VAV Basics and Installation Guidelines

An installation of VAV boxes in the Star TV building in Mumbai, before the false ceiling goes up to conceal the ductwork. A total of 500 boxes will be installed on this project.

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Introduction

The global HVAC industry has changed significantly in the last few years. All stakeholders have understood the need for ultra high-efficiency equipment and systems, as also for variable speed systems that minimize energy use through the seasons and for varying cooling loads imposed by building users and the ambient. The Indian HVAC industry has adopted this change with open arms. Today, consulting engineers and HVAC companies deploy significant resources and efforts in energy efficient air conditioning systems.

Optimizing the air distribution is an important step towards achieving energy conservation. Air distribution systems bring conditioned air (heated or cooled) to people occupying a building and therefore directly affect the occupant's comfort. Over the last several decades, significant improvements have been made to the design of air distribution systems as well as the way in which these systems are controlled. These improved designs and controls can result in dramatic energy savings; yet many buildings continue to rely on obsolete, inefficient systems for critical functions.

To meet the growing demand and emphasis on energy conservation, many projects are designed with Variable Air Volume (VAV) systems. The number is growing by the day. Many projects are being successfully designed, installed and used. The pace of this change has been quite brisk, both in terms of its deployment and its adaptability across the industry. But not every one in industry is able to adopt this important change in air distribution. Though projects are designed with great attention to details, not every project is fetching the desired results. The user gets discouraged due to the 'below par' results after paying a little higher capital cost, when compared to a constant air volume system. Hence it is the need of the hour to discuss the basics of a VAV system, the design and

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installation issues commonly associated with it and operational guidelines. The prime objective should be to help the HVAC engineer achieve the important composite goal of user comfort and power savings.

Operating Principle of VAV

The most important component of VAV air distribution is VAV terminal unit, often called VAV Box.

The VAV terminal regulates the volume of air to the zone by opening or closing the damper, thus controlling the amount of air directed to the zone. Each zone has a thermostat which controls its VAV terminal, telling it when to open or close the damper based upon the needs of the zone.

Types of VAV Terminals

There are several varieties of VAV terminals.

Single duct: This is a basic terminal consisting of a casing, a damper, a damper actuator and the associated controls. This is preferred for cooling applications, but is also used for heating applications. The terminal resets the volume of conditioned air delivery to the space in response to the room thermostat.

Single duct with reheat: This consists of a basic unit as above with the addition of a heating coil (hot water or electric). The terminal resets the volume of conditioned cold air delivery to the space in response to room thermostat. Upon a call for heat in the space, the heating coil is energized and reheats the conditioned air.

Dual duct (non-mixing): This essentially consists of two single duct boxes side-by-side with separate cold and hot air inlets and volume control assemblies. The terminal unit resets the volume flow of either hot or cold air (without mixing) to the space in response to the room thermostat.

Dual duct (mixing): The basic unit incorporates separate cold and hot air inlets, volume control assemblies and mixing section. The terminal unit resets the volume flow of the hot and cold air supply ducts in response to the room thermostat.

Parallel fan powered: In this terminal, a fan is added to recirculate plenum air, for heating only. The heating cycle occurs generally when the primary air is off or at minimum flow. Heat is picked up as the recirculated air is drawn from ceiling space and the fan motor. Additional heat can be provided by hot water or electric coil. During cooling cycle, the fan is off and cool primary air is supplied from the central system.

Series fan powered: The fan runs continuously, fed by a mixture of primary air and plenum air. The more primary air is forced in, the less plenum air is drawn in. The result is a variable volume from the central system, and constant volume supply to the room.

Induction: The terminal resets the volume of conditioned air delivery to the space in response to the room thermostat. As primary air flow is reduced, plenum air is drawn in automatically feeding a constant volume to the room.

By-pass: The basic unit consists of a primary air damper, actuator, bypasses port and selected pressure dependent controls. The terminal delivers conditioned air to the space during the maximum cooling requirements (as demanded by room thermostat). As the cooling demand diminishes, the unit damper is modulated to bypass increasing amounts to ceiling plenum.

