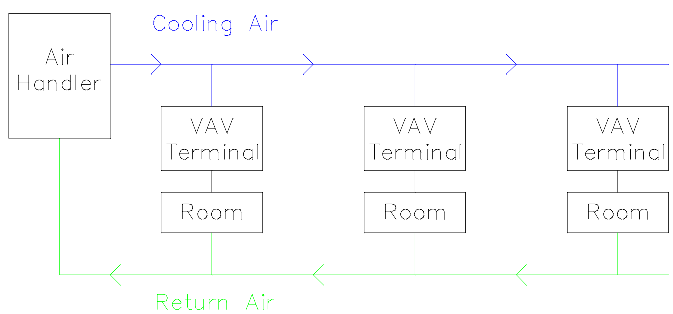
Variable Flow VAV Terminal Fans

VAV systems were developed in response to the early 1970's energy crisis. These systems reduced energy usage, sometimes at the expense of comfort. Today's building owner wants the VAV system's economy without sacrificing comfort.

Many applications require a VAV terminal fan to achieve satisfactory comfort. Recent advances in air moving motor technology allow efficient variable speed operation of these fans.

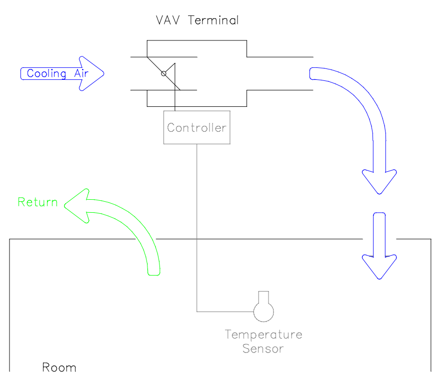
Variable Air Volume Basics

VAV systems provide comfort by varying the amount of cooling air[1] delivered to each room[2]. Insulated air ducts route cooling air from an air handler to VAV terminals fitted in each room. Air handler controls regulate the cooling air to a preset temperature, dew point and freshness.



The air handler uses a fan to circulate warm air returned from the rooms through a cooling coil and back to the rooms through the air ducts and VAV terminals. Air handlers include dampers and controls to regulate the mixing of fresh, outside air with the returned air, and controls to regulate the cooling air temperature.

The VAV terminal regulates the amount of cooling air delivered to each room. A temperature sensor mounted in the room signals a controller mounted on the VAV terminal. When the temperature is too high, the controller commands the VAV terminal to provide more cooling air to the room. When the temperature is too low, the controller commands the VAV terminal to provide less cooling air to the room. The controller never commands the terminal completely closed, so the room always receives fresh air.



To obtain acceptable comfort, the VAV system must accurately control the cooling air temperature and room temperature. Accurate control keeps the system from continually hunting[3], and holds room humidity to predictable limits.

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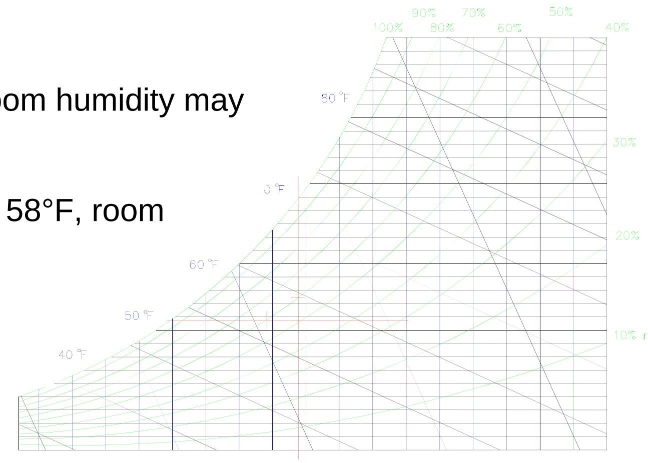
[1] Industry terms for cooling air are primary air or supply air

[2] This discussion uses the term room for an air conditioning zone. A zone most often includes a large area or a group of rooms or offices.

[3] Hunting is an industry term describing a condition where the system's controls continually reposition in an effort to provide the proper temperature, but never succeed.

The room temperature may never be stable if the cooling air temperature continually changes. A change in cooling air temperature changes the room temperature. The room sensor signals the controller of the change, and the controls respond by repositioning the VAV terminal. The control system takes about 20 minutes to sense the change and reposition the VAV terminal. In that time, a system with poor cooling air control allows the cooling air temperature to change again. In this scenario, the room temperature is always changing as the VAV terminal tries to respond to the fluctuating cooling air temperature.

