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VAV Systems and Open Ceilings

Can You See the Noise?

Open ceilings in new and retrofit buildings have become very popular. Exposing the structure and some mechanical system components provides a neat, industrial look while the perceived space height increases, creating a more open and lofty atmosphere. However, there are several unintended consequences that should be considered. This *Engineers Newsletter* discusses considerations for open ceiling systems when using variable air volume (VAV) systems and expands upon the 2018 *Engineers Newsletter* "Understanding VAV Sound Standards."[1]

Eliminating Ceiling Tiles

Considerations

Acoustical ceiling tiles serve several purposes. First, ceiling tiles can be used to conceal ceiling plenums and hide overhead mechanical, electrical, and plumbing equipment from the building occupant's view. Next, tiles provide a physical separation between the occupied zone and the ceiling plenum, which often also serves as part of the return air path. Finally, ceiling tiles provide several acoustical benefits—ceiling tiles absorb sound generated in the plenum and occupied space. High density acoustical ceiling tiles can provide significant sound transmission loss, even in the difficult-to-attenuate lower octave bands.

Sound generated by equipment typically located in the plenum, such as variable air volume (VAV) terminal boxes, can easily propagate into the occupied space if the tiles are absent. Compounding this, hard reflecting surfaces like exposed concrete decking in the ceiling can reverberate these and other sounds. This results in additional HVAC noise in the space. This will make the overall background noise in the space louder, which might make it more difficult for occupants to communicate and concentrate on tasks.

There are many methods used to replicate the attenuation provided by acoustical ceiling tiles. Designers may choose to use spray-on acoustical materials to increase sound absorption and reduce reverberation. Another popular option is to incorporate acoustical panels, baffles, or "clouds" to add some aesthetically pleasing attenuation. These panels may be mounted to the wall or suspended from the ceiling. Finally, designers may select soft materials, like carpeting, furniture, and fabric-walled office cubicles to increase the space sound absorption and reduce reverberation. While these choices will help reduce reverberation, they do not prevent direct radiation of sound from the mechanical systems, including the VAV boxes.

VAV Sound Standards

AHRI Standards 880-2017 and 885-2008

There are two common AHRI Standards that are used with VAV boxes in North America. Representatives from AHRI-member companies participate in standards development, resulting in industry agreed-upon standards. AHRI publishes its standards online and are available to view at no cost. To view these and other standards, visit www.ahrinet.org.

ANSI/AHRI Standard 880-2017. "Performance Rating of Air Terminals"[2] is often used to obtain octave band sound power for VAV boxes. The scope includes pressure-dependent and -independent air valves, fans with on/off or speed control, heating elements, and diffusers. The standard does not apply to air registers or diffusers and grilles without an air valve.

ANSI/AHRI Standard 885-2008. "Procedure for Estimating Occupied Space Sound Levels in the Application of Air Terminals and Air Outlets"[3] includes a method to calculate the noise criteria (NC) level in a space served by VAV boxes. Appendix E "Typical Sound Attenuation Values-Normative" provides "typical sound attenuation values," which are also commonly called transfer functions. These values are used with VAV box sound power to estimate octave band space sound pressure. The NC procedure is used to compute the space NC level for a standard room, which may not reflect the actual application. For an example, see the Estimating Space NC Level with AHRI Standard 885-2008 Appendix E Values sidebar (p. 3).

> The NC values provided through this process should only be used for VAV box comparison and not expected in the actual system installation.

The Published NC Value versus the As-Applied Value

It is very unlikely that the published NC value will match the as-applied value. As an example, a 1,000 cfm cooling–only VAV box was selected in Trane® Select Assist™ to serve a 62 foot by 32 foot acoustically sensitive space with 9-foot ceilings with a sound target of NC 25. Unit sound power was taken in accordance with AHRI Standard 880-2017 and the NC values were determined based upon the procedure described in Appendix E of AHRI Standard 885-2008.

These values are reported in Table 1. The discharge path represents the sound that leaves the VAV box outlet and passes through the terminal duct system to enter the space through diffusers. The radiated sound path represents the sound that radiates from the VAV box casing into the ceiling plenum or occupied space.