Based on the operating principle, there are two types of VAV terminals:

1) Pressure independent type
2) Pressure dependent type

A VAV terminal is said to be pressure independent when the flow rate passing through is maintained constant regardless of variation in system inlet pressure. The duct pressure may vary due to rejection of air by other terminals in the same duct line, but VAV damper modulates and ensures the required flow rate within the design parameters.

A VAV terminal is said to be pressure dependent when the flow rate passing through it varies as the supply duct pressure fluctuates. In this case, the flow rate is dependent on both supply duct pressure and damper position of the terminal unit.

Types of Controls

Pressure independent VAV control scheme may include some or all of the following components:

1. Flow sensor/ pick-up
2. Flow controller
3. Damper actuator
4. Thermostat or sensor

Mounted in the inlet of the terminal, flow sensor senses the air velocity, which can be easily converted into the air flow rate and provides a feedback signal to the flow controller. This control loop is the essence of pressure independent operation.

Flow controller is 'the brain' of the VAV control. It receives the signal from the flow sensor and processes this information along with signals from room thermostat. Then it sends a signal to the damper actuator.

The room thermostat contains not only a temperature sensing element, but also a means of changing the set point. The room sensor used with a direct digital control system is simply an electronic temperature sensor; set point changes are handled along with other signal processing in the digital controller.

The preset air flow rate can be varied between calibrated minimum and maximum limits by the thermostat output.

Pressure dependent VAV control scheme includes the following components:

1. Damper actuator
2. Room thermostat/ controller

The room thermostat senses the room temperature, allows set point adjustment and also signals the controller to operate the damper actuator. There is no flow rate control in this scheme. As the airflow rate varies with inlet pressure, the room may experience temperature swings until the thermostat repositions the damper. Excessive air flow may also lead to unacceptable noise level in the space, resulting in occupant complaints.

Comparing the above two categories of VAV, it is quite

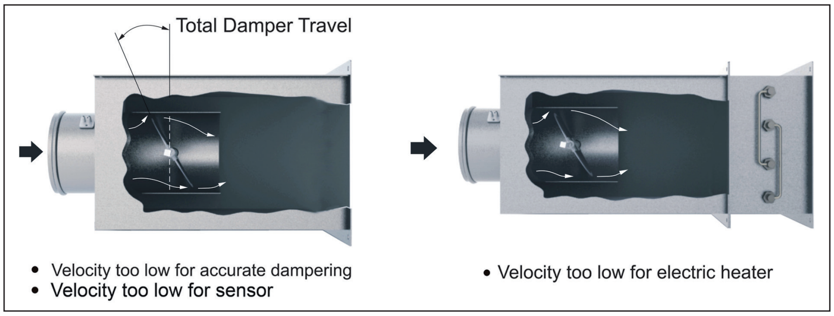

Figure 1: Low velocity effects

evident that pressure independent VAV is a much better option over pressure dependent VAV, so it is a preferred by design engineers.

The capital cost for VAV air distribution system is comparatively higher than the conventional constant air distribution system. And to save cost, a combination of VAV and CV systems is sometimes used, in which VAV terminals cater to only a few cabins and conference rooms, while the rest of the area is catered to directly. All the air terminals are selected for 0.1″ H_2O (or less) duct static pressure, whereas the VAV terminal needs higher duct static pressure. This imbalance makes the air balancing an almost impossible task. The areas catered to by the VAVs are starved of air flow and face a no cooling problem. The public area faces an over-cooling problem. Since there is hardly any variation in supply duct static pressure, the fan speed remains constant. Such a design fails to achieve the prime goal of 'comfort and power savings.'

Sizing VAV Terminals

As a practice, it is necessary to select terminals based upon the recommended air volume ranges. A common misconception is that oversizing a terminal will make the unit operation quieter. In reality, the terminal damper may operate in a pinched down condition most of the time, which may actually increase noise levels in the space. Control accuracy may suffer as the terminal is only using a fraction of its total damper travel or stroke. In addition, the low inlet velocities may be insufficient to produce a readable signal for the sensor and reset controller. This means that the minimum settings may not sustain, resulting in loss of control accuracy and undesirable hunting *(Figure 1)*.