Small changes in cooling air or room temperature have a large influence on room humidity. Saturated (100% rh) 54°F cooling air produces 50% rh in the room when the room temperature is 74°F. These are ideal conditions for comfort.



- If the room temperature drops to 70°F, room humidity may increase to 60%.
- If the cooling air temperature increases to 58°F, room humidity may increase to 60%.

This humidity level is uncomfortable, and above ASHRAE[4] 62-1 2013 recommendations for acceptable air quality.

Where cooling air temperature control is poor, tenants suffer from temperature fluctuations, humidity fluctuations, and cyclical noise as air flow from the diffusers continually changes.

To maintain a stable cooling air temperature, the air handler must quickly and accurately adjust its cooling capacity to accurately match the cooling load.

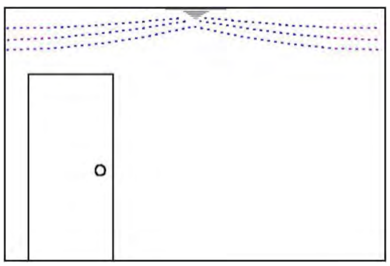
Many systems reset the air handler's supply air temperature. Supply air temperature reset saves energy and improves each VAV terminal's primary airflow control accuracy. These applications must limit the dew point of the cooling air sent to the terminals.

4 The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

VAV Terminal Theory

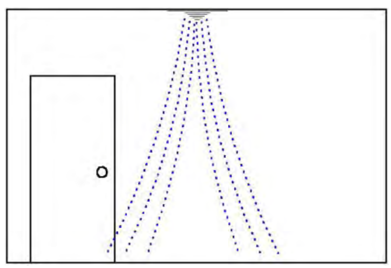
When a VAV controlled space's cooling demand is low, the cooling air volume is low, producing a low velocity discharge from the diffusers. The result is poor air distribution and a poor temperature envelope. When the cooling air temperature is low, the problem becomes greater.

When the cooling demand is high, the cooling air volume is high, producing a high diffuser velocity. This high velocity air stream is lower pressure than the still air surrounding it, so the cooling air stream clings to the ceiling, drawing in the warmer, still air that has accumulated at the ceiling.



As the air stream travels away from the diffuser, it continues to take in surrounding air. The air stream slows down and moves away from the ceiling. This action mixed the cooling air with warm air, so the temperature is much closer to the actual room temperature. This air drops toward the bottom of the room in a broad, gentle pattern. Adequate diffuser velocity produces proper air distribution and a proper temperature envelope.

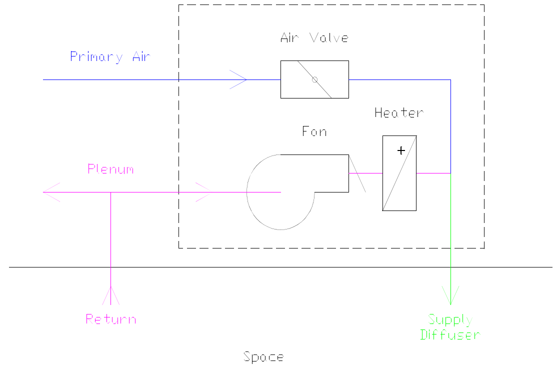
When the diffuser velocity is low, cooling air drops in a column between the diffuser and the floor. The air velocity is too low to cling to the ceiling or draw in warm room air. The diffuser does not work, yielding a very spotty temperature and airflow envelope.



Increasing the VAV terminal minimum cooling air volume cures low diffuser velocity. In many applications, this causes over cooling during low load conditions. Raising the discharge air temperature helps, but often increases humidity in the conditioned space.

VAV terminal fans may be used to obtain satisfactory temperature and airflow envelopes. The terminal fan draws air from the conditioned space, mixes it with the cooling air, and delivers it to the diffuser with adequate volume to keep the diffuser working. There are two types of terminal fans: parallel and series.

Parallel Fan VAV Terminals



The first VAV terminals with fans were parallel fan VAV terminals. They were developed for systems in the Southeastern and Gulf States where humidity control requirements prevented raising the cooling air temperature. The parallel terminal fan re-circulates air from the conditioned space via the return plenum, through the diffusers and back into the conditioned space. Cooling air is mixed in at the fan's discharge.

The parallel fan turns on when the cooling volume falls below the level required for the diffuser to function. The fan turns on, increasing the diffuser velocity. Cooling air mixes with air from the fan, and the diffusers distribute it evenly throughout the conditioned space. When the fan is off, a back draft damper prevents cooling air from flowing backward through the fan.

