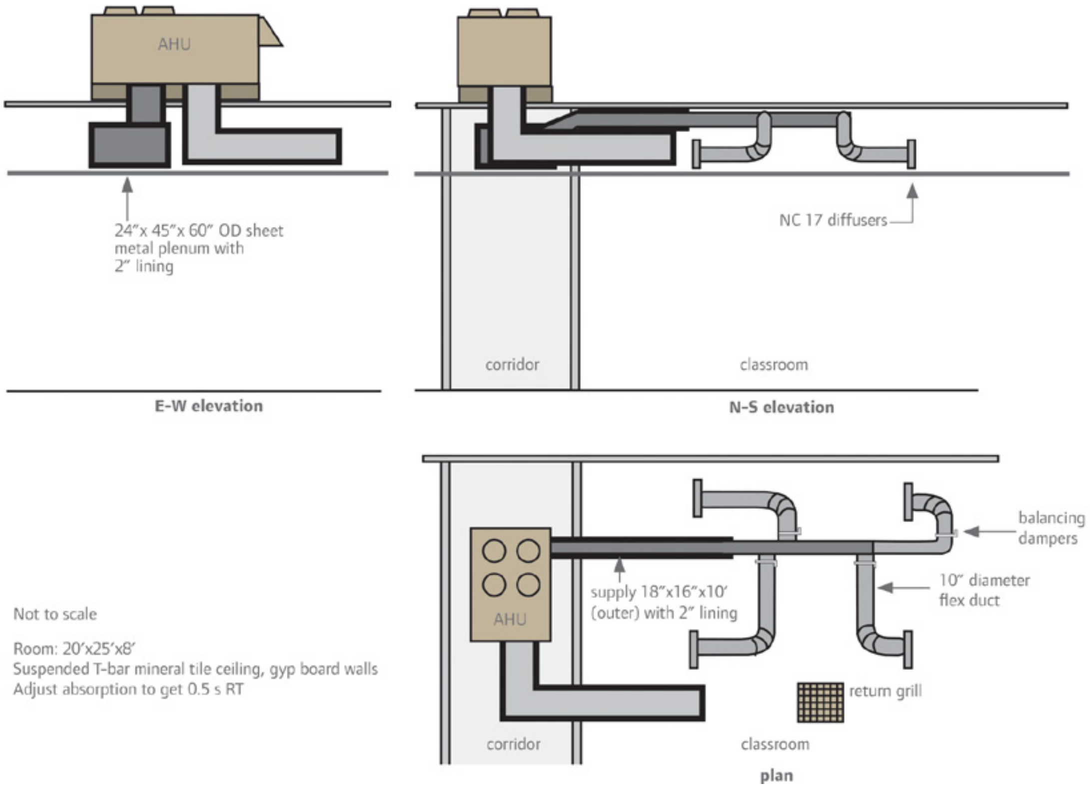
The analysis indicates that the 63 and 125 Hz bands are set by the air handler and the rest are set by the diffusers. To better account for the effect of flow disturbance on diffuser acoustical performance, the prediction model was rerun with NC 22 diffusers as shown in Figure 3. (For more information on the effect of flow disturbance on diffuser sound, see the Lessons Learned section.)

