Specifying VAV Boxes

By **JEFF STEIN, PE** • Taylor Engineering • Alameda, Calif.

Although differences in quality among the offerings of major variable-air-volume (VAV) box manufacturers tend to be small, a number of important zone-level decisions regarding VAV boxes must be made to achieve a system that is both quiet and energy-efficient and that provides thermal comfort. Assuming the most common building-level choice (overheard single duct with hot-water reheat), this article will focus on the important zone-level and controls decisions a specifying engineer must make.

BOX TYPE

The first decision concerns which type of box to use. The options are:

• *Cooling only*. Generally, cooling-only boxes should be used only where minimum ventilation is not a concern and, therefore, can be set at zero. A telecommunication room is just such a place. Another is a large open office with multiple boxes, some serving heating and ventilation needs and others cooling only.

• *Reheat*. Because they are less expensive, quieter, and more efficient and require less maintenance than fan-powered boxes, reheat boxes should be used for most heating applications.

• *Series fan-powered*. Series-fan-powered boxes make sense where very high minimum-airflow rates are required. For example, a series box could be used in an interior conference room in which the minimum ventilation is more than 50 percent of the design cooling airflow. (Using reheat boxes with carbon-dioxide controls to reset the minimum-airflow set point is another good way to deal with densely occupied spaces.)

• *Parallel fan-powered*. Parallel-fan-powered boxes make sense in zones with relatively high heating requirements, such as north-facing, perimeter zones. Energy codes, such as ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, and Title 24, Part 6, of the California Code of Regulations, generally prohibit reheating more than 30 percent of maximum airflow.

BOX SIZE

For a given design airflow, at least two or three sizes of VAV box could be chosen. Box sizing is a tradeoff between first cost, pressure drop, reheat energy, space requirements, and noise. Larger boxes cost slightly more, require more space, and have higher minimum controllable airflow rates (which could result in more wasted reheat energy) than smaller ones, which have higher pressure drops and are noisier.

Research has shown that the best way to optimize these tradeoffs is to develop a sizing chart based on a total-pressure drop of about 0.5 in. wg.[1] Following are the basic steps of box sizing:

1) Select a product line to design around.

2) Decide on an acoustical criteria (e.g., radiated NC 30). Note that VAV-box manufacturers report Noise Criteria (NC) using the standard attenuation factors in ARI Standard 885-98, *Procedure for Estimating Occupied Space Sound Levels in the Application of Air Terminals and Air Outlets*, which

Jeff Stein, PE, is a senior engineer with Taylor Engineering and a member of ASHRAE Standard Project Committee 130, Methods of Testing for Rating Ducted Air Terminal Units.

assumes a mineral-fiber ceiling and a plenum that is 3-ft deep and at least 30-ft wide or is lined with insulation. If your application is not close to these assumptions, develop new attenuation factors, or use revised NC criteria.

3) Compare the manufacturer's data to your load calculations for a few relatively high heating-load zones to determine if you can get away with using only one-row coils. If you need any two-row coils, develop your sizing chart based on two rows.

4) Use the manufacturer's software or catalog and a spreadsheet to determine the maximum airflow each box size can achieve without violating the acoustical criteria and the total-pressure-drop criteria. Most manufacturers, unfortunately, publish only static-pressure drop, so you probably will need to calculate velocity-pressure drop based on box dimensions and iterate to find the maximum airflow.

Table 1 is a sample VAV-box sizing chart.

Calculating Total-Pressure Drop

VAV boxes should be selected based on total pressure, not static pressure, because it is total pressure that a central fan must overcome. The ratio of static pressure to velocity pressure can vary by box type, box manufacturer, and even box size. Total-pressure drop can be calculated as follows:

$$TP = SP + VP$$

$$= SP + \left[\left(\frac{v_{in}}{4005}\right)^2 - \left(\frac{v_{out}}{4005}\right)^2\right]$$

$$= SP + \left[\left(\frac{4\,cfm}{4005\pi D^2}\right)^2 - \left(\frac{cfm}{4005\,WH}\right)^2\right]$$

where:

ΔTP = total-pressure drop

ΔSP = static-pressure drop

ΔVP = velocity-pressure drop

v_{in} = inlet velocity

v_{out} = outlet velocity

cfm = airflow rate

D = box inlet diameter (feet)

W = inside (clear) width of box outlet (outside dimensions [feet] less insulation thickness)

H = inside (clear) height of box outlet (outside dimensions [feet] less insulation thickness)

AMPLIFICATION

One of the few distinguishing features of VAV boxes is airflow-sensor design. Most manufacturers use a velocity-pressure sensor that provides an amplified pneumatic signal to the VAV-box controller. The shape of the sensor determines the amount of amplification it can provide, as well as the amount of noise and pressure drop it creates. The greater the amplification, the lower the minimum controllable airflow. The first two references listed at the end of this article discuss how to calculate amplification from manufacturers' data and how to calculate minimum controllable airflow.