Table 1. Trane VCCF 1000 cfm cooling-only VAV box octave band sound power and NC

Sound path	125	250	500	1000	2000	4000	NC
Discharge	68	60	55	52	48	44	19
Radiated	54	51	42	33	29	26	19

The Trane Acoustics Program (TAP™[4]) was used to predict the sound pressure in the actual occupied space. The VAV box discharges supply air into a straight run of unlined rectangular duct which terminates in a T-shaped junction. Flexible ducts are used to convey the supply air to linear slot diffusers serving the space. Sound contributions from other equipment, including rooftop units or air handlers, was not included in this analysis. Two scenarios were considered:

Scenario 1—VAV installation with an acoustical ceiling. In this first scenario, the VAV box, ductwork, flexible duct, and diffusers were installed inside of the ceiling plenum. The ceiling plenum and occupied space were separated with acoustical ceiling tiles.

Scenario 2—VAV installation without an acoustical ceiling. In this second scenario, the VAV box and ductwork are exposed to the occupied space and no acoustical ceiling tiles were used to create and isolate the ceiling plenum.

The results of this analysis are summarized in Table 2. While the procedure in Appendix E of AHRI Standard 885 shows a discharge value of NC 19, the acoustical model shows a louder value of NC 25 and NC 27 based upon the actual installation scenarios. For the radiated path, Standard 885 shows a prediction of NC 19 while the TAP model predicts NC 17 based upon the modeled application with ceiling tiles and NC 32 in an open ceiling installation. Standard 885 automatically assumes attenuation from a ceiling system and does not account for an open ceiling.

The NC values provided by the Appendix E procedure in Standard 885 do not match either scenario. In fact, the room dimensions, construction materials, floor coverings, and presence of acoustical ceiling tiles are not provided during VAV box selection and subsequent Standard 885 NC-value calculations.

In both scenarios, the total space sound pressure NC value is quiet, however the difference between NC 25 and NC 32 is significant and cannot be discounted in a sound-sensitive application. In an open ceiling application, designers would need to implement additional attenuation to reduce the radiated VAV box sound contribution to meet the NC 25 goal.

Table 2. AHRI Standard 885-2017 Appendix E sound pressure NC levels compared to acoustical model predictions with and without ceiling tiles (Sound target = NC 25)

	AHRI Standard 885-2017 Appendix E	Scenario 1 VAV installation with acoustical ceiling tiles	Scenario 2 VAV installation in an open ceiling
Discharge path	NC 19	NC 25	NC 27
Radiated path	NC 19	NC 17	NC 32
Total	not applicable	NC 25	NC 32

In this example, the exact same VAV box with certified acoustical output data was applied in two different configurations. The resulting sound pressure in both configurations does not match the NC value provided through the Standard 885 procedure. Ultimately, the acoustical ceiling provided a significant radiated path attenuation that must be achieved by other means to meet the same sound target if it were installed in an open ceiling system.

Estimating Space NC level with AHRI Standard 885-2008 Appendix E Values

AHRI Standard 885-2017 Appendix E provides values that can be used to compute NC levels in the occupied space. The computed NC values can be used as a rough comparison of VAV boxes and should not be used to predict the NC level in the actual installed application. The following steps can be used to manually determine NC levels based upon Standard 885-2008 Appendix E:

Step 1: Identify the VAV box discharge and radiated sound power.

For example, consider a 700 cfm single-duct shut-off VAV box:

	125	250	500	1000	2000	4000
Radiated sound power	57	51	45	36	35	32
Discharge sound power	72	62	52	49	48	45

Step 2: Subtract the appropriate “typical sound attenuation values” found in Table E1 of Standard 885-2008 Appendix E for each octave from the VAV box sound power.

Continuing with the example, the “Type – Mineral Fiber” attenuation values are subtracted from the radiated sound power:

	125	250	500	1000	2000	4000
Radiated sound power	57	51	45	36	35	32
Type- mineral fiber	18	19	20	26	31	36
Resulting sound pressure	39	32	25	10	4	0*

The discharge sound category includes multiple “typical sound attenuation values” relating to the physical size and airflow range of the VAV box. For this example, the “Medium Box (12 in. × 12 in.) 300–700 cfm” option is appropriate.