**Figure 3. Measured and predicted sound levels with a zone-level air handler**



# Packaged rooftop unit installation details

**Figure 4. Mock-up classroom layout for a packaged rooftop unit**



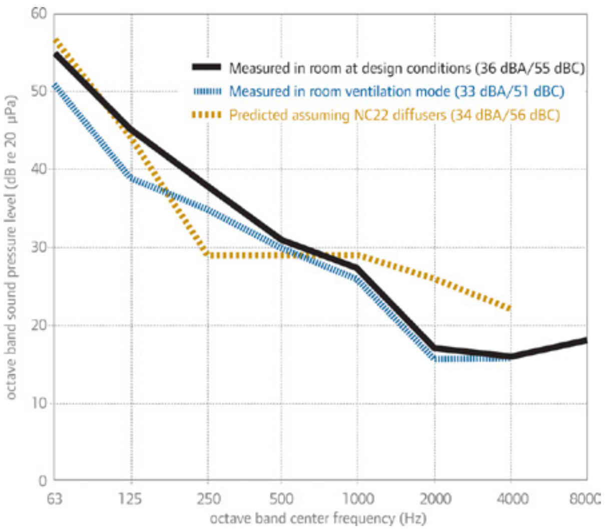
The acoustical analysis for the packaged rooftop unit indicated that a configuration similar to the one used for the air handling unit would be required. The rooftop unit was placed above the corridor on a curb above a simulated roof slab. Some ductwork changes were made to accommodate differences between an indoor air handler and a roof-mounted unit. This resulted in a slightly longer inlet duct than required by the analysis. The supply plenum was changed to a different size and shape to match the unit discharge with the existing supply ductwork. The room layout is shown in Figure 4.

Prior to taking acoustic measurements, airflow was verified to match the design condition using a flow hood, and fan speed and static pressure across the fan and unit were measured. Sound pressure levels were measured directly underneath each diffuser at a height of 4 ft.

The measured sound, under the diffuser with the highest sound pressure level, was 36 dBA (55 dBC) with the compressors on (cooling mode) and 33 dBA (51 dBC) with the compressors off (ventilation mode). The prediction and measurement results are shown in Figure 5.

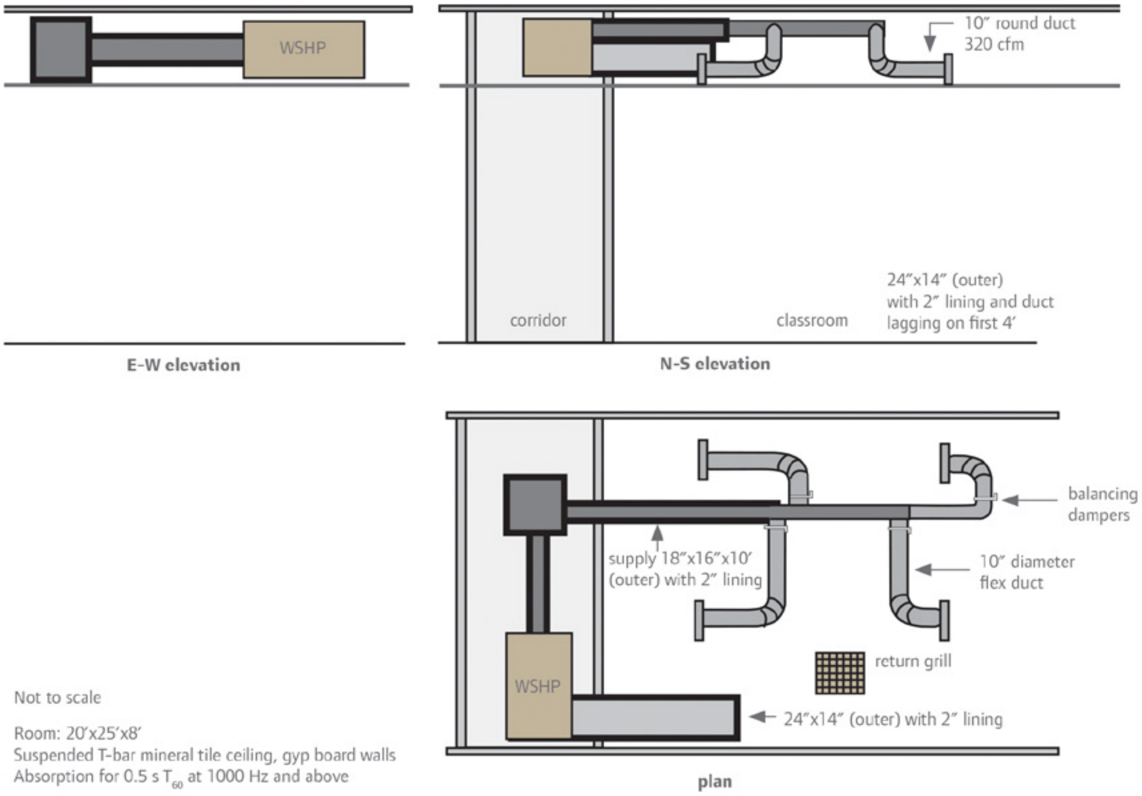
ANSI/ASA S12.60 includes an allowance for units that produce different sound levels in different operating modes (e.g., cooling, ventilation, and off). This rooftop unit meets the requirements of the standard because the hourly equivalent sound level is less than 35 dBA.

