VAV PERFORMANCE CASE STUDY

PLUS

THE CFM IMPACT OF BLOWN VAV BOX DIAPHRAGMS

PLUS

CHALLENGING ENERGY LOSS IN VAV WITH REHEAT COILS

Analysts of Pneumatic Systems Limited
APS
PHONE (905) 640-2333
FAX (905) 640-2444
analystsofpneumatic@bellnet.ca
http://www.apscontrols.ca

PREFACE

VAV FUNCTIONS

Temperature control and ventilation is maintained in some HVAC systems by Variable Air Volume (VAV) systems.

Some of the most common VAV systems are presented on pages one to three.

A system that varies airflow to occupied spaces, but the supply fan CFM remains constant is on page four.

A specific ventilation quantity of fresh air per person is a code requirement demanding that a percentage of the VAV's airflow must be the minimum air flow setting of the VAV box. Airflow above the minimum to the maximum is for cooling purposes.

There is a logic issue in that the quantity of fresh air contained in the supply fans air most often is variable. For example: The supply fan's air contains 20% to100% fresh air mixed with building return air, controlled to a mixed air temperature of about 13˚C.

At a fixed minimum airflow setting in any VAV box the true quantity of fresh air varies significantly.

CASE STUDY ON STATIC PRESSURE VARIATION TO LOSS OF CONTROL

Manufacturer data sheets claim the airflow controllers on VAV boxes correct for supply duct pressure variations.

They do to a point, but if the static pressure drift significantly the VAV box will provide different quantities of air to the space at the exact demand signal from the thermostat.

If an air balancer starts in the morning balancing a building at 1" WG duct pressure and the pressure drops through the day to .4" WG and he/she does not notice the drift the balancing report will be erroneous.

VAV WITH REHEAT ENERGY LOSS

Some systems combine a VAV box with a reheat coil to provide cooling, heating and ventilation control.

The minimum airflow setting on the VAV box s higher than it would be without a reheat coil because more airflow is required to carry the heat into the rooms than just the ventilation quantity.

For example: A VAV may require only 25% of its volume to provide the ventilation requirement, but has to be set at 50% to provide the heating capacity.

The issues created are:

1. This costs energy to heat the extra "minimum" VAV airflow.
2. The boilers have to run more because the air flow which is double the required ventilation amount will overcool the occupied space if the boilers are shut down.

There is a solution for this presented on page eight.

Many electronic VAV boxes in BAS systems have "canned programing" with a fixed minimum ventilation quantity. Compatibility of the BAS and VAV programing may vary from system to system.

The loss still stands and the correction logic still stands, whether BAS or pneumatic.

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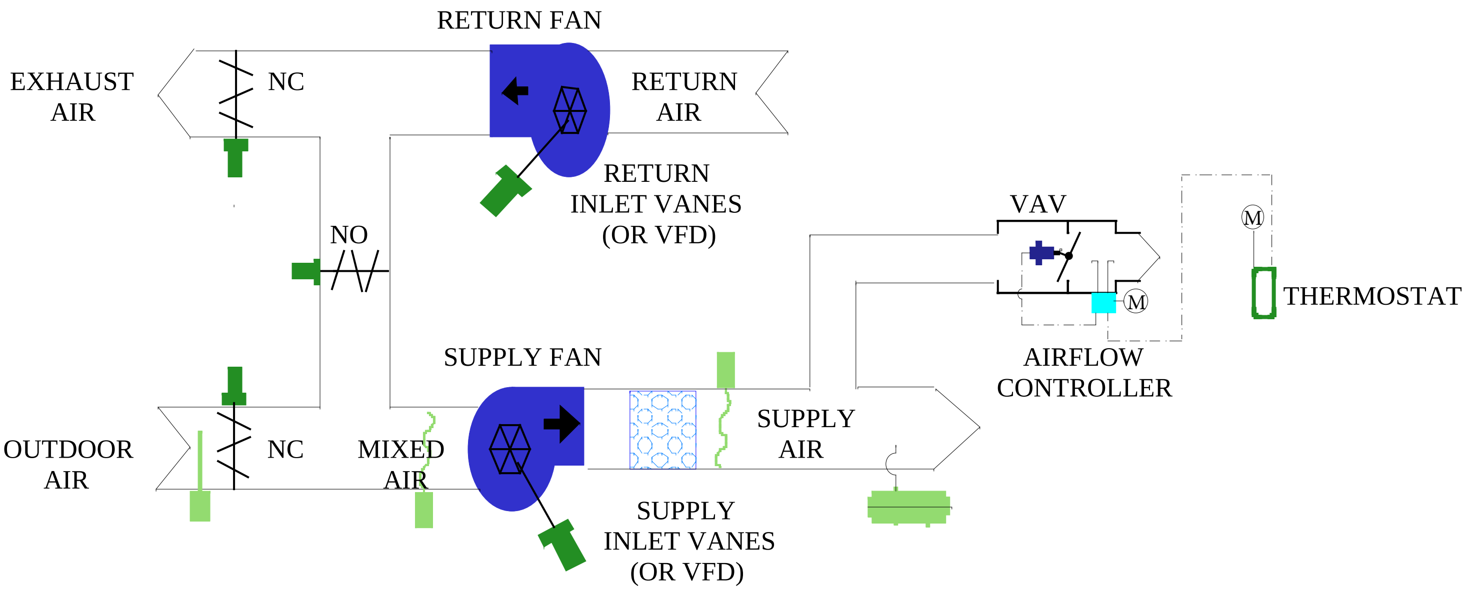
<u>VAV SYSTEM PRESSURE INDEPENDENT</u>



