Proper Setup of HVAC System in Conjunction with Sound Building 'Skin' Design for Alleviation of IAQ and Energy Performance Problems

Mike Rosenberg P.E.
Project Manager
Affiliated Construction Services, Inc
Madison, WI

Abstract: Energy consumption in buildings is a growing concern. Many buildings are energy hogs simply because they were not set up properly to begin with. The building envelope and infiltration of unconditioned air is also a major concern in hot and humid climates, not only because of the loss of energy, but also because of damage that can result to insulation, drywall, and structure in addition to promotion of mold and mildew growth. Proper setup of the HVAC system, in conjunction with sound building "skin" design, can alleviate many of these problems. This paper will explain how most mixed air HVAC systems are set up with problems to begin with and how to identify and solve those problems. It will explain different control schemes that specifically deal with proper building pressurization.

ABOUT THE AUTHOR

Michael Rosenberg has over 25 years commissioning building systems and training countless Owners Representatives in the proper operation of their facilities. Prior to joining ACS, Mr. Rosenberg worked for a Johnson Controls setting up, programming, and commissioning building automation systems. Mr. Rosenberg has a degree in Electrical Engineering Technology from the Hertzing Institute in Madison, Wisconsin and has received his PE license in Controls Engineering.

CONTROLLING BUILDING LEAKAGE

Buildings by nature leak. They have doors, windows, and other penetrations such as pipe, conduit, and structural members. Controlling the amount of leakage is critical to the life of the building. A properly installed vapor barrier is crucial to the function of a building. It's just as important to properly seal penetrations and apply thermal breaks in order to save energy and deter growth of mold and mildew.

We can keep our buildings cool in the summer and warm in the winter. We can't however change the weather. Eliminating cracks and crevices by tight construction practices will help keep a building comfortable. More importantly, it will help keep a building from destruction from excess moisture along with mold and mildew growth. A vapor barrier should be used on exterior walls in hot and humid climates. Penetrations from pipe, conduit, structural members, etc. should be sealed with caulking, weather-strip, or flashing. Stuffing insulation in the cracks and crevices does not constitute a vapor barrier.

In addition to providing a sound vapor barrier, it's also just as important to operate the buildings HVAC systems properly to prevent excess infiltration of unconditioned air. No matter how hard we try to prevent it, there will always be a certain amount of leakage in a building. Proper operation of the buildings HVAC systems can drastically reduce the negative effects of building leakage.

HUMAN AND MILDEW COMFORT ZONES

Formula for Mold Growth: Nutrients + Warmth + Humidity + Spores = Mold Growth

Molds feed on the organic materials used in building construction. The warmth that provides comfort for people also encourages mold growth. As temperature rises, molds grow faster. Humidity supplies the moisture for mold growth. Spores are tiny seeds of molds. They are everywhere. If given the right environment, the spores will grow. Besides eating away at building materials, some molds can cause serious illness or even death in susceptible individuals.

Figure 1 shows the ranges of temperature and humidity in which human comfort zone and mildew growth overlap.

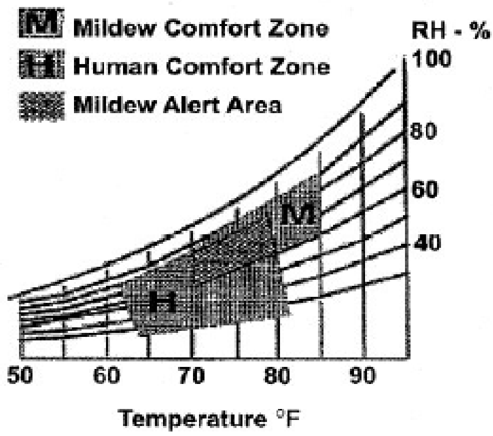

Fig.1 Human and Mildew Comfort Zones

High temperatures, poor air circulation, dim light, and accumulated grime assist and accelerate the growth of mold once it has germinated, but only high relative humidity and moisture contents can initiate and sustain mold growth.

BUILDING OPERATING PRESSURES

Operating a building at a negative pressure can cause serious problems, especially in hot and humid climates. The interior walls are cool from the air conditioning. When the hot and humid air is drawn into the building through cracks and crevices, moisture condenses on the cool interior portion of the wall. This condensed moisture along with the warm humid air creates an excellent breeding ground for mold and mildew.

