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Volume Matching Control

Leave the Outdoor Air Damper Wide Open

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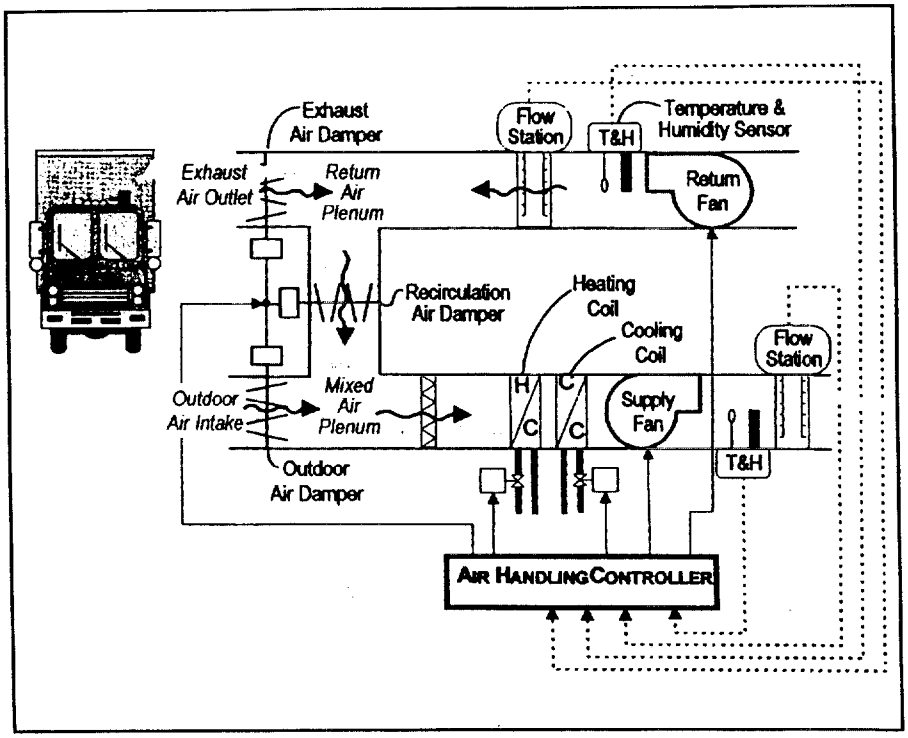

Fig. 1: Reverse airflow in an air-handling unit.

Maintaining indoor air quality (IAQ) requires careful consideration of the location of the outdoor air intake. However, less concern is given to the location of the exhaust air outlet. Janu et al. (1995), Elovitz (1995) and a number of experienced mechanics have observed air entering air-handling units (AHUs) through the exhaust air outlet. Air entering an AHU through the exhaust air outlet will negatively impact IAQ if the exhaust air outlet is located near a pollution source. *Figure 1* shows what may happen if the exhaust air outlet is located near a loading dock. Exhaust from the truck enters the air-handling unit through the exhaust air outlet. The exhaust fumes then travel from the return air plenum to the mixed air plenum. Eventually, the fumes will end up in occupied rooms.

In some AHUs, prefilters or preheat coils (or both) are placed in the outdoor air duct. Air entering an AHU through the exhaust air outlet bypasses these components. If the prefilter is bypassed, IAQ will suffer. If the preheat coil is bypassed and the air is very cold, the coils in the AHU could be damaged or the freeze protection thermostat may shut down the entire AHU.

This article describes a new control system for variable-air-volume AHUs that uses volume matching to control the return fan. The purpose of the new control system is to prevent outdoor air from entering an AHU through the exhaust air outlet. The new control system links the position of the exhaust air damper and recirculation air damper, while the outdoor air damper is in the fully open position during occupied times. Traditional AHU control systems link the position of the exhaust air damper, recirculation air damper, and the outdoor air damper.

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Traditional AHUs

In North America, AHUs are usually controlled to maintain a positive air pressure in the building relative to the outdoors. This helps prevent unconditioned air from entering the building through cracks in the building structure. The supply fan is controlled to maintain a static pressure in the supply duct. A common strategy for controlling the return fan is to maintain a constant difference between the supply and return airflow rates. This strategy is called volume matching. With a volume matching strategy, the difference in the volume of air entering and exiting the AHU through the outdoor and exhaust air ducts must equal the difference in the supply and return airflow rates.

As stated earlier, traditional AHU control systems link the positions of the exhaust air damper, recirculation air damper and outdoor air damper. The exhaust and outdoor air dampers are normally closed, and the recirculation air damper is normally open. The dampers

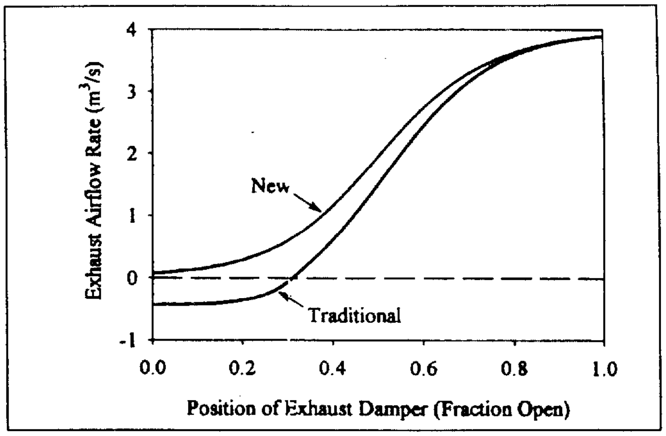

Fig. 2: Simulation exhaust airflow rates for the traditional and new control systems.

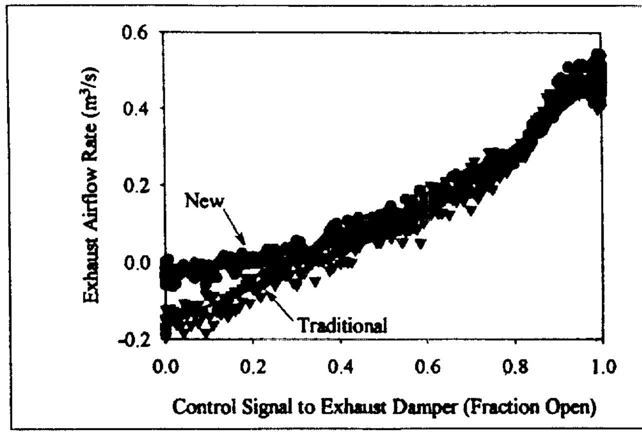

Fig. 3: Laboratory exhaust airflow rates for the traditional and new control systems.

are sequenced such that as the exhaust and outdoor air dampers begin to open, the recirculation air damper begins to close. Either mechanical linkage or the control system is used to maintain the position relationship between the three dampers. For traditional AHUs, damper positions are related by

$$\theta_{out} = \theta_{ex}, \tag{1}$$

and

$$\theta_{re} = 1 - \theta_{ex} \tag{2}$$

where θ_{out} is the fraction of fully open position of the outdoor air damper, θ_{ex} is the fraction of fully open position of the exhaust air damper, and θ_{re} is the fraction of fully open position of the recirculation air damper.

New AHU Control System

The new AHU control system links the position of only the exhaust air damper and the recirculation air damper using the relationship in *Equation 2*. During occupied times, the outdoor air damper remains 100% open, i.e., $\theta_{out} = 1$. If the minimum ventilation airflow requirement is the same as the volume matching differential, the exhaust air damper should be fully closed ($\theta_{ex} = 0$) and the recirculation air damper should be fully open ($\theta_{re} = 1$) when minimum ventilation is desired.

Simulation Results

Simulations were performed to compare the traditional and new control systems for an AHU with the following characteristics: supply airflow rate is 5 m^3/s (10600 cfm), return airflow rate is 4 m^3/s (8500 cfm), area of outdoor air damper is 2.5 m^2 (27 ft^2), and areas of exhaust and return air dampers are 2 m^2 (22 ft^2). A general-purpose equation solver (Klein and Alvarado, 1994) was used to solve a system of equations for modeling the airflow in AHUs. The system of equations is based on the principles of conservation of mass and energy (Seem and House, 1996).

Figure 2 shows the flow rate of air through the exhaust air outlet as a function of the exhaust air damper position for both the traditional and new control systems. Negative values of the exhaust airflow rate indicate that air is entering the AHU through the exhaust air outlet. For the traditional control system, outdoor air enters the AHU through the exhaust air outlet when it is less than 30% open. Also, the problem occurs more often at low load conditions. For the new control system, outside air does not enter the AHU through the exhaust air outlet.

Other simulations showed reverse airflow with the new control system for an AHU with oversized dampers and a supply airflow rate three times as large as the return airflow rate. These are the extreme conditions alluded to previously. When conditions such as these exist, increasing the flow resistance through the recirculation air damper can prevent the reverse airflow problem. The flow resistance of a damper can be increased by disabling and closing a damper blade, or by limiting the maximum open position of the damper. Additional simulations showed that for these extreme conditions, the reverse airflow problem was more severe with the traditional control system than with the new control system.

Laboratory Results

Experiments were performed on a laboratory AHU to compare the traditional and new control systems. The laboratory AHU has an opposed blade exhaust air damper and parallel blade outdoor and recirculation air dampers. Each damper has a separate actuator. Airflow measurements were obtained using airflow stations and differential pressure transducers. The airflow stations use an array of pitot tubes to produce an average velocity pressure for a cross section of the duct. Smoke tests were used to determine if outdoor air was entering the AHU through the exhaust air outlet. The smoke tests consisted of holding a smoke generator near the exhaust air outlet and observing whether the smoke was blown away from the outlet or drawn into the outlet as the dampers were stroked from fully open to fully closed. Seem and House (1996) review the instrumentation used in the laboratory AHU. For the laboratory tests, the supply airflow rate was nearly constant and approximately equal to 1.38 m^3/s (2900 cfm). The return fan was controlled to maintain the flow difference between the supply and return air ducts at 0.57 m^3/s (1200 cfm).

Figure 3 shows the exhaust airflow rates for the traditional and new control systems as a function of the control signal to the exhaust air damper. (A control signal of 0 indicates that the damper is commanded to a fully closed position, and a control signal of 1 indicates the damper is commanded to the fully open position.) Reverse airflow occurs when the exhaust airflow rate is negative. From *Figure 3*, it appears that both control systems allow reverse airflow for control signals ranging from 0 to 0.2. However, smoke tests did not show any reverse airflow for the new control system, but did show significant reverse airflow for the traditional control system. It is possible that the small negative airflow rates seen in *Figure 3* for the new control system are attributable to difficulties associated with obtaining accurate airflow measurements.

Field Results

Field tests were performed with both control systems for an AHU at the Iowa Energy Center Energy Resource Station located near Des Moines, Iowa. The AHU has opposed blade dampers, each with a separate actuator. Commercially available airflow measuring stations, that use thermal sensing technology, were used to measure the supply, return, and outdoor airflow rates.

A custom-made airflow direction indicator was installed in the exhaust air duct. The airflow direction indicator consisted of a lightweight foamboard panel fastened to a pivot rod. The pivot rod was suspended from the sides of a horizontal section of the exhaust duct. The foamboard panel was nearly the same size as the duct cross sectional area, making it very sensitive to airflow direction and velocity. At no flow or neutral flow conditions the indicator would hang vertically in the duct. As the exhaust airflow changed, the airflow indicator panel would rotate on the pivot rod corresponding to the direction and relative magnitude of exhaust airflow. This device made it very easy to determine the direction of airflow in the exhaust air duct.

During the field tests, the supply airflow rate varied from approximately 1.32 m^3/s to 1.56 m^3/s (2800 cfm to 3300 cfm). The return fan was controlled to maintain the flow difference between the supply and return air ducts at 0.28 m^3/s (600 cfm). The measured flow difference varied from approximately 0.21 m^3/s to 0.35 m^3/s (445 cfm to 740 cfm).

Figure 4 shows the exhaust airflow rate for the traditional and new control systems as a function of the control signal to the exhaust damper. The curves in *Figure 4* are sixth order polynomials that were fit to the field data using least-squares regression. Note that the curves in *Figure 4* appear to have the same shape as the curves in *Figure 2* for the simulation results. From *Figure 4* it appears that the traditional control system allows reverse airflow and that the new control system prevents reverse airflow. The flow direction indicator confirmed that when the exhaust air damper is less than 30% open, air is drawn into the AHU with the traditional control system. Also, no reverse airflow was observed with the new control system.

Conclusions

Simulation, laboratory, and field results presented in this article demonstrate that air can enter an AHU through the exhaust air outlet of a traditional volume matching control system. The traditional control system links the positions of the outdoor air damper, exhaust air damper and recirculation air damper. This article described a new control system for AHUs that use a volume matching control strategy to control the return fan. During occupied times, the outdoor air damper is fully open, and the positions of the exhaust and recirculation air dampers are linked. Simulation, laboratory, and field results presented in this paper demonstrate that the new control system prevents air from entering AHUs throuh the exhaust air outlet.

However, the new control system will not prevent reverse

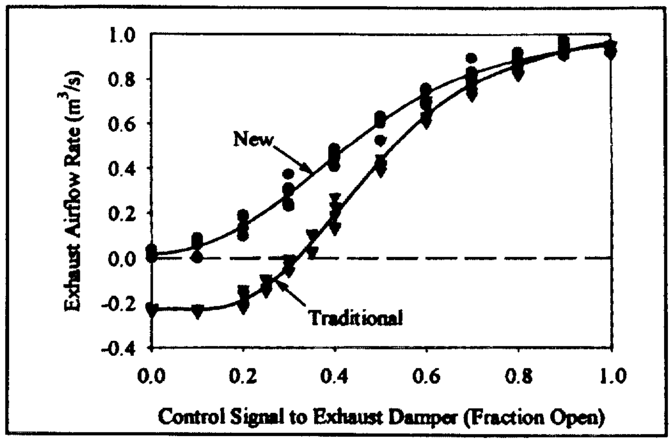

Fig. 4: Field site exhaust airflow rates for the traditional and new control systems.

airflow for poorly designed AHUs operating under extreme conditions. For situations in which reverse airflow occurs using the new control system, the problem will also occur and will be more severe with the traditional control system. In summary, leave the outdoor air damper wide open when using a volume matching strategy to control the return fan.

Acknowledgments

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