<u>VAV (VARIABLE AIR VOLUME) SYSTEM</u>

This type of system allows each area's thermostat to vary the amount of cold air entering the occupied space, addressing the varying cooling loads.

The VAV box illustrated has an air flow controller that senses the velocity pressure exerted by the airflow. The airflow controller sets the maximum and minimum amount of air allowed through the VAV box. The thermostat is allowed to vary the airflow between these two limits. This arrangement is referred to as pressure independent, as the airflow controller tends to correct for varying upstream static pressure values.

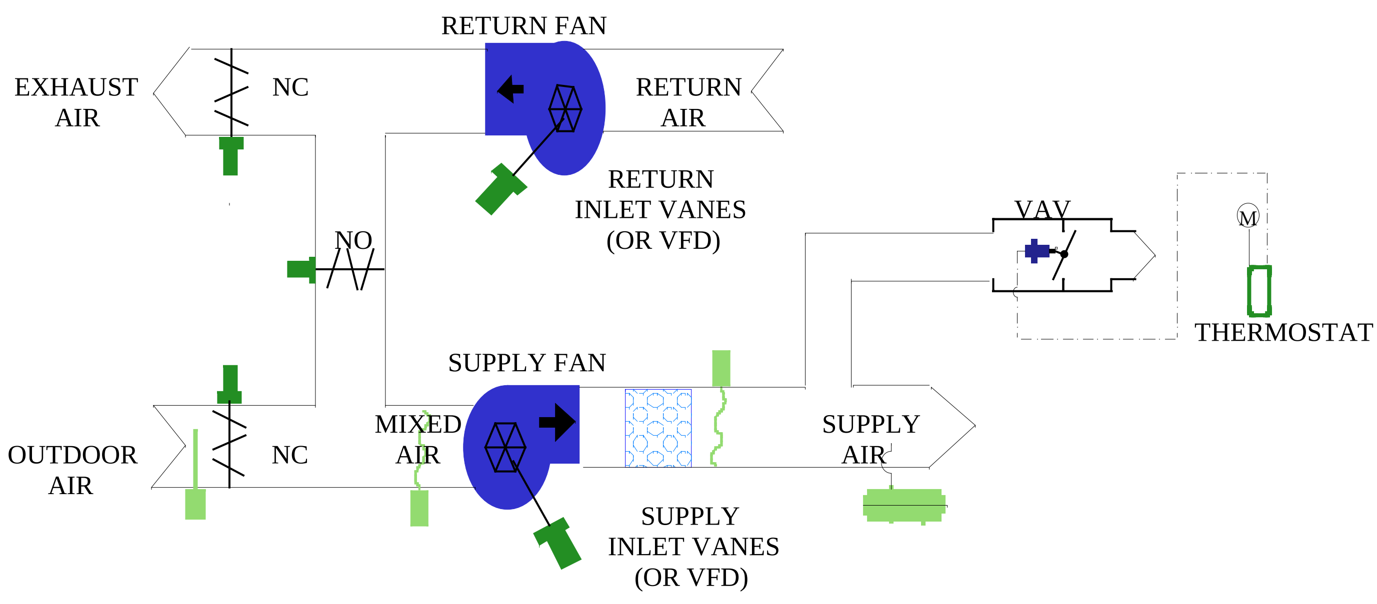
The airflow controllers are proportional with no integral reset; therefore, significant shift in control point is experienced if the static pressure variation is excessive.