	125	250	500	1000	2000	4000
Discharge sound power	72	62	52	49	48	45
Medium box 300 - 700 cfm	27	29	40	51	53	39
Resulting sound pressure	45	33	12	0*	0*	6

Step 3: Compute the NC value for the calculated sound pressure. A software tool or plot can be used to determine the resulting NC value. Each sound path is plotted on an NC chart showing NC 19 for radiated sound pressure and NC 26 for discharge sound pressure.

*Negative octave values resulting from subtraction are replaced with zero.

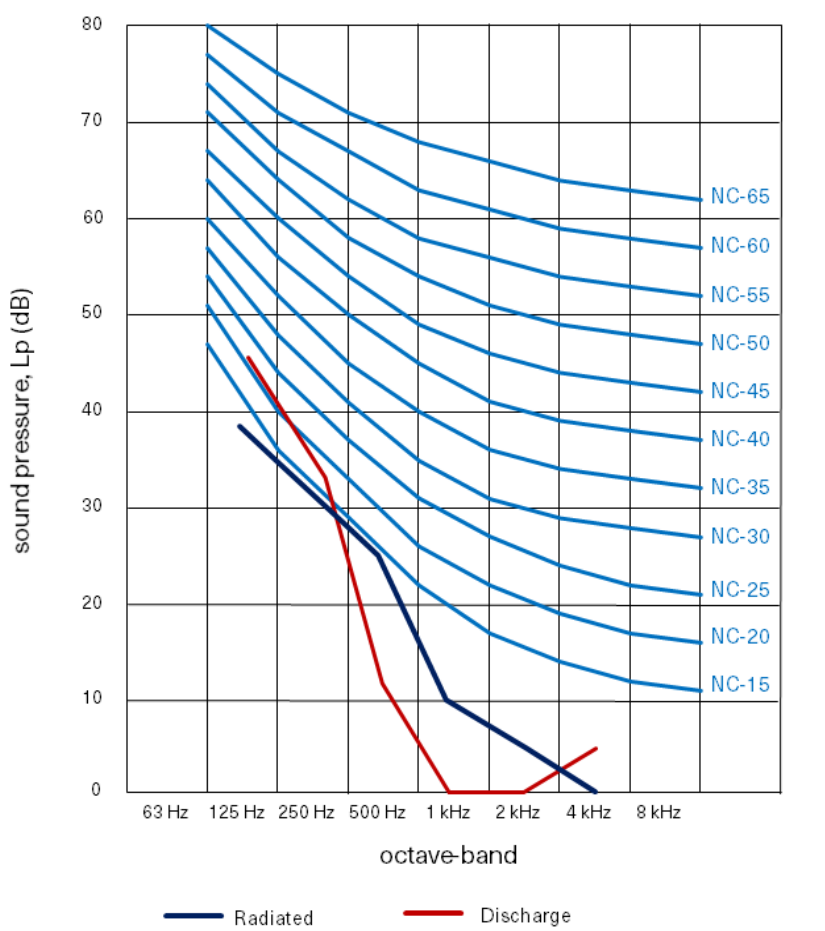
Best Practices for VAV Terminal Units

There are a variety of considerations when selecting and designing a VAV system for sound. A traditional VAV installation with acoustical ceiling tiles is more forgiving than an open ceiling system. The following considerations are relevant for all installations, however they're arguably more important in open-ceiling systems:

VAV box location. It's best to locate the terminal units away from critical spaces. Instead, locate VAV boxes over corridors, storage rooms, or other spaces that are less sensitive to radiated sound. This helps reduce radiated sound from entering critical spaces. Additionally, locating terminal units *far* from critical zones can help. This becomes especially important with fan-powered VAV boxes, which have an additional sound-producing component that may cycle on and off or ramp its speed up and down. Also, depending upon the fan-powered system type, the terminal fan may operate constantly (series fan-powered VAV) or intermittently (parallel fan-powered VAV). Fan-powered VAV boxes may use ECM motors to slowly modulate fan speed, reducing abrupt changes that produce noticeable sound changes.

VAV box sizing. It may be tempting to purposefully oversize a VAV box, however, an oversized air valve can adversely affect the box's ability to modulate airflow and properly control zone temperature. In the worst-case scenario, the air valve might be unable to modulate airflow and instead operate like a two-position valve (on/off). When selecting VAV boxes, ensure minimum air velocity limits are met—generally, all manufacturers require a minimum air velocity of 300 feet per minute for pressure-independent flow.