**Figure 5. Measured and predicted sound levels with a packaged rooftop unit**



# Water-source heat pump unit installation details

**Figure 6. Mock-up classroom layout for a water-source heat pump unit**



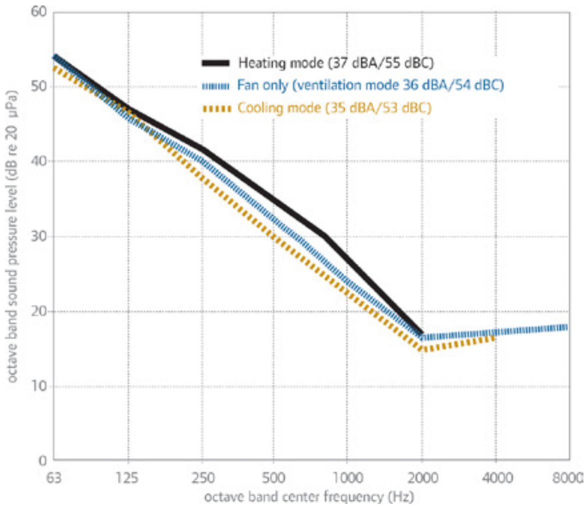
For ease of installation, the return elbow was removed and the return duct lengthened to reach the unit. Acoustical analysis indicated that elimination of the return elbow would require the addition of lagging to the first 4 ft of the return duct to control duct breakout. Otherwise the installation was similar to the air handling unit. The room layout is shown in Figure 6.

Prior to taking acoustic measurements, airflow was verified to match the design condition using a flow hood, and fan speed and static pressure across the fan and unit were measured. Sound pressure levels were measured directly underneath each diffuser at a height of 4 ft.

The measured sound, under the diffuser with the highest sound pressure level, was 35 dBA (53 dBC) in cooling mode, 37 dBA (55 dBC) in heating mode, and 36 dBA (54 dBC) with the compressors off (ventilation mode). The prediction and measurement results are shown in Figure 7

ANSI/ASA S12.60 includes an allowance for units that produce different sound levels in different operating modes (e.g., cooling, ventilation, and off). This unit meets the requirements of the standard 35 dBA because the hourly equivalent sound level is within test tolerances of +/- 2 dB.

**Figure 7. Measured and predicted sound levels with a water-source heat pump unit**



# Results

### Cost

The cost of installing the ductwork was estimated by the mechanical contractor to be $3,200 without the plenum or fiberglass lining. The cost including the acoustic plenum and duct lining was $4,000. The $800 increase for a room of 500 ft² suggests an increase of $1.60/ft². Since the equipment was sized for a 900 ft² room, the cost increase may be as low as $0.89/ft² for an actual installation.

AHRI estimated the total cost associated with constructing a classroom space in the upper Midwest to range from $130/ft² for single story construction to $135/ft² for multistory construction. Applying mock-up costs estimates to this range results in a cost increase of 0.7 percent to 1.2 percent to make standard HVAC equipment comply.

### Conclusions

The ANSI/ASA S12.60 limit of 35 dBA can be met using standard HVAC equipment without greatly increasing installed cost. However, meeting the requirements does require good selection, design, and application practices such as:

1. Obtaining accurate sound power levels for the equipment, such as those acquired by AHRI 260. Having accurate sound power data will reduce the need for a large factor of safety in the design and reduces the risk of a job with higher-thandesired classroom sound pressure levels.
2. Performing an acoustical analysis to predict the space sound levels and to ensure adequate attenuation is in place.
3. Locating the equipment outside of, and away from, the classroom. Good locations include those in or above less critical areas such as corridors, utility areas, or mechanical rooms.
4. Evaluating the trade-off between purchasing quieter equipment and implementing path attenuation.
5. Keeping the airflow velocity in the ductwork low to minimize regenerated noise.
6. Ensuring diffuser design and installation follow the manufacturer's design recommendations to achieve the stated NC goals. Linear slot diffusers should be considered, especially for shallow ceiling plenums.