The main duct pressure is controlled based on input from a pressure sensor located normally two-thirds of the way down the duct, based on air volume. The controller varies the position of the inlet vanes on the supply and return fans or controls variable frequency drives for these fans, maintaining constant duct static pressure.

Most systems have a diversity factor. This factor is the percentage difference between the total maximum volume of the VAV boxes and the maximum CFM of the supply fan. This is based on the fact that the sun can not shine on all sides of the building at one time; therefore, full cooling will not be required every where, at any one time.

The minimum ventilation requirement of a building is usually a fixed CFM value and the setting is normally a percentage of the supply fan's volume. The fact that the supply fan volume varies, requires that the relative percentage of air for minimum ventilation must vary also. This fact is rarely considered in setting the minimum ventilation logic.

VAV SYSTEM PRESSURE DEPENDENT



VAV (VARIABLE AIR VOLUME) SYSTEM

This type of system allows each area's thermostat to vary the amount of cold air entering the occupied space, addressing the varying cooling loads.

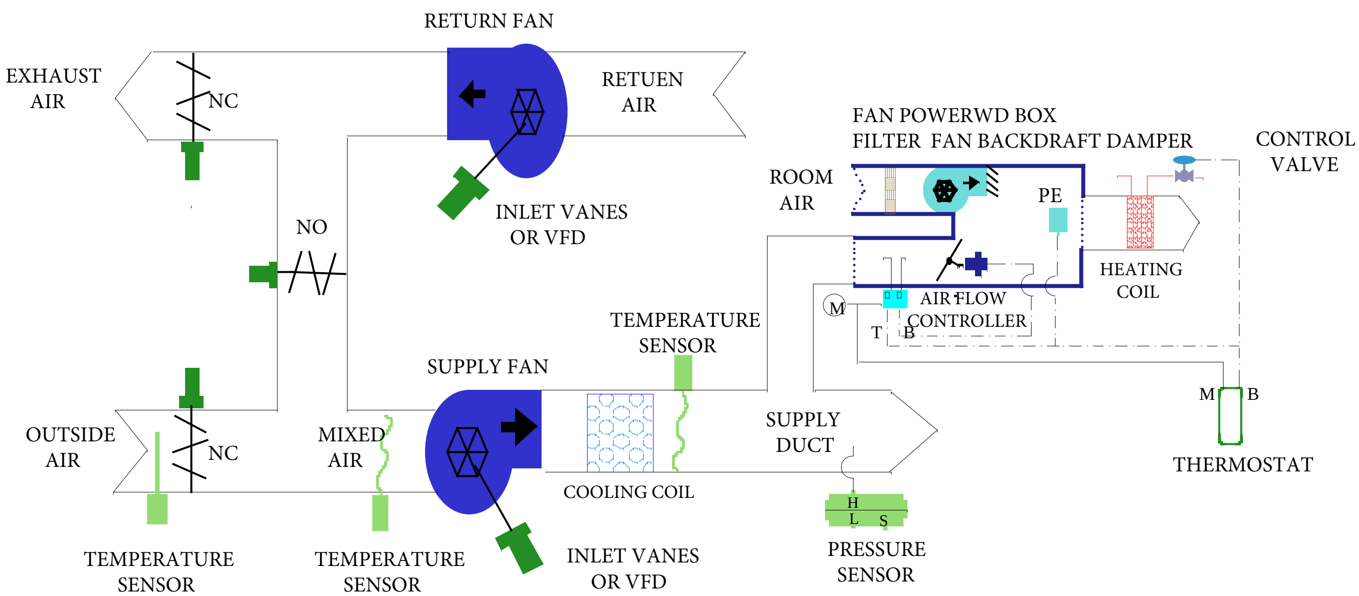
The VAV box illustrated does not have an air flow controller. This arrangement is referred to as pressure dependent. If the static pressure in the main duct varies, the amount of air entering the occupied space will vary even with the VAV box damper fixed at a set degree of opening. Precise control of the main duct pressure is critical in these systems.