Problems

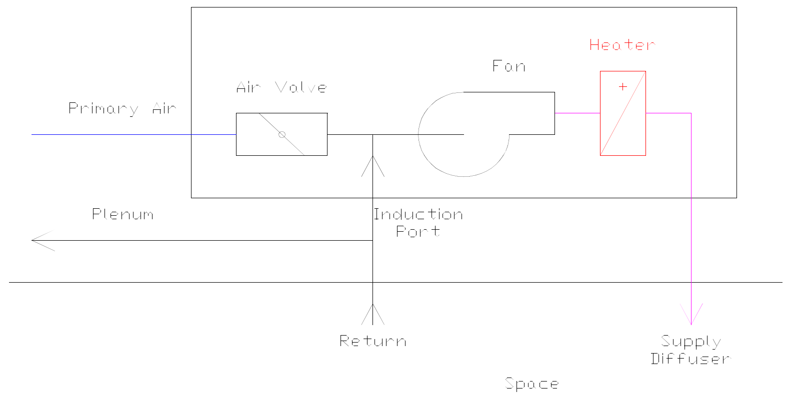
The pressure drop across the cooling air valve changes when the fan starts. This changes the airflow through the cooling valve, disturbing temperature control to the zone. This problem is easily corrected by providing pressure independent control of the cooling valve.

When the fan turns on, the abrupt increase in diffuser velocity disturbs everyone occupying the conditioned space. To make this disturbance worse, the fan repeatedly cycles on and off during certain load conditions.

The electrical energy consumed by the fan ends up in the conditioned space as thermal energy. When the cooling load is stable at the fan turn on point, this fan heating effect increases the cooling load, so the controls call for more cooling air. The increased cooling air turns the fan back off and the on-off cycle starts over again! At certain load conditions, parallel fan cycling occurs every ten to fifteen minutes.

Parallel fans provide a solution to air flow and temperature envelope problems, but create a discomfort issue when the fan cycles........... Notice the discharge air volume at turn on is much higher than necessary for the diffuser to work.

Series Fan VAV Terminals



Series fan VAV terminals eliminate fan start and cycling noise associated with parallel terminals. The fan runs continuously providing an almost constant airflow from the diffusers.

Series terminals mix re-circulated air with cooling air introduced at the inlet to the fan.

The series fan attempts to deliver a constant air volume to the supply diffusers. It draws air from the outlet of the air valve, or from the induction port to maintain this air volume.

The controls regulate the cooling valve to provide the required cooling air volume to the fan inlet. Because the cooling volume is less than the fan volume, the fan draws in additional air from the ceiling return. The diffusers are always supplied with adequate air volume, yielding excellent air flow and temperature envelopes.

Because the cooling air passes through the fan, the fan air volume is adjusted to handle peak cooling loads. The series fan operates at maximum cooling volume (CFM) at all times. Since the diffuser is working at peak output; the series fan terminal, ductwork and diffuser must be selected to minimize noise.

Series fan powered terminals allow VAV central fans to be smaller. Without series fan powered terminals, VAV central fans must be sized to deliver static pressure at the VAV terminal outlet great enough to overcome the resistance of the distribution box, duct work and diffusers.

Series terminals are often used in tenant office buildings. A smaller central fan lowers the property manager's equipment and operating cost. The smaller fan also leaves more revenue generating floor space and makes less noise. Part of the central fan equipment and energy costs associated with simple VAV systems are diverted to the tenants.

Series terminal fans provide the best air flow and temperature envelope. The airflow is constant, with the cooling air mixed in as needed to maintain room temperature.

Problems

Series fans are expensive! Each terminal must have a fan large enough to handle the peak-cooling load. The large fan requires extra care in sound absorption and mounting hardware. To compound the problem, these terminals are usually selected on noise criteria, instead of cooling capacity. This results in a terminal with a cooling capacity 30 to 40 percent higher than required for the application. Because they are large and heavy, series terminals are more costly to install.

Series fans must be supplied by a power distribution system capable of handling the large load. The expense does not end with purchase and installation. Because the fans must operate continuously at maximum air volume, operating costs are high.

Series fan terminal systems allow use of a smaller air handler fan. Series box systems are designed for neutral pressure at the outlet of the cooling valve with the box at maximum cooling. Conventional systems require adequate pressure at this point to drive the distribution ductwork and diffusers. Series fan terminal systems rely on the terminal fan to provide this energy. Air handler fans are usually high efficiency, while VAV terminal fans are usually low efficiency, especially when the fan voltage is adjusted by a phase cut (triac) control. Total system efficiency can be maintained by using high efficiency variable flow motors in the terminal units.