The recommended selection for maximizing the performance is to size the terminal's maximum airflow limit for 80-85% of its rated capacity (approximately 2100 fpm inlet velocity) in accordance with the catalog recommendations. For accurate control, the minimum setting guideline is not lower than 15% of the unit's rated total capacity.

Another problem associated with oversizing terminals with electric reheat is insufficient velocity, causing occasional tripping of the airflow safety switch.

When one large terminal serves space that should be served by two or more smaller ones, comfort problems can result. There may be a noticeable temperature differences between rooms, since the thermostat is located at one end of the catered zone. Also, for a given air velocity, the larger the terminal, more will be the sound power it will generate.

Many times one terminal is used for multiple cabins (zones) to save capital cost. In such cases, the thermostat is installed in one of the cabins and senses the temperature in that cabin, leaving the other cabins at the mercy of the first cabin's occupant. Some occupants may suffer over-cooling or otherwise. The important goal of occupant comfort is lost.

Flow Rate Capacity of VAV Terminal

Each VAV terminal has its standard air flow capacities: maximum capacity and minimum capacity. It maintains supply airflow rate within these limits. Deciding the maximum capacity is an easy task. The design engineer works out the air flow rate required to cool the zone/cabin. This air quantity is decided as the maximum airflow rate for VAV calibration. But deciding the minimum air flow rate is a delicate issue. One has to work out the minimum airflow to maintain the correct ventilation rate. The minimum airflow required for ventilation is 0.15 cfm/ft^2, and this may work out to 15% of the maximum airflow rate. In the earlier days, when interior lighting and PC loads were substantially higher than now, the space could be served with cooling-only boxes. Loads were sufficient to allow the boxes to be set to the minimum rates required for ventilation without overcooling. But with very low lighting and plug load power densities now common, overcooling is possible, even likely. So one should consider all aspects to decide on minimum air flow rate settings.

There is a tendency to increase the maximum air flow rate as design safety, especially for cabins of important officials. If, as per heat load calculations, 400 cfm is worked out as the maximum airflow rate, it is often inflated to 550 cfm or so. The minimum flow rate is decided based on the maximum flow rate of the VAV terminal, which may be higher than the ground requirement. Due to higher minimum airflow rate, the room is overcooled and user comfort is compromised. Additionally, this safety arrangement leads to oversizing of the VAV box and

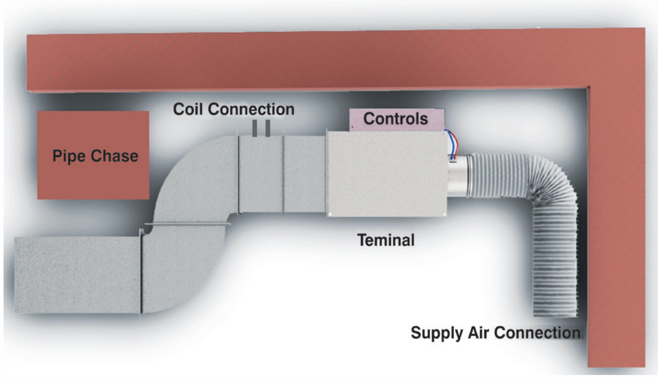

Figure 2: Installation affecting performance

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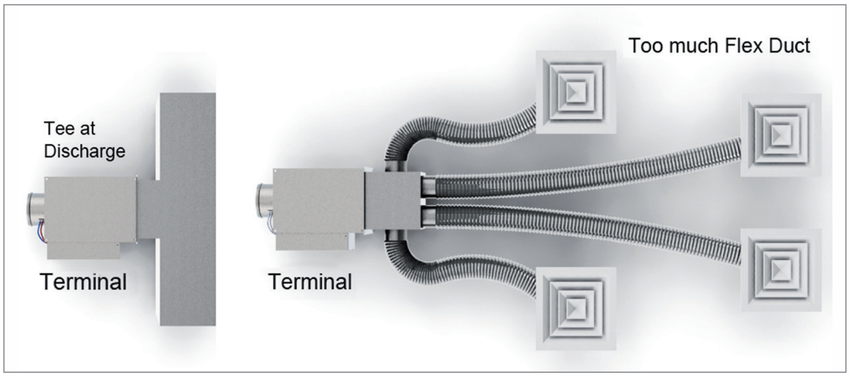