The main duct pressure is controlled based on input from a pressure sensor located normally two-thirds of the way down the duct, based on air volume. The controller varies the position of the inlet vanes on the supply and return fans or controls variable frequency drives for these fans, maintaining constant duct static pressure.

Most systems have a diversity factor. This factor is the percentage difference between the total maximum volume of the VAV boxes and the maximum CFM of the supply fan. This is based on the fact that the sun can not shine on all sides of the building at one time; therefore, full cooling will not be required every where, at any one time.

The minimum ventilation requirement of a building is usually a fixed CFM value and the setting is normally a percentage of the supply fan's volume. The fact that the supply fan volume varies, requires that the relative percentage of air for minimum ventilation must vary also. This fact is rarely considered in setting the minimum ventilation logic.

PARALLEL FAN POWERED BOX



The fan powered box illustrated has an air flow controller that senses the velocity pressure exerted by the primary airflow. The airflow controller sets the maximum and minimum amount of air allowed through the fan powered box on cooling mode. The thermostat is allowed to vary the primary airflow between these two limits, modulate the heating valve and cycle the fan.

On a drop in temperature, the thermostat reduces the cooling primary air from maximum to minimum airflow. If the temperature drops further the control valve will open to the heating coil and then closes the pressure switch, increasing the airflow through the coil on heating mode. A backdraft damper prevents primary air exiting to the ceiling space.

The primary supply fan may be shut down at night and the primary damper in the fan powered boxes close. The fan powered boxes may be cycled at the night set back temperature.

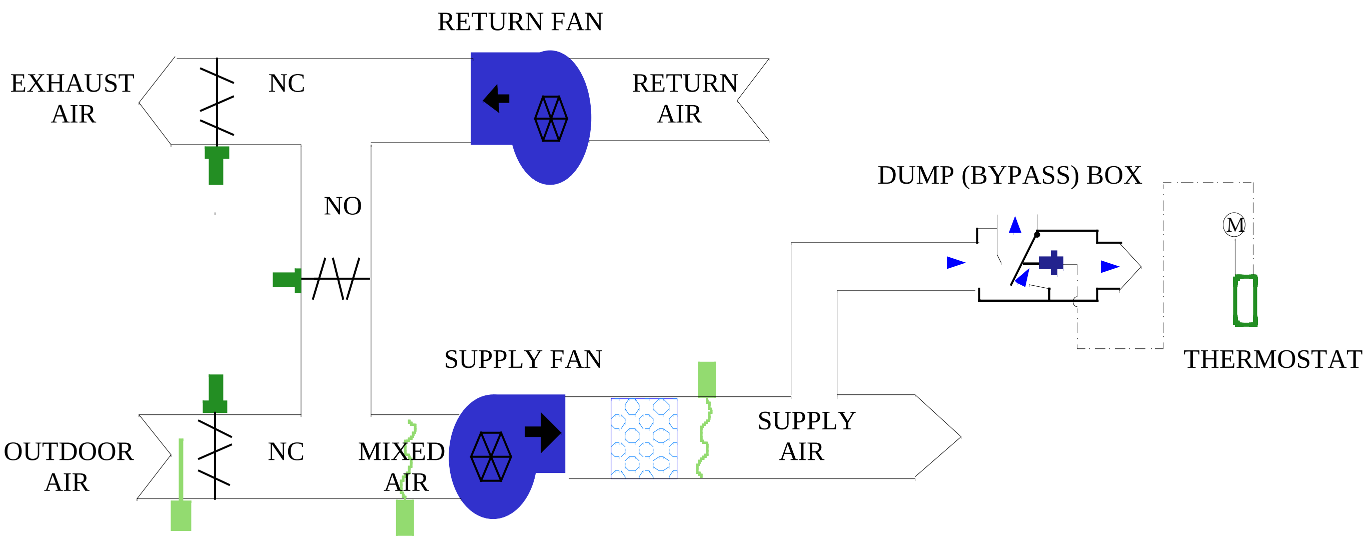
The main duct pressure is controlled based on input from a pressure sensor located normally two-thirds of the way down the duct, based on air volume. The controller varies the position of the inlet vanes on the supply and return fans or controls variable frequency drives for these fans, maintaining the required duct static pressure. On some systems the supply fan’s inlet vanes are controlled based on supply duct pressure and the return fan’s inlet vanes are controlled from building pressure. More advanced systems control the supply duct pressure just high enough to satisfy the VAV terminal with the greatest cooling requirement.