If the building is operated at too high of a positive pressure, conditioned air is exfiltrated through cracks and crevices. The result is wasted energy. In addition to wasting energy, outside doors may not close properly resulting in a security problem.

The ideal conditions for operating a building are at a neutral to slightly positive differential with respect to the outdoors. Most building owners are aware of this but not all have their buildings set up properly to achieve this on a regular basis.

BUILDING HVAC SYSTEMS

Constant Volume Air Systems

Constant volume systems are set up for design building loads. Building occupants are kept comfortable by modulating a reheat valve in response to temperature variations within the space. The amount of air delivered to the space is kept at a constant flow.

The Test and Balance (TAB) contractor adjusts volume dampers throughout the distribution system to provide a fixed amount of air to the space. The supply and return air volumes are set at the Air-Handling Unit (AHU) to provide proper offset for building pressurization taking into consideration toilet and miscellaneous exhausts in the space.
Figure 2 shows a simplified constant volume AHU.

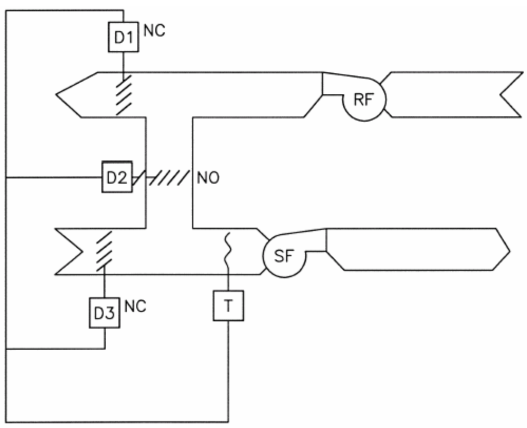

Fig. 2 Constant Volume Air Systems

The supply fan and return fan operate at a constant speed. The only dynamic operation is through modulation of the mixed air dampers.

Variable Volume Air Systems

When the energy crunch came in the early 80's, building owners looked to the industry to help cut rising energy costs. Variable volume ventilation systems could significantly reduce the amount of energy used to heat and cool their buildings. The progression of variable speed drives (VFD)'s for motors, variable air volume (VAV) terminals for delivering conditioned air, and the advancement of building automation systems (BAS) has continued to improve the cost effectiveness of conditioning our buildings.

Consider the variable volume air-handling unit as a cooling only device. It delivers 55°F air to the VAV terminals. The terminals modulate from minimum to maximum airflow to deliver more or less cooling as determined by the setpoint on the space thermostat. A hot water reheat coil is installed downstream of the air terminal to provide heat to the space upon demand. The whole system is dynamic and provides only the heating and cooling that is required for occupant comfort. The minimum flow setting of the air terminal box provides the minimum amount of fresh air for ventilation to the space.

Building pressurization is accomplished by maintaining an offset between supply air and return air volumes as measured by Air Flow Measuring Stations (AFMS). When the supply AFMS senses an increase in supply air volume, a control signal is sent to the return fan VFD to increase the return air volume by the same amount. The offset between supply and return volumes is calculated from total exhaust from the space. For example, if the toilet and miscellaneous exhaust in the space totals 500 cfm, then the offset between supply and return air volume would be 500 cfm in order to maintain neutral space pressurization. The 500 cfm exhausted would be brought in through the minimum setting on the outdoor air damper.

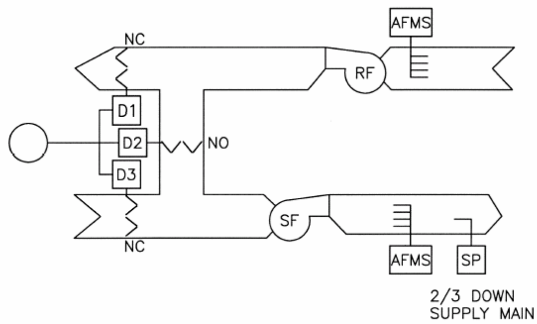

Fig. 3 Variable Volume Air Systems

D1, D2, D3 are the relief air, return air, and outdoor air dampers respectively. Supply and return air volumes are measured by Air Flow Measuring Stations (AFMS). Supply duct static pressure (SP) is traditionally measured 2/3 down the length of the supply duct main.