Figure 1. VAV noise criterion



VAV box operation. Systems which feature many shutoff VAV boxes run the risk of creating excess duct system pressure at low flow when many boxes simultaneously shut off. This can result in a condition where the system supply fan can go into stall, creating a roar or rumbling noise and accompanying airflow surge.

Additionally, the use of fan pressure optimization (also known as critical zone reset) helps reduce the likelihood of supply fan stall, while keeping air valves as wide open as possible. This control scheme resets the supply duct static pressure setpoint downward whenever all VAV box unit controls report partial closure of their dampers. This results in reduced supply fan noise, reduced noise generated by the air valve restriction in the VAV box, and supply fan energy savings, all while maintaining space temperature.

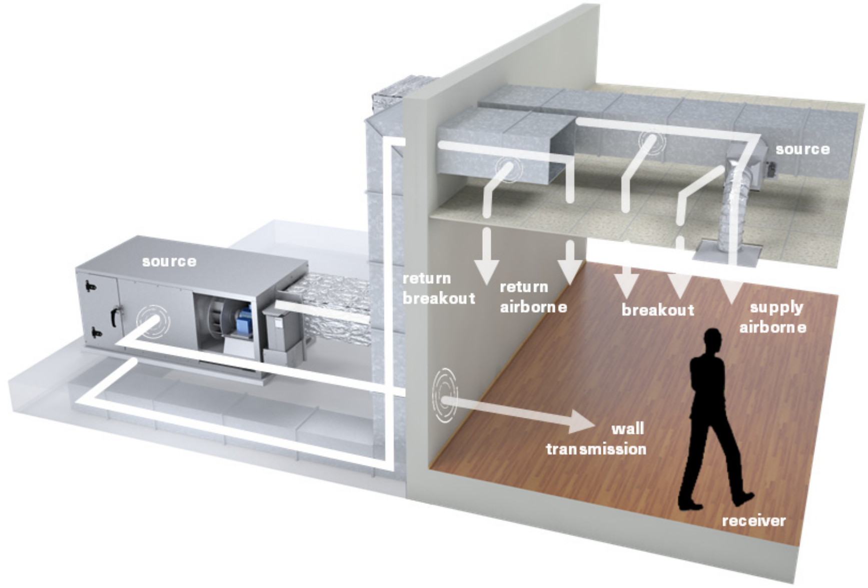
Unit insulation. VAV box manufacturers offer a variety of insulation types and options, including matte, foil-faced fiberglass, double-wall, and closed-cell foam. Generally, double-wall and closed-cell foam provide less attenuation because of the reflective surface area provided by the inner wall.

Unit attenuation. Factory- and field-installed attenuation options are available to address the discharge sound path for VAV boxes. Many manufacturers provide a lined duct section that is installed on the VAV box discharge. Alternatively, during installation, the contractor can provide acoustical lining in the downstream discharge duct. This is often easier and less expensive than the factory options.

Often, the plenum opening on fan-powered terminals is the critical sound path that allows sound to escape into the return air plenum or open ceiling. Factory-provided attenuators can be attached to the plenum inlet to reduce this noise.

Duct shape. Spiral and flat oval duct is often more rigid than rectangular duct. As a result, spiral or flat oval ductwork can reduce sound breakout. This reduces the amount of sound generated upstream or inside the duct from being transmitted through the duct wall into the surrounding space.

Figure 2. Sound pressure level in relation to the receiver's location



Consider Acoustical Modeling

VAV terminal units can pose acoustical challenges, especially in sound-sensitive applications or installations with open ceilings. Addressing acoustical problems after installation and commissioning is often more difficult and expensive compared to addressing them up front, which makes identifying the challenges a critical step in design—more so for open ceiling systems.

Acoustical modeling can be used to make a prediction and estimate space sound pressure levels. The source-path-receiver method is a systematic method for acoustical analysis that identifies sound from its origin to the location where it is heard by an occupant. Everything encountered by sound in between the source and receiver constitutes the path.