Most VAV systems have a diversity factor. This factor is the percentage difference between the total maximum volume of the VAV boxes and the maximum CFM of the supply fan. This is based on the fact that the sun cannot shine on all sides of the building at one time; therefore, full cooling should not be required everywhere, at any one time.

When the air volume required exceeds the maximum volume capability of the supply fan, the duct static will drop below the design value. Some factors causing this are supply duct leaks, VAV boxes allowing more than their original design, more VAV boxes added to the system, cooling load exceeding original design or the supply fan providing less volume than its original design.

The minimum ventilation requirement of a building is usually a fixed CFM value and the setting is normally a percentage of the supply fan’s volume. The fact that the supply fan volume varies, requires that the relative percentage of air for minimum ventilation must also vary. This fact is rarely considered in setting the minimum ventilation logic.

DUMP (BYPASS) BOX SYSTEM CONSTANT VOLUME



DUMP BOX (VARIABLE AIR VOLUME) SYSTEM

This type of system allows each area's thermostat to vary the amount of cold air entering the occupied space, addressing the varying cooling loads.

The dump box (bypass box) illustrated, always (in theory), consumes the same CFM from the main supply duct. The air is bypassed to the return air duct, forced into the occupied space or split between the two destinations. At a practical level the total CFM is different when the box is positioned to full bypass or full air flow to the occupied space relative to mixing positions between these two points.

The main fans do not require a means of varying their CFM as the system requirement in the main supply and return ducts does not vary.

As with all the fan systems, the air balancing should be performed by a qualified and experienced Air Balancing Technician.

VAV PERFORMANCE CASE STUDY

THE PROBLEM

The building experienced many complaints of stuffiness and over-heating.

Three different air balancing companies calibrated and checked the VAV boxes and the building continued to have many complaints.

Analysts of Pneumatic Systems Limited (APS) was called to investigate. APS found the static pressure in the supply duct dropped to 0.4” WG in the afternoon, which is very low from the design set point of 1.0” WG. The inlet vanes were fully open, but the system was requiring more CFM (cubic feet of air) than the fan’s capability.

The VAV’s were pressure independent, with airflow controllers (see page one), which should compensate for some drift in the supply air static pressure value, based on the airflow controller's data sheet.

The drifting static pressure values in the supply duct would cause the air balancers’ efforts to become out of calibration if the varying static pressure had an impact.

We tested to see if the manufacturers’ data sheets were unconditionally true in the pressure independent claims.

TEST PROCEDURE

-1- We selected a VAV box and installed a 0 PSIG to 30 PSIG pressure gauge and 0” WG to .5” WG Magnehelic gauge allowing us to read the box’s velocity pressure and airflow controller’s branch pressure.

-2- We checked the damper motor stroking range which was 3# to 13#.

-3- We dropped the supply duct static pressure in steps, recorded the maximum velocity pressure, determined the relative CFM and recorded the branch pressure from the airflow controller as per the chart below.

SYSTEM PRESSURE (“WG)	MAXIMUMVELOCITY PRESSURE (“WG)	CUBIC FEET/MINUTE (CFM)	AIRFLOW CONTROLLER BRANCH PRESSURE (PSIG) (ACTUATOR RANGE 3# to 13#)
1.60	.200	450	6.3
1.50	.190	440	6.0
1.25	.180	430	6.0
1.00	.150	400	5.0
0.75	.125	370	4.0
0.60	.070	290	3.0
0.50	.060	270	0.0
0.20	.020	187	0.0

OBSERVATIONS

-1- The thermostat was demanding maximum cooling at all times through the test period.

-2- The box CFM dropped as the supply static pressure dropped.

-3- At .60” WG the damper motor, with a range of 3# to 13#, was still theoretically under control of the airflow controller, which was producing a branch pressure of 3 PSIG.