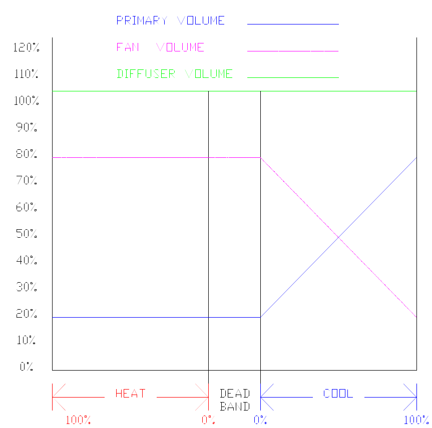
Some applications allow conventional VAV systems to use smaller air handler fans because of fan diversity. Series fan terminal VAV terminal systems may not completely exploit air handler fan diversity.

The smaller central fan costs less to purchase, install and operate. It also makes less noise and takes up less space. This can be especially attractive in leased spaces, where installation and operating costs are deferred to the tenant.

Controlling the Terminal Fan Volume

Too much fan volume wastes energy and generates unnecessary noise. Controlling the terminal fan volume reduces cost and improves comfort. Terminals can be selected by capacity, and fans deliver only the volume of air required to maintain comfort.

Terminal fan volume can be defined by three fan volume setpoints and their relation to the calculated (heating/cooling) load. These setpoints are maximum cooling, dead band, and maximum heating. In cooling, the fan volume is modulated between the dead band volume setpoint and the maximum cooling volume setpoint. In dead band, the fan operates at the dead band volume, and in heating, the fan volume modulates between the dead band volume and the maximum heating volume. If the application includes electric heat, the fan volume is set to the maximum heating volume only when the heater is on.



Parallel Fan Control

Parallel fan terminals provide a good temperature and air flow envelope while maintaining the cost saving benefits of the VAV system.

The system moves no more air than necessary.

The economy of the high efficiency central fan is maintained.

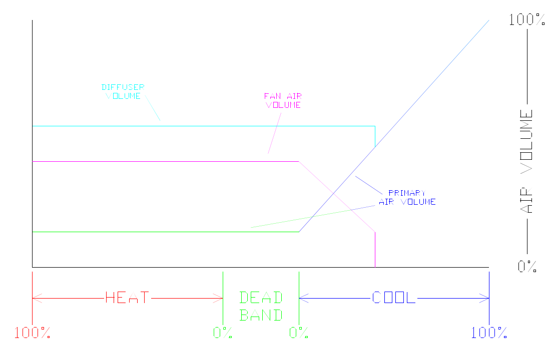
Fan diversity is maintained.

Parallel terminal fans are typically 40% smaller than series terminal fans. These terminals are smaller, lighter and less costly to install. The power distribution system is also 40% smaller, further reducing the installation cost. The cost of operating the parallel fan is also much lower. The fan uses 40% less power and it does not run continuously!

Series fans were developed because parallel fans can be noisy when the cooling load is around the fan turn on point. If this problem is solved, the efficiencies of the parallel fan and the VAV system can be maintained.

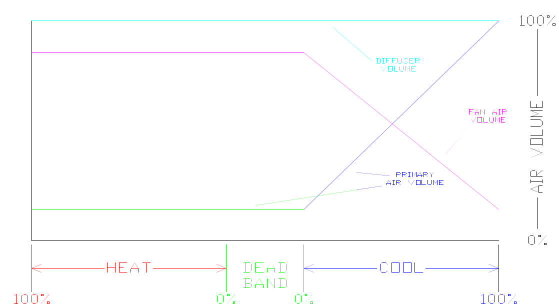
Intermittent Control

Start the fan at minimum volume when the cooling volume falls to the minimum volume required by the diffusers. Increase the fan volume as the cooling volume continues to fall. Control the fan volume to maintain the diffuser minimum airflow when the cooling volume falls to minimum.



Constant Volume

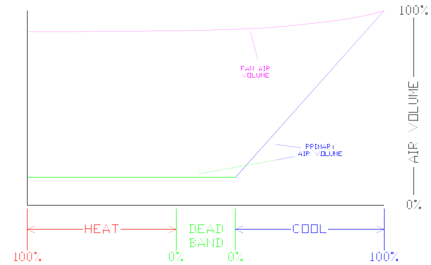
Run the fan when the zone is occupied. When the cooling volume is at maximum, run the fan at minimum volume. When the cooling volume drops to the minimum volume, run the fan at the minimum volume. Schedule the minimum fan volume to produce a diffuser volume equal to volume produced during full cooling.