While all manufacturers claim that their patented airflow sensors provide better amplification, less noise, and lower pressure drop than those of their competitors, there is a clear tradeoff: Some airflow sensors provide higher amplification, but at the expense of higher pressure drop. Thus, comparing manufacturers based only on pressure drop (or the maximum airflow rate for a given total pressure drop) may not be fair because a VAV box with a low pressure drop could have poor amplification. A better metric for comparing VAV boxes is turndown (i.e., the ratio of minimum controllable airflow to maximum airflow). Although amplification typically is not included in VAV-box schedules, requirements for amplification and/or turndown are good to include in specifications.

Inlet size (in.)	6	8	10	12	14	16
Maximum flow (cfm)	343	568	940	1,210	1,667	2,162
Inlet area (sq ft)	0.20	0.35	0.55	0.79	1.07	1.40
Velocity in (fpm)	1,747	1,627	1,723	1,541	1,560	1,548
Inlet velocity pressure (in. wg)	0.190	0.165	0.185	0.148	0.152	0.149
Outlet width (in.)	12	12	14	16	20	24
Outlet height (in.)	8	10	12.5	15	17.5	18
Outlet area (sq ft)	0.53	0.69	1.04	1.46	2.18	2.72
Outlet velocity (fpm)	641	826	905	830	766	796
Outlet-velocity pressure (in. wg)	0.026	0.043	0.051	0.043	0.037	0.040
Velocity-pressure drop (in. wg)	0.16	0.12	0.13	0.11	0.12	0.11
Static-pressure drop (in. wg)	0.24	0.28	0.27	0.30	0.29	0.29
Total-pressure drop (in. wg)	0.40	0.40	0.40	0.40	0.40	0.40
Radiated Noise Criteria	28	25	27	27	27	24
Minimum controllable velocity-pressure signal (in. wg)	0.004	0.004	0.004	0.004	0.004	0.004
Amplification factor	2.80	2.24	1.96	2.03	1.97	1.94
Minimum velocity (fpm)	151	169	181	178	180	182
Minimum controllable flow (cfm)	30	59	99	140	193	254
Best turndown (percent)	9	10	10	12	12	12
Worst turndown (percent)	30	17	17	15	16	15
Average turndown (percent)	15					

TABLE 1. Sample VAV-box sizing chart. A two-row hot-water coil, 1.5-in. dP across the box, and ARI Standard 885-98 noise-attenuation factors assumed.

SUBMITTAL REVIEW

If a contractor submits a product line other than the one you designed around, create a new sizing chart, compare it to your box schedule, and issue a revised schedule if any of the boxes are too big or too small. Also, see if the new sizes and/or the amplification of the new airflow sensors affect the minimum-airflow set point for any of your zones. If they significantly increase any of your minimum-airflow set points, consider using the minimum-airflow set points on your schedule and the amplification requirements in your specification as grounds for rejecting the substitution.

EVEN VS. ODD SIZES

Most VAV-box manufacturers make boxes of the following sizes: 4 in., 5 in., 6 in., 7 in., 8 in., 9 in., 10 in., 12 in., 14 in., 16 in., and 24 in. by 16 in. While one might assume that life-cycle cost (first cost, energy cost, etc.) would be optimized by including all of these sizes in a sizing chart, you should consider specifying only the even sizes from 6 in. and up because:

• The odd sizes (and the 4-in. size) usually are nothing more than the next-larger even-sized box with an adapter at the inlet to accommodate smaller inlet duct. This extra fitting can affect pressure drop, leakage, and airflow-sensor performance, particularly if it is not installed properly (which can be difficult to verify in the field).

• Most contractors do not provide odd-size ducts, making reducers and

VAV-Box Control Points and Control Sequences

One of the most important (and, unfortunately, often overlooked) decisions an engineer must make concerns what VAV-box control points and control sequences to include in control specifications. Many engineers still are using the single-maximum-control sequence, a relic from the days of pneumatic controls. With modern direct-digital-control systems, there is a much more energy-efficient way to control VAV boxes: the dual-maximum-control scheme.

The single-maximum-control and dual-maximum-control sequences are illustrated in figures 1 and 2, respectively.

The single-maximum-control sequence requires that the minimum-airflow set point be high enough to provide design heating airflow at a reasonable supply-air temperature (e.g., 90 F). Thus, the minimum typically is set at 30 to 50 percent of the maximum, which means that at low load, the space is overcooled in deadband and driven into reheat.