-4- From 1.60” WG to 0.60” WG the maximum controlled airflow dropped from 450 CFM to 290 CFM as the controlling branch pressure of the airflow controller dropped from 6.3 PSIG to 3.0 PSIG.

CONCLUSIONS

-1- In this test we witnessed a 35.5% drop in maximum air flow when the supply duct static dropped from 1.60” WG to 0.60” WG.

-2- The drop of 35.5% was when the airflow controller had continual control over the throttling range of the VAV box damper motor.

-3- The airflow controllers are proportional only control and the observations are exactly what a proportional controller should do. Proportional controls require an error from set point for the branch pressure to change. From a maximum air flow of 450 CFM to a maximum air flow of 290 CFM the controls were exactly on calibration.

-4- Air balancers should be very sensitive to the supply duct static pressure, assuring it is at normal set point while adjusting VAV boxes.

-5- The term “pressure independent” creates the illusion that the supply duct static can vary without impacting the VAVs’ performance.

This is true if the vstatic variation is slight; however, this is a false understanding in situations of large pressure drops.

-6- Some causes of a system not having sufficient duct static pressure are:

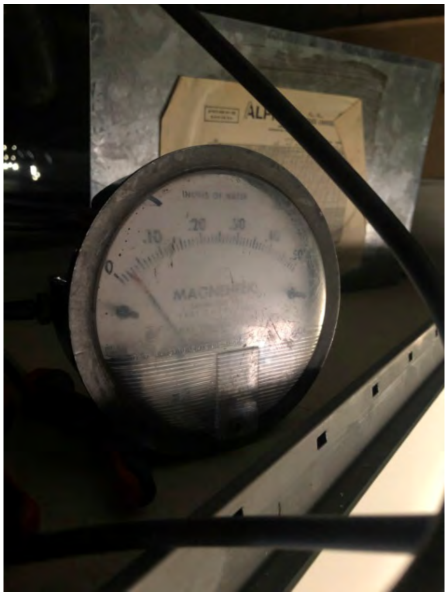
a) blown diaphragms in VAV boxes
b) defective airflow controllers
c) broken supply duct work
d) too many added VAV's to original system
e) oversights in original design
f) increasing maximum CFM on some existing VAV boxes
g) poorly sealed duct work

-7- Some VAV systems perform well in the morning, but as the cooling load increases during the day, the supply duct static pressure drops to cause severe control issues.

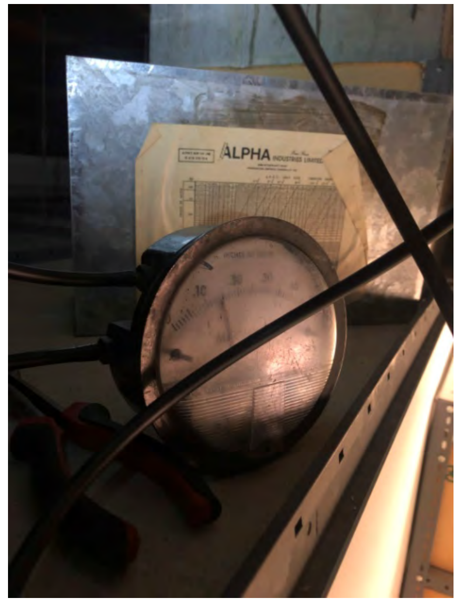
IMPACT OF DEFECTIVE AIRFLOW CONTROLLER OR BLOWN DIAPHRAGM ON A PNEUMATIC VAV BOX

VAV BOX IS 8” WITH AN AIRFLOW CONTROLLER RESET RANGE OF 8 PSIG TO 13 PSIG.