Series Fan Control

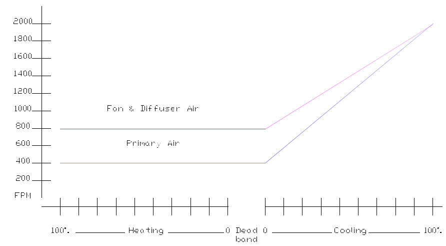
Constant Volume

Control the fan to produce the scheduled air volume at the diffuser.



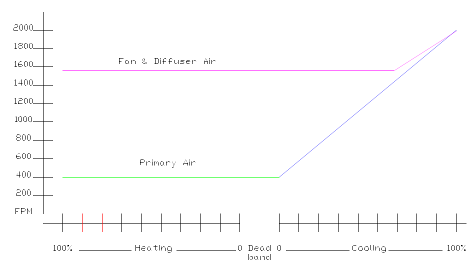
Variable Volume

Control the fan volume to equal the cooling volume when the terminal is at maximum cooling. When the cooling volume drops to minimum, control the fan to provide the minimum diffuser volume.



Peak Load Boost

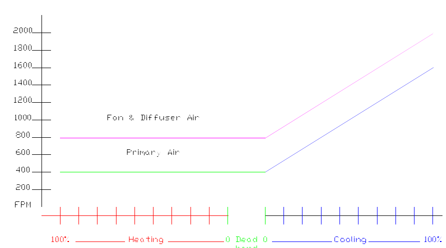
Control the fan volume to equal the cooling volume when the terminal is at maximum cooling. When the cooling volume drops to minimum, control the fan to provide 80% of the maximum cooling volume.



Peak load boost reduces the need to oversize the terminal to reduce noise. A properly sized terminal operates quietly except during peak loads. When peak loads do exist, tenants tend to accept some increase in system noise because they associate the noise with maintenance of their comfort during periods of adverse weather.

Low Temperature

Control the fan to produce a diffuser air temperature 10°F above the maximum space dew point when the terminal is at maximum cooling. When the terminal is at minimum cooling, control the fan to produce a diffuser air temperature 10°F above the maximum space dew point.



Low temperature systems allow reduction in central fan size and may also be used with ice storage systems. In these applications, the series terminal mixes warm plenum air with low temperature cooling air to prevent low temperature discharge from the diffuser.

Low temperature systems allow a smaller central fan and smaller VAV terminals to be used. Smaller VAV terminals allow reduced above ceiling heights which reduce construction costs and may even allow an additional floor to be planned where building height restrictions exist.

Series fan modulation with low temperature systems reduces terminal fan noise and restores some of the economy of a VAV system. The fan dead band volume is set to raise the discharge air to a usable temperature by mixing in re-circulated air. The fan maximum cooling volume is set greater than the primary maximum cooling volume to increase the discharge air temperature.

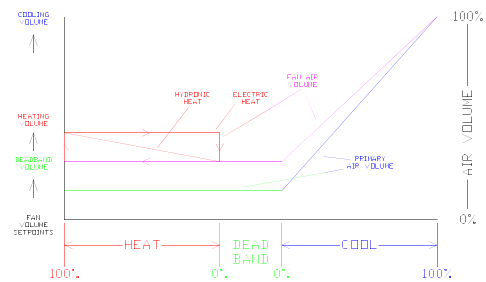
The discharge air volume remains constant while the volume varies to satisfy the cooling load, just like a VAV system. (The discharge air temperature may be lower at high diffuser volumes since higher velocity air diffuses better.) The heating volume is set to match the requirements of the heater.

Modulation of the series fan allows the fan to be operated only at the required volume. This reduces operation cost, purchase cost and improves comfort by reducing system noise.

Heating

Fan powered VAV terminals used in northern climates requiring high heating air volumes.

If the heater is hydronic, the fan volume increases as the heating valve modulates open. Therefore, the fan runs at full heating volume only when a 100% heating demand exists.



If electric terminal heat is used, the fan speeds up to the heating volume when the heating element is on. When the heating element turns off, the terminal fan slows to a lower volume.

This allows the fan volume to operate lower than the heating volume during dead band and low cooling loads. Energy is saved and diffuser noise is reduced.