### Lessons learned

Path attenuation, e.g., duct lining and sound plenums, is effective in reducing equipment generated sound. However, diffusers— because they are at the end of the duct run and in the occupied space—can generate sufficient sound to exceed the sound level limit. Our testing found that sound levels in the room were significantly affected by the noise generated by the diffusers.

Diffuser sound not only adds to the sound traveling down the duct, but it also adds to the sound produced by the other diffusers. Both of these must be taken into consideration when selecting diffusers. However, the biggest challenge can be installing the diffuser correctly.

The ASHRAE HVAC Applications Handbook states that the diffuser sound rating is valid only for uniform airflow and that the sound levels rise quickly—as much as 12-15 dB over the NC rating of the diffuser—with any misalignment or disruption. Our tests confirmed that the room sound levels increased 10-15 dB from minor duct misalignments.

Achieving uniform airflow at the diffuser is particularly challenging for top entry diffusers. One manufacturer recommends a solid radius elbow followed by 3 duct diameters of straight duct prior to the diffuser. Considering that the diffuser generally extends partway into the plenum space, there is rarely room in a common plenum to achieve the recommended installation.

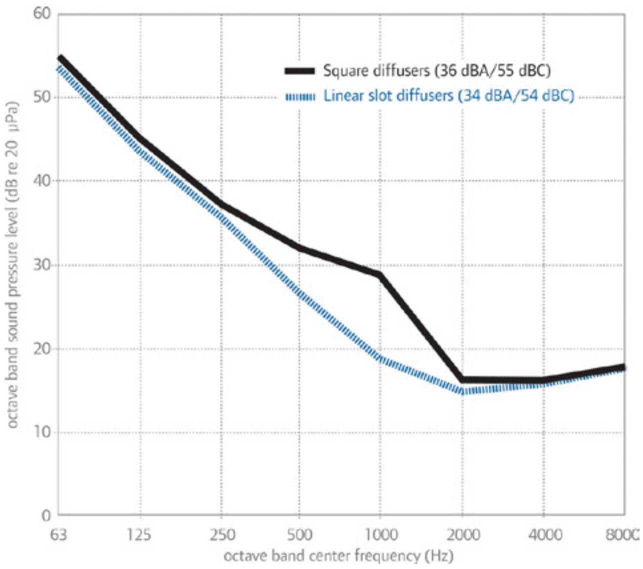
Initially, diffusers were installed using a section of lined flex duct between the end of the supply duct and the diffuser, as is common practice. This resulted in space sound levels considerably above the target. We then reconnected the diffuser using a radius elbow and 2 duct diameters of straight duct. This was less straight duct than recommended by the diffuser manufacturer but all that would fit in the 38-inch plenum space. The change significantly lowered the sound level measured in the classroom, but not enough to meet the desired level.

A subsequent investigation looked at the effect of replacing the square diffusers used in the original test with linear slot diffusers. The inlet to the linear slots diffusers is horizontal, so a longer section of straight duct is easily accommodated.

The linear slot test was run using the single-zone air handler and associated ductwork installed per the original setup shown in Figure 2. The sound pressure levels with the original square diffusers were verified to be unchanged and then the test was rerun using linear slot diffusers with an acoustic criteria catalog rating.

The differences in the sound pressure spectrum relative to the diffuser types are shown in Figure 8. Because the linear slots generated significantly less sound between 250 and 2000 Hz, they should always be considered when designing classrooms to meet ANSI/ASA S12.60.

**Figure 8. Effect of replacing square diffusers with linear slot diffusers**



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