SETTING UP THE AHU

Adjusting the Mixed Air Dampers

Setup of the mixed air dampers is identical with both constant volume and variable volume systems. Traditionally, a common control signal is piped to the mixed air dampers (outside air, return air, and relief air). The outdoor air damper and relief air damper are normally closed (NC) while the return air damper is normally open (NO). As the control air pressure is increased to the dampers, the outdoor air and exhaust air dampers modulate open while the return air damper modulates closed. As the pressure is decreased, the reverse occurs.

To ensure proper system operation, the dampers must be adjusted so there is consistent modulation as the control signal varies. This sounds simple but may be quite tedious. Mechanical linkages, hysterisis, and actuator spring range all affect damper operation. A pilot positioner installed for each damper section is necessary for the required adjustments.

For sake of example, lets say we have a constant volume system. The space is served by an AHU sized to deliver 50,000 cfm supply air. The total exhaust from the space is 25,000 cfm. A neutral space pressure is desired so the system is set up to return 25,000 cfm and bring in a minimum of 25,000 cfm outdoor air to make up for the air exhausted.

The dampers are set to stroke from a control signal of 3-15 psi. The linkages and pilot positioner's are adjusted for consistent movement throughout the operating range. After the adjustments are made, a setpoint of 50% is input to the control system, which would equate to 25,000 cfm. Right? Wrong!

First of all, 50% damper stroke doesn't necessarily equate to 50% damper position and 50% airflow. Secondly, since the dampers are controlled off the same signal, the relief damper would be modulated open by the same amount as the outdoor air damper.

For the above example, the controller should have been set to output a signal of 3-15 psi. The outdoor air damper would be set to stroke from 3-15 psi while the relief and return air dampers set to stroke from 9-15 psi. Remember, the positions on the dampers are initial settings and must be verified by measurement for proper operation. Upon startup of the AHU, the controller would output 6 psi to position the outdoor air damper to minimum position.

Setting up Static Pressure Control

To balance the VAV system, the TAB contractor must first determine where the worst-case duct run is and start with a controlling static pressure setpoint just enough to satisfy the terminals in that section. The minimum and maximum airflows are set at the air terminals throughout the system while actual flow measurements are taken at the diffusers. There may be a case in which the maximum airflow cannot be achieved at a terminal so the static pressure setpoint must be increased. The TAB contractor is responsible for giving the final static pressure setpoint to the control technician to record in the software program.

With the VAV system, the supply fan delivers just enough air to maintain the static pressure setpoint in the supply duct as measured by a sensor normally placed 2/3 down the length of the duct. As the VAV boxes modulate open to deliver more air for cooling, the static pressure within the duct starts to drop which in turn signals the supply fan VFD to increase speed. As the fan speed increases, the static pressure increases to the meet setpoint.

System Operation

The many innovations that have allowed the building operator to save money through energy management may also cause problems in overall building operation. The operator may be specialized in computer software programming or hardware control devices but may be lacking in the fundamental understanding of the Heating Ventilating and Air-Conditioning (HVAC) systems being controlled. It is too easy to change setpoints or system functions in the name of energy conservation without fully comprehending the consequences of these actions.

Take for instance a building operator who decides to shut down a fan system in the evening to save energy. The toilet exhaust may be software interlocked to the air-handling unit. Later in the week someone complains of smells in the restrooms so the operator removes the interlock allowing the exhaust fan to operate to operate continually. Now during the unoccupied mode, the building is maintained at a negative pressure.

Another example is an operator who decides to save money by decreasing the amount of outside air from 50% to 25%. The system still appears to operate ok and no one is complaining. No thought was ever given to building pressurization and the amount of outside air required to maintain the proper building pressure with respect to the outdoors.

Still another example is when outdoor air conditions drop below freezing. The AHU trips on a low limit safety device. The operator decides to reduce the amount of outside air to keep the unit running. Again, the required air to maintain building static pressure is endangered. Just how often are these Band-Aids applied to the building HVAC systems? Will the minimum damper position be readjusted as outdoor air temperature rises above freezing?