Figure 3: Improper discharge condition

brings in the issues discussed above. Often, the minimum air flow rate becomes less than the lowest controllable airflow set point by the terminal, and air flow measurements become erratic.

To avoid overcooling and to maintain adequate ventilation for conditioned space, reheat is probably required to be part of a VAV terminal. VAV terminals are equipped with electric heaters or hot water coils for reheat.

For all except very noise-sensitive applications, it is most appropriate to select VAV terminals for a total (static plus velocity) pressure drop of 0.5" H_2O. For most applications, this provides the optimum energy balance.

Space Requirement

Location of the terminal should be planned carefully to avoid problems with installation, performance and maintenance. In the example shown, the control side of the terminal is against the wall, making connections difficult and servicing almost impossible. The cramped location also creates the need for close-coupled duct elbows, which reduce performance *(Figure 2)*.

It is observed that access doors are missed in many installations, making it impossible to access terminal boxes for maintenance. In the event of a VAV malfunctioning due to controller failure or power failure or simply due to dust accumulation on the flow sensor, VAV needs to be accessed to fix the problem. In such cases, the false ceiling needs to be cut open. To carry out such work at a finished site is very tedious and costly. It also leaves a bad impression about workmanship. So, it is important for the installation engineer to ensure a proper access door to avoid any unpleasant situation for the operating engineer.

Optimize Discharge Conditions

Improper discharge conditions have an adverse affect on pressure drop *(Figure 3)*. A tee close to the discharge is especially to be avoided, along with transition pieces and elbows. Another common error is running to much flex duct, as shown in the image. It adds to static pressure drop in the system, and you may have to set the fan at a higher speed to maintain the necessary duct pressure, and the fan consumes more power. It is better to continue the rectangular duct to the last diffuser, and then install short flex branches. Lower discharge velocity (maximum 1000 fpm) is recommended for minimum static pressure loss and low noise levels.

Optimize Inlet Conditions

The type of duct and its approach may have a large and adverse impact on both pressure drop and control accuracy. *Figure 4* shows several typical poor conditions that generate unwanted turbulence. Although multi-point sensors can compensate these to a large degree, good design practice should always prevail. It is recommended to have a straight duct inlet connection with minimum length of two duct diameters, the same size of inlet. Either conical or 45° taps should be used at VAV box connections. It is also preferred to have sheet metal inlets to VAV terminals, rather than using flexible ducts. Avoid too many fittings like elbows and bends at the VAV terminal inlet, as these can dramatically increase pressure drop.

The terminal collars are undersized to suit nominal ductwork dimensions. The inlet duct slips over the terminal inlet collar and is fastened and sealed in accordance with job specifications. Never insert a duct inside the inlet collar, as it can adversely affect the control calibration.

Sometimes it is not possible, due to space restrictions, to provide an ideal inlet condition. In such cases, field adjustment