In the dual-maximum-control sequence, as the load goes from full cooling to full heating, the cfm set point is reset from maximum to minimum before the supply-air-temperature set point is reset from minimum (e.g., 55 F) to maximum (e.g., 90 F). If more heat is needed, the cfm set point is reset from minimum to heating maximum. Because it is decoupled from

Continued on Page 44

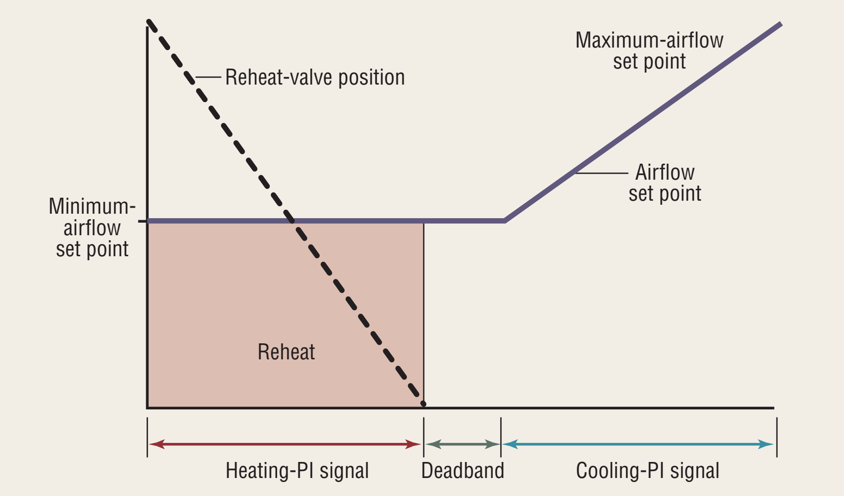

FIGURE 1. Single-maximum-control sequence.

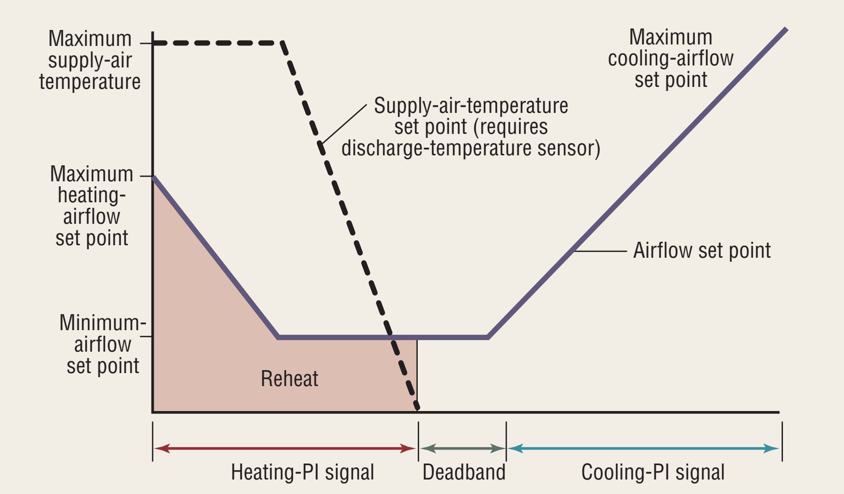

FIGURE 2. Dual-maximum-control sequence.

expanders necessary.

• Many local dealers do not stock odd-size VAV boxes in their warehouses and, thus, may substitute even sizes anyway. Using only even sizes 6 in. and larger does not significantly affect average turndown.

REFERENCES

1) Taylor, S.T., & Stein, J. (2004). Sizing VAV boxes. *ASHRAE Journal*, *46*, 30-35.

2) Hydeman, M., Taylor, S., Stein, J., Kolderup, E., & Hong, T. (2003, October). *Advanced variable air volume system design guide*. California Energy Commission Publication 500-03-082-A-11. Available at http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF

3) Hydeman, M., & Stein, J. (2003, May). A fresh look at fans. *HPAC Engineering*, pp. 28-30, 32, 35-37, 39-41.

Continued from Page 43

the heating needs, the minimum-airflow set point can be as low as the controllable minimum of the VAV box (as long as ventilation requirements are met). When a dual-maximum-control scheme is used, the minimum-airflow set point typically is 10 to 20 percent of design airflow. Simulation models of typical office buildings have shown that switching from a single-maximum-control approach with a 40-percent minimum-airflow set point to a dual-maximum-control approach with a 20-percent minimum-airflow set point can save 30 cents per square foot per year.[2]

For the dual-maximum-control sequence to be implemented, controls specifications must require an analog input for VAV-box supply-air temperature. (This is not required for the single-maximum-control scheme.) Additionally, controls specifications should require that VAV-box controllers be fully programmable. The dual-maximum-control sequence still is a new concept to most controls vendors; even if they tell you that their configurable, pre-programmed controllers can implement the dual-maximum sequence, chances that they will not be able to do it correctly are good. Therefore, the best way to ensure that the dual-maximum-control sequence can be implemented properly is to require fully programmable controllers.

Another VAV-box control point one should consider requiring is VAV-box damper position—either modulating (analog output) or floating (two digital outputs). Knowing VAV-box damper position is extremely helpful in implementing static-pressure reset, which can save as much as 50 percent of fan energy.[3]