I can go on and on with "what ifs". The bottom line is however, that the building operator must understand the building functions as whole and not just portions.

Internal Static Pressure Control in AHU's

Remember when we talked about how difficult adjusting the mixed air dampers can be? If correct adjustment is not achieved, static pressures fluctuate significantly within the plenum. With the variable volume system, this fluctuation is amplified due to the ramping up and down of the supply fan in concert with modulating dampers from the VAV boxes. As the fan ramps up and down to meet the demand of the system, so does the quantity of outdoor air for ventilation and building pressurization.

A method for overcoming the variations in damper linkages, hysterisis, and damper stroke is through internal static pressure control. The advantage of this method is primarily to reduce stratification and maintain a consistent minimum outdoor quantity. This is done because the static pressure in the mixed air plenum is kept at a constant. In order to operate this system properly, however, the devices must be set up correctly. The next diagram shows a typical AHU designed for internal static pressure control.

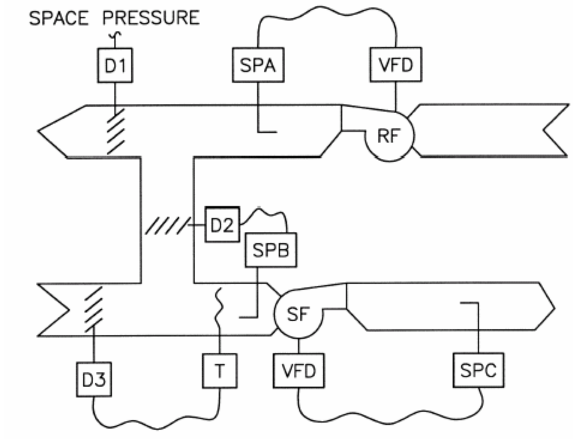

Figure 4 Internal Static Pressure Control

D1 Relief Air Damper
D2 Return Air Damper
D3 Outdoor Air Damper
SPA Return Static Pressure Sensor
SPB Mixed Air Static Pressure Sensor
SPC Supply Air Static Pressure Sensor
T Mixed Air Temperature Sensor

This system operates very effectively but is seldom set up properly. The next few diagram show how to set up this system correctly.

Return Static Pressure Control

Static Pressure Sensor SP-A measures return air static pressure, which is used to modulate the speed of the return fan through a VFD. The setpoint is dependant on the actual pressure drop across the relief air damper. To determine this pressure drop, override the return air damper fully closed and the relief air damper fully open. Ramp return fan speed to 100% and verify scheduled airflow by performing a duct traverse on the return duct. The pressure read at SP-A under full flow conditions is the actual setpoint to be entered into the control software for return fan control.

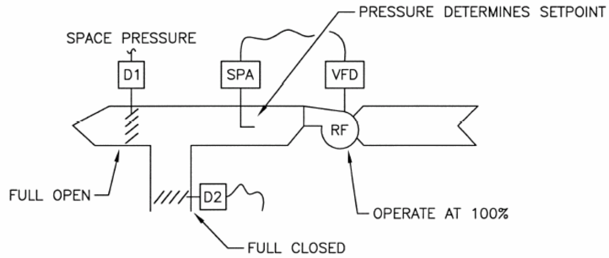

Fig.5 Return Static Pressure Control

Mixed Air Static Pressure Control

Static Pressure Sensor SP-B measures mixed air static pressure, which is controlled by modulating the return air damper. Maintaining a constant static pressure in the mixed air plenum ensures a constant minimum outdoor air amount with a fixed damper opening. In order to determine what the setpoint should be in the mixed air plenum, the return damper must be overridden closed and the outdoor damper overridden fully open. Send a command to the VAV boxes to open to maximum flow and then override the supply fan to 100% flow. *CAUTION…monitor supply static pressure to prevent over pressurization of the supply duct.* The static pressure measured at SP-B under full flow will be the controlling setpoint for operating the return air damper.

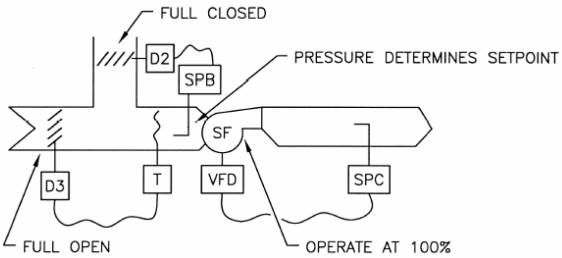

Fig. 6 Mixed Air Static Pressure Control

Minimum Outdoor Air Setting

Once the mixed air pressure setpoint is determined, the minimum setting can be set for outside air. To do this, leave the return air damper overridden fully closed. Override the supply fan to operate at minimum outside airflow.

EXAMPLE………..If the supply fan maximum flow is 30,000 cfm and the unit is scheduled for minimum outdoor air of 25%, operate the supply fan at 7,500 cfm. This must be measured by traversing the supply duct.

Once the minimum airflow is determined at the fan, override the outdoor air damper closed just until the reading at SP-B is the same as determined for maximum airflow. The damper setting is the setpoint given to the controls contractor for minimum outdoor air damper position. Again, this airflow must be verified by duct traverse.

Space Pressurization Using Differential Pressure

Modulating the relief air damper in response to differential pressure from the space being controlled and outdoor static pressure will ensure a proper pressure relationship. Normally the space is controlled neutral to slightly positive with respect to outside air. This will keep unconditioned air from infiltrating into the space. As the return fan speeds up, more air is drawn from the space, which in turn drops the space pressure in relation to the outside.

Space Pressurization Using Flow Tracking

Another example of space pressurization is through flow tracking. This is where the actual return airflow and supply airflow is measured and the relief air damper is modulated to maintain a defined offset. The offset is the difference between supply airflow minus total exhaust (toilet exhaust, general exhaust, etc.) in the space. An additional amount of offset may be added to maintain the space slightly positive.

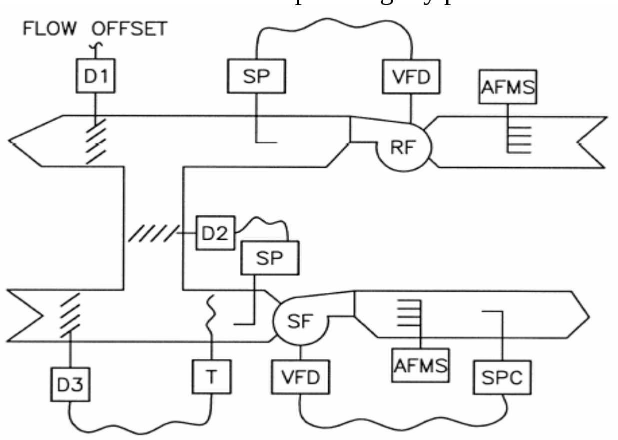

Fig.8 Flow Tracking Method

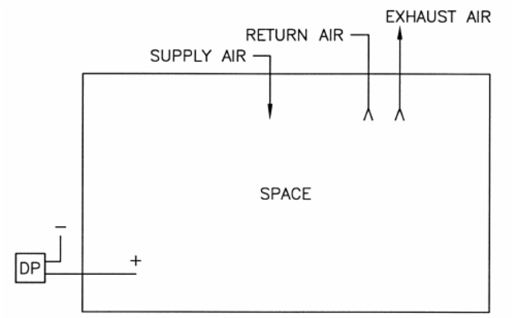

Fig.7 Differential Pressure Method

In the above example, the relief air damper is modulated to maintain an offset between the supply and return air amounts as measured by the AFMS's.

CONCLUSION

A building operating under a negative static pressure can cause moisture to condense inside the wall cavities. Moisture can cause mold and mildew to grow which in turn can cause deterioration of building materials in addition to health hazards.

Operating a building at too high a positive pressure can be very expensive due to loss of energy to the outdoors. It may also cause security problems by not allowing the exterior doors to close properly.

After setup of the HVAC system, all setpoints must be recorded and entered properly into the controller. Trend system static pressures, temperatures, damper positions, and fan speeds for a period of 24 – 48 hours to verify proper operation.

Know your building. When changing the mode of operation in your air systems, understand how these changes can affect overall building operation. Commissioning building systems can help ensure proper building setup and operation. A solid training program should include system relationships and consequences of "what ifs"

.