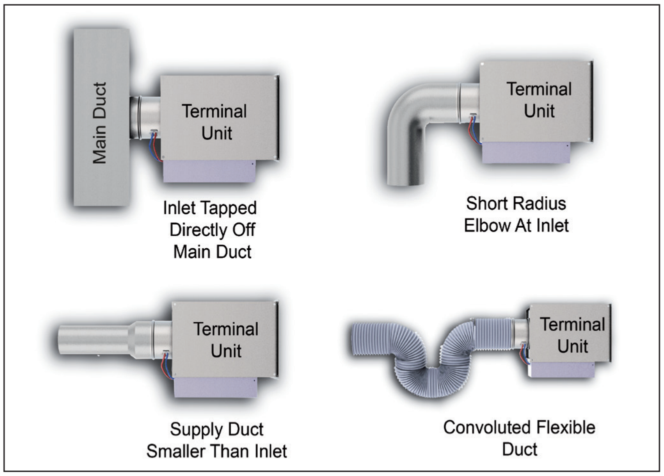

Figure 4: Poor inlet connection

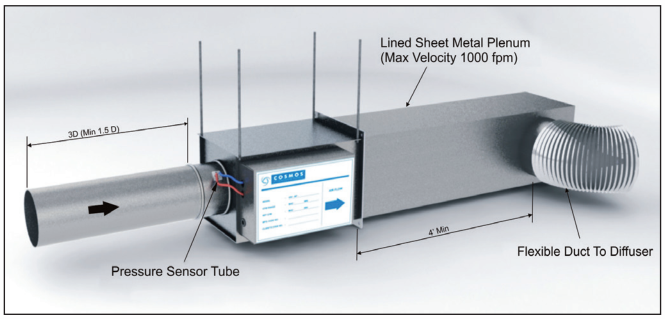

Figure 5: Ideal VAV installation

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of airflow settings on the velocity controller may be required to compensate. The use of flow straightening devices (equalizing grids) are recommended after short radius elbows that are immediately ahead of the terminal and where terminals are unavoidably tapped directly off the main duct *(Figure 5)*.

Minimize Duct Leakage

At many sites it is observed that duct connections, which include terminal inlet connection, discharge connection and air outlet plenum connections, are not properly sealed. Any such leakage has bad impact on the system, which needs to maintain a certain static pressure in the supply duct to cater to the design air quantity through all the VAV terminals in the system. Due to insufficient duct pressure, a few terminals may starve and fail to achieve the set room temperature.

Sometimes the discharge connections are improper. Here, the terminal maintains the maximum designed air flow rate, but since the air does not reach the conditioned space, the set temperature cannot be achieved.

Setting Correct Duct Pressure

In VAV air distribution, the supply duct static pressure is an important factor. If the static pressure is less than required, VAV terminals may starve for airflow and the set temperature will not be achieved. In case of excessive static pressure in the duct, VAV terminals will modulate to control the airflow rate, but overworking the fan would waste energy.

As cooling loads change, the VAV terminals modulate to vary airflow to the zones. This causes the pressure inside the supply ductwork to change, which is sensed by the pressure sensor installed in the duct. By using this data, the air handling unit (equipped with a Variable Frequency Drive) varies the speed of the supply fan to maintain the static pressure in this location at a constant set point. Duct pressure sensor should be located approximately two-thirds of the distance down the main supply duct. If the pressure sensor is installed close to air handling unit, the system generates more static pressure than necessary and fan energy is wasted.

When communicating controllers are used on the VAV terminals, it is possible to optimize this static pressure control function to minimize duct pressure and save fan energy. Each VAV controller knows the current position of its damper. The Building Automation System (BAS) continually polls these individual controllers, looking for the VAV terminal with the furthest-open damper. The set point for supply fan is then reset to provide just enough pressure so that at least one damper is nearly wide open. This results in the supply fan generating only enough static pressure to push the required quantity of air through this critical (furthest-open) VAV terminal.

Selection of Controls

Various control options are available for different applications. If the VAV terminal is to be connected to BMS (Building Management System), the VAV terminal should have a communicable type controller. The most recommended protocol for BMS communications today is ASHRAE's BACnet/IP. If the VAV uses a different protocol, a protocol converter is used to convert it to BACnet/IP. This facilitates the integration of VAV with BMS. VAV controls have improved in the last few years. A full featured VAV controller can have additional options viz. occupancy sensors, CO_2 sensors and humidity sensors, and can control heaters through thyristors. It is also important to note that some controllers are not able to fully close the VAV when switched off, but keep a minimum air flow rate. While selecting the controller, this drawback must be kept in mind and a model which allows 100% closing of damper in switch-off mode should be selected.

Some advanced features like the display of actual air flow on the thermostat can be very helpful for the commissioning engineer for air balancing and validation, and also for future trouble shooting.

Not all the buildings have BMS. Further, in some buildings, VAV terminals are not integrated with the BMS. For such applications, VAV control can be stand-alone type. This is an economical but not-so-advanced solution. The room thermostat is set by the user and VAV terminal is controlled individually. Stand-alone controls can use cost effective digital thermostats. In case of stand-alone controls, the VAV cannot be monitored or controlled from the central control room.

Some More Site Problems

Due to lack of knowledge about VAV terminal, it is handled poorly at site. The flow sensor grid at the inlet is used for lifting the terminal and in this process it gets damaged or ripped off. With 'no' pressure sensor or 'damaged' pressure sensor, the VAV terminal malfunctions. There are two tubes connecting the flow sensor to the VAV controller. One senses the total pressure (Pt), and other senses the static pressure (Ps). The controller then processes this data to decide airflow rate. These tubes are sometimes mistakenly detached by the installer. Either these are left open or reconnected to the wrong port. This paralyzes the controller operation and the VAV terminal fails to work. There are instances of the tubes being reconnected by the installer, but the connecting ports of flow sensor being blocked with dirt and glue. Even the holes of the flow sensor are blocked with dust. Due to this, pressure sensing accuracy is lost and the VAV terminal malfunctions.

Thermostat location is the key factor for VAV operation. It has to sense correct room temperature, so as to modulate the airflow rate as per demand. But often this is ignored by the installer and thermostats are installed near the supply air terminal. Here, the thermostats sense the supply air temperature, which is very low, and the VAV terminal modulates to minimum air flow rate. The set temperature is never achieved in such cases.

Specification of the wire for connecting the thermostat with the VAV controller is always provided by manufacturer, which should be strictly followed. Incorrect or loose connections lead

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to malfunctioning of the VAV terminal.

For centralized control, VAV terminals are integrated with BMS in all modern buildings. The control companies specify the type of wire for looping, e.g. for LonWorks protocol the recommended wire is cat5. Using a different wire may slow down the BMS communication or result in loss of data. So it is better to adhere to the recommendations. The controllers should be looped in a daisy chain connection. T-junctions are not acceptable for control cabling. But installers ignore this basic instruction and BMS integration becomes an impossible task.

It is recommended to maintain a copy of the floor plan, which includes the BMS looping path. It helps the service engineer to pin down looping errors.

Some Tips for Facility Managers

Facility managers or system operators control the operations of the HAVC system including VAVs, once it is successfully commissioned and handed over. The system operator should correctly analyze the complaints received from the user. This is very important to achieve the goal of 'comfort and energy savings'.

The user complains in two situations, no cooling or overcooling. Higher minimum airflow rate leads to overcooling, as the terminal damper does not close once it has reached the minimum airflow rate. But often it is considered as a problem with the damper mechanism, and technicians fiddle with that. As the problem persists, they switch off the VAV terminal.

When the maximum set airflow rate is less than requirement, the set temperature is never achieved and the user complains of 'no cooling'. In such a case, the damper position may be less than 100%, but it maintains the set maximum airflow rate. The simple solution is to increase the maximum airflow setting. Sometimes, due to lack of supply duct pressure, airflow rate from the terminal remains less than the maximum setting, despite the damper being 100% open. The supply duct pressure should be increased by fine tuning the fan speed through the Variable Frequency Drive.

The supply air to the zone should be as per design. Increase in supply air temperature results in 'no cooling' situation. While attending the call of 'no cooling', the facility engineer should check the supply air temperature. The correct assessment of the problem helps to resolve it better.

Conclusion

In conclusion, installers and service engineers need to be trained and knowledgeable about basics of VAV working and process to be able to carry out a root cause analysis of the problem before undertaking any quick fix solutions. There needs to be a focus from HVAC contractors on keeping a tab on the latest technologies available and to ensure that these percolate throughout the industry. Doing so alone will enable HVAC engineers to achieve the twin objectives of 'customer comfort and energy efficiency.' ❖