THERMOSTAT SIGNAL BELOW 8 PSIG;
THEREFORE, MINIMUM AIRFLOW SETTING.
VELOCITY PRESSURE .03” WG = 150CFM

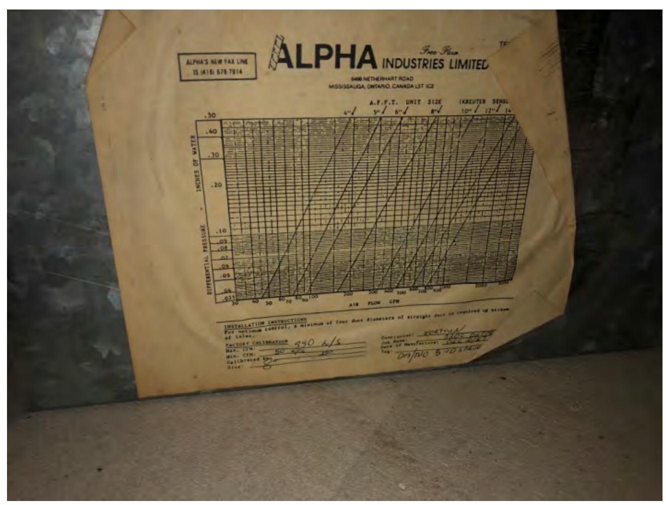


THERMOSTAT SIGNAL ABOVE 13 PSIG;
THEREFORE, MAXIMUM AIRFLOW SETTING.
VELOCITY PRESSURE .14” WG = 340CFM



BLOWN DIAPHRAGM
VELOCITY PRESSURE .23” WG = 450 CFM
(DAMPER WIDE OPEN)

VAV CALIBRATION CHART (8” BOX)



The diversity factor on a VAV system is the percentage the fan is undersized relative to the total of all the VAVs’ maximum airflow settings. (Example: If a fan can pass 100,000 CFM and the VAV’s total maximum capability is 115,000 CFM, the diversity factor is 15%.) This leaves the fan 15% undersized, but the sun cannot shine on all building faces at once, so maximum airflow should never be required and the duct static pressure setting of (example) 1” WG should be attainable.

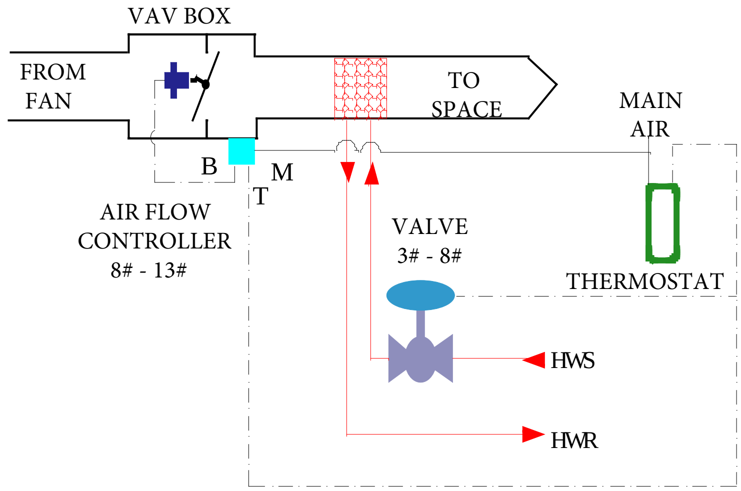
The above example of defective airflow controller or blown diaphragm demonstrates that this VAV passes 32% more system air than when working properly at maximum air flow.

Once issues cause the system demand to exceed the example fan’s 100,000 CFM the duct static pressure set point of 1” WG cannot be maintained and the duct static could drop to a level we have witnessed of, for example .4” WG.

The airflow controllers’ data sheets claim to be pressure independent, but as per our VAV case study this is not true if the duct static variation is large. Calibrating a building at various duct static pressures can result in a very poor accomplishment.

Duct leaks up stream of the VAV’s, dirty filters and coils, plus adding more VAV’s to the system, without consideration, will also impact the system’s ability to maintain proper duct static pressure.