Sound coming from a source will often follow multiple paths, so the sound pressure level at the receiver's location is the logarithmic sum of these various paths. For a VAV system, sound is produced by the air handler or rooftop and VAV boxes. Figure 2 illustrates with a packaged rooftop unit installed beside the occupied space with acoustical ceiling tiles.

Sources

- Rooftop—the supply fan and compressors produce sound that moves into the building through multiple paths
- VAV box—the VAV box produces sound in the discharge and radiated sound paths; fans in fan-powered VAV boxes produce additional sound

Paths

- Supply airborne— a combination of rooftop sound and VAV box discharge sound
- Breakout—a combination of sound breaking out of the ductwork and the VAV radiated sound in the plenum that passes through the ceiling tiles into the occupied space
- Return airborne—sound produced by the packaged rooftop unit moves through the return air duct system
- Return breakout—return airborne sound can break out of the duct system into the plenum that passes through the ceiling tiles and into the occupied space
- Wall transmission—sound produced by the packaged rooftop unit transmits through the building envelope into the occupied space

Receiver(s)

- The person(s) inside the occupied space

There are a variety of software tools available to create acoustical models. In addition, Standard 885 includes a procedure that can be manually completed to analyze many common system configurations. Acoustical modeling, like energy modeling, allows designers to evaluate different attenuation options, placement options, and make informed decisions before installation.

Summary

Using VAV terminals in open ceiling systems creates additional considerations that should be addressed before installation and commissioning.

VAV box sound power is often available from the manufacturer, taking in accordance with AHRI Standard 880. AHRI Standard 885 is used to produce two NC values—one for discharge and the other for radiated sound. These values should only be used for unit comparison. The NC value in the actual application will be different from the NC value provided during selection. This is especially true for open-ceiling applications where no acoustical ceiling tiles are present.

It's important for the designers to consider the additional acoustical challenges that come from open ceiling applications. Acoustical modeling can help identify these challenges and allows designers to model various attenuation solutions before committing to a specific solution.

By Eric Sturm, Trane. To subscribe or view previous issues of the Engineers Newsletter visit trane.com. Send comments to ENL@trane.com.

References

[1] Sturm, E. "Understanding VAV Sound Standards". *Engineers Newsletter.* ADM-APN068-EN. Trane. 2018.

[2] AHRI. Standard 880-2017, *2017 Standard for Performance Rating of Air Terminals*. Arlington: AHRI. 2017.

[3] AHRI. Standard 885-2008, *2008 Standard for Procedure for Estimating Occupied Space Sound Levels in the Application of Air Terminals and Air Outlets.* Arlington: AHRI. 2008.

[4] Trane. Trane Acoustics Program™. https://www.trane.com/commercial/north-america/us/en/products-systems/design-and-analysis-tools/trane-acoustics-program.html

2021 Engineers Newsletter *Live!* program schedule

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ASHRAE® Standard 62.1-2019. The 2019 version of ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*, was published in late 2019. This ENL will overview the standard, discuss several key changes implemented in the 2019 version, explain the three allowed procedures for determining ventilation airflows (Ventilation Rate Procedure, IAQ Procedure, and Natural Ventilation Procedure), and walk through calculation steps using an example building.

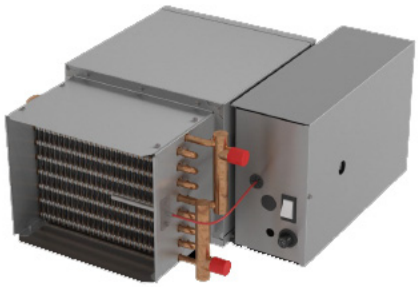
SEPTEMBER

Air Cleaning Technologies for Indoor Air Quality (IAQ). The COVID-19 pandemic has renewed focus on indoor environmental quality (IEQ), air quality, and air cleaning technologies. This ENL will provide an overview of the components of IEQ with a focus on air quality. A review of common air cleaning technologies will be presented, with emphasis on viral mitigation.

NOVEMBER

ASHRAE Standard 15. In this ENL we will cover the recent updates made to ASHRAE Standard 15 in regards to next generation 2L refrigerants and safe equipment operation as well as the safety classification changes to Standard 34.

Contact your local Trane office for more information or visit www.Trane.com/ENL.



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