ASHRAE JOURNAL

Outside Air Ventilation Control and Monitoring

By Eric G. Utterson

and

Harry J. Sauer, Jr., Ph.D., P.E.
Fellow ASHRAE

Indoor Air Quality (IAQ) is considered acceptable in buildings if there are no known harmful contaminants in the air and if a substantial majority of people exposed do not express dissatisfaction.[1] Unacceptable IAQ has led to an increased number of complaints of headaches, eye and throat irritation, and breathing difficulties.

One accepted method of preventing IAQ problems is fresh air dilution. This is accomplished by supplying fresh outside air into the building and exhausting contaminated return air. *ANSI/ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality,* a standard written into many building codes, requires at least 20 cfm (10 L/s) of outside air to be supplied for every office building occupant.

With variable-air-volume (VAV) systems, maintaining a constant or controlled ventilation rate is not achievable without some control method. In VAV systems, the supply air temperature is constant, and the amount of supply airflow to individual spaces is modulated to control return air temperature. Similarly, outside airflow changes with the building cooling load. When VAV systems without outside air controls are used, the possibility of having IAQ problems increases.

About the Authors

Eric G. Utterson is an HVAC Engineer with AJT and Associates in Huntsville, Ala. During this research, he received support from ASHRAE through an Undergraduate Grant-In-Aid and a Graduate Grant-In-Aid. He received his bachelor and master degrees in mechanical engineering from the University of Missouri, Rolla. **Harry J. Sauer, Ph.D., P.E.,** is Professor of Mechanical and Aerospace Engineering at the University of Missouri-Rolla.

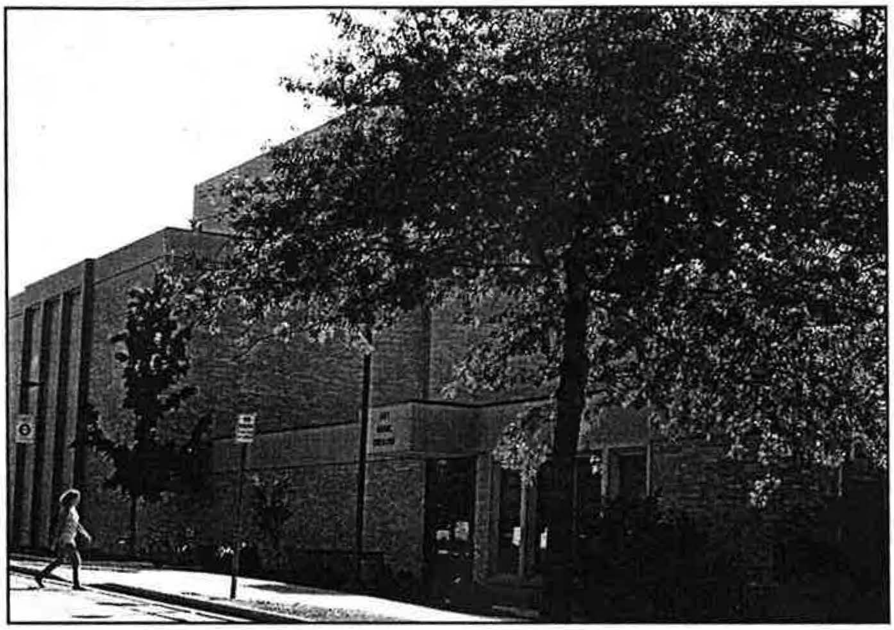

Fig. 1: Castleman Hall music wing.

The goals of our research were to instrument a VAV building on the campus of the University of Missouri-Rolla (UMR) with IAQ measuring devices, to investigate methods of ventilation control on VAV systems, to modify the building control system to achieve ventilation control, and to observe and analyze IAQ before and after system changes. The IAQ measuring devices used for this study include a total volatile organic matter (VOM) sensor, a real-time dust sensor and CO_2 sensors. Other measurements include temperature and relative humidity at various locations, outside airflow and space pressure.

In addition to these parameters, the building was studied in normal operation, as well as when the economizer dampers were used to maintain the minimum outside airflow rate. As expected, CO_2 and VOM levels decrease when the outside air ventilation rate increases.

Additionally, methods of controlling outside air on a VAV building were studied using computer simulation. The results indicate that building performance can be improved when the economizer is controlled by the ventilation rate when ambient air conditions call for operation with minimum outdoor air.

Castleman Hall

Constructed in 1990, Castleman Hall houses the music, theater and fine arts departments for UMR. Located inside this building are offices, classrooms, music practice rooms, a large theater and stage, and instrument storage rooms. Six different air handlers are used in the building. Three constant volume (CV) systems serve the theater, basement, and work room. Three VAV systems serve the alumni center, music wing, and front lobby. For the purpose of this study, only the music wing VAV system is evaluated. The music wing of Castleman Hall is displayed as *Figure 1*.

The HVAC system used for the music wing is a VAV system with two fans (see *Figure 2*). The supply fan speed is controlled to maintain a supply duct static pressure of 1.75 in. of water (435 Pa). The return fan is set to turn at the same speed (RPM) as the supply fan. There is no direct space pressure control in this arrangement.

Figure 3 shows the arrangement of equipment used on the air handler for the music wing. Included on this figure is the location of the sensors used in this study. A hot-film anemometer, x-grid pitot tube anemometer, and CO_2 sensor are mounted approximately 10 ft (3 m) before the minimum outside air damper and economizer inlet damper. Particulate concentration is measured before entering the return fan and after returning from the space. Finally, both the VOM sensor, a second CO_2 sensor and a temperature/relative humidity sensor are mounted after the return fan. Each of these devices measure continuously.

Because Direct Digital Control (DDC) is available on this building, most modifications to the control scheme are possible through software changes. The control system utilizes a finite time difference proportional feedback control, proportional integral (PI) feedback control and proportional integral differential (PID) control. When direct ventilation control is used on this system, the PID controller receives a signal from the outside air duct-mounted anemometer only.

For most of the measurements in Castleman Hall, automatic data acquisition is accomplished with a PC and data acquisition board. This system allows for eight channels of analog voltage inputs, with a sampling rate of roughly one sample per second (for all eight channels). The analog to digital conversion provides 16 bits of resolution over a +/– 5 volt range. This device is well-suited for measuring small voltage differences encountered with pressure sensors and the particulate sensor.

Data acquisition was controlled by software that enables the user to program the sampling time. For most of this study, the computer was programmed to sample every half hour on the half hour. Data was stored directly on the computer's hard drive.

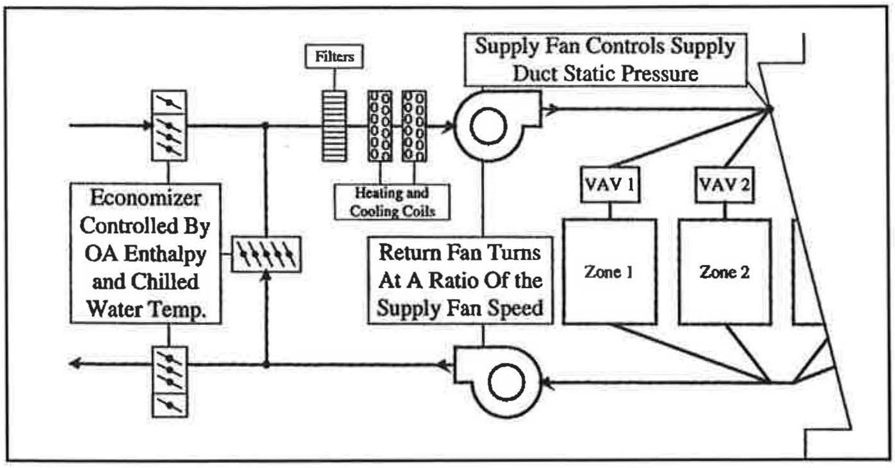

Fig. 2: VAV system layout.

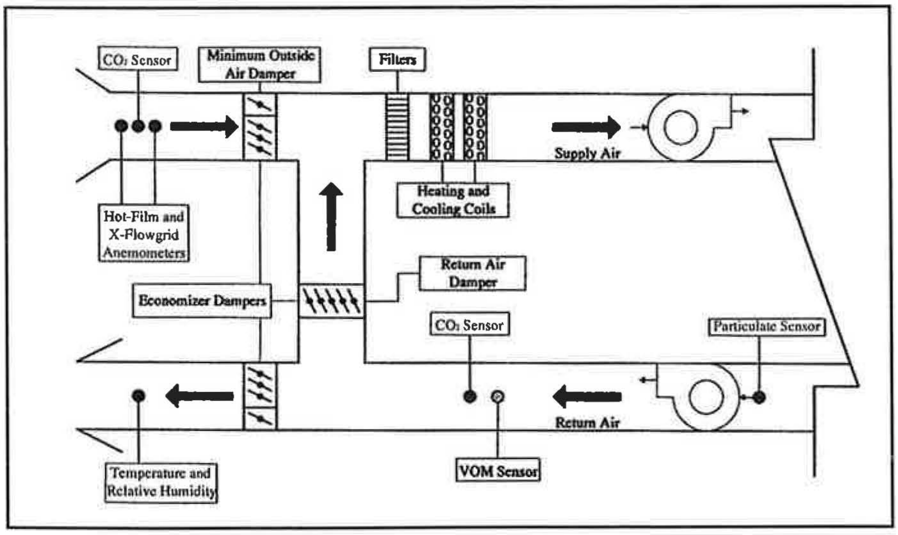

Fig. 3: Equipment layout.

Ventilation Control on VAV Buildings

Direct control of ventilation on VAV buildings has been successfully tried in the past. Janu, et al.[2] describe a control scheme which utilizes the economizer set of dampers to control outside air based on CO_2 concentration and the minimum ventilation requirement. Graves[3] describes another system of ventilation control that utilizes mixed air plenum pressure and the return air damper to maintain the minimum ventilation requirement.

For this study, the economizer is controlled to provide a constant ventilation rate by opening and closing the economizer damper. If the economizer can be used to save energy while maintaining minimum ventilation requirements, the system behaves as usual. However, if the outside airflow rate tends to go higher or lower than the minimum requirement during non-economizing times, the economizer damper is modulated to maintain minimum required outside air. The logic for this control scenario is displayed in *Figure 4*.

When the outside air temperature lies between the supply air temperature and the set point temperature (a temperature which is several degrees below the return air temperature to account for potentially higher humidity in the outside air), the economizer will open up fully to save cooling costs. When the outside air temperature is above the set point air temperature, the economizer will modulate to maintain minimum outside air. If the outside air temperature falls below the supply air temperature, the economizer modulates to maintain minimum outside air and attempts to raise the mixed air temperature to that of the supply air temperature.

In addition to making control system changes, the dampers must also be modified to enable full control. For Castleman Hall, the minimum outside air damper was manually closed, and the economizer damper and return air damper were modulated for control. In a new building, a minimum outside air damper would not be needed.

When these changes were implemented for a sample case, the energy savings occur mainly in the summer months when large zone load fluctuations during the day can result in corresponding fluctuations in economizer

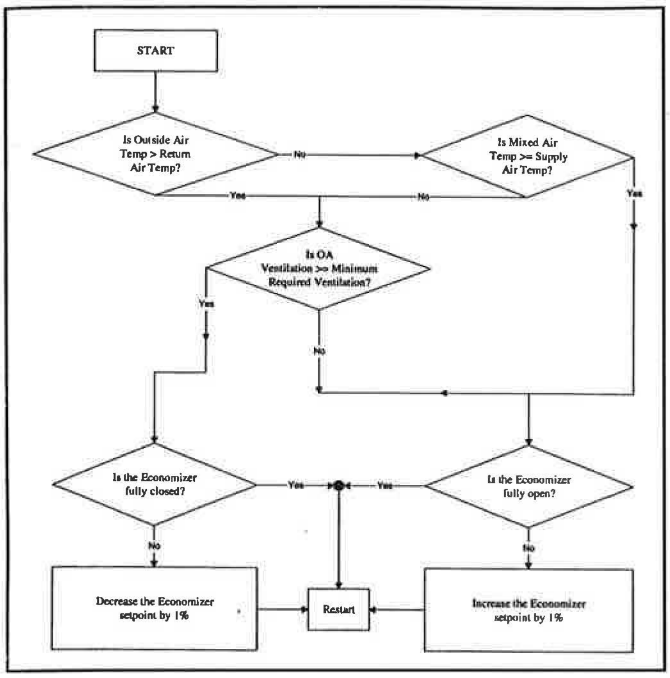

Fig. 4: Control scheme for economizer controlled ventilation.