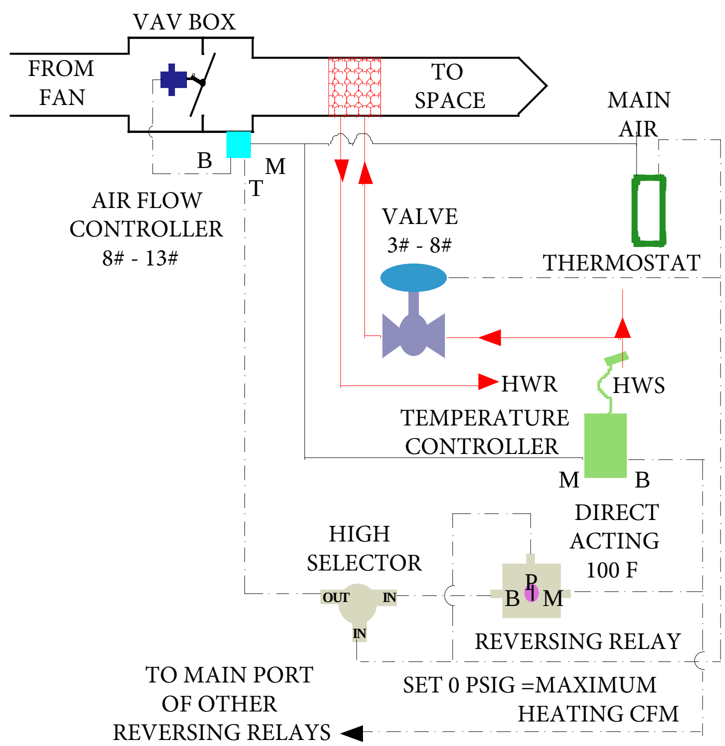
VAV/REHEAT ENERGY PERFORMANCE IMPROVEMENT



AS EXISTING

The airflow controller has minimum, as well as maximum, airflow settings. The maximum setting addresses the maximum airflow requirement at 100% design cooling load. The minimum setting normally addresses the required ventilation rate (example 25%) for the area being served, respecting air quality.

When a reheat coil is associated with a VAV box, the minimum setting relates to the quantity of air required carrying heat to the space (example 50%). This is normally much more than required for air quality maintenance. This arrangement requires that the heating be available all year, as the space will overcool at the minimum setting of 50%, if no heat is available to warm the air.



SUGGESTED SOLUTION

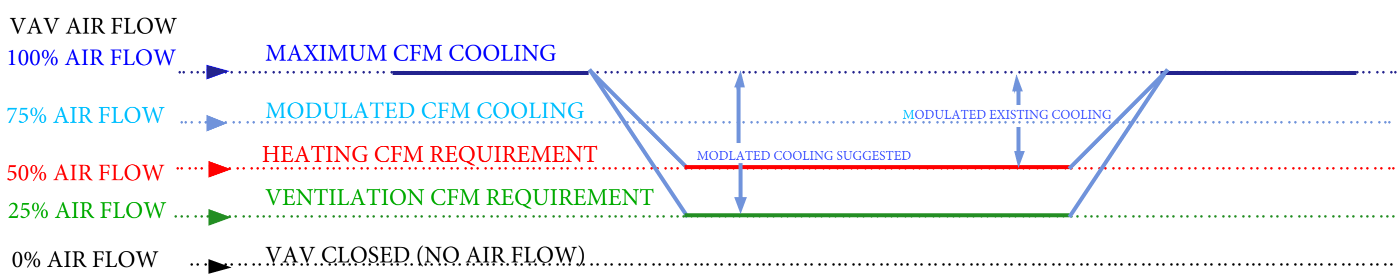
This arrangement allows the VAV box to be set at the ventilation rate (example 25%) as a minimum setting.

As the room cools, the thermostat will modulate the VAV box back to the 25% minimum ventilation position. As the room continues to cool, the thermostat opens the reheat valve. When heat is available and if the room continues to cool, the thermostat, through the reversing relay and high selector, increases the airflow through the VAV box from 25%, variable as needed, up to 50% airflow, delivering the required heat.

If no heat is available, as determined by the supply heating pipe temperature controller, the reversing relay will not receive main air, thus the VAV box is disallowed modulation from the minimum ventilation rate of 25% up to the maximum heating rate of 50% airflow.

This circuit provides the most effective energy use while still attaining the best comfort conditions in the space, both summer and winter, while allowing the boiler to be turned off during the summer.

NOTE:
The Kreuter RCC1502 reversing relay allows the required bias. Predetermine if the relay intended for use can achieve this.



The existing design caused the VAV to over ventilate at a minimum airflow of 50%, when the actual ventilation airflow required was only 25%.

Heat, via the heating valve, had to be added compensating for the over ventilation in addition to the space's normal heat loss.

The suggested solution allows the VAV to modulate airflow down to the actual ventilation minimum rate of 25% if cooling is not required. If heating is required, the thermostat opens the heating valve fully; then gradually increases the airflow from the minimum 25% to a maximum of 50%, as required, delivering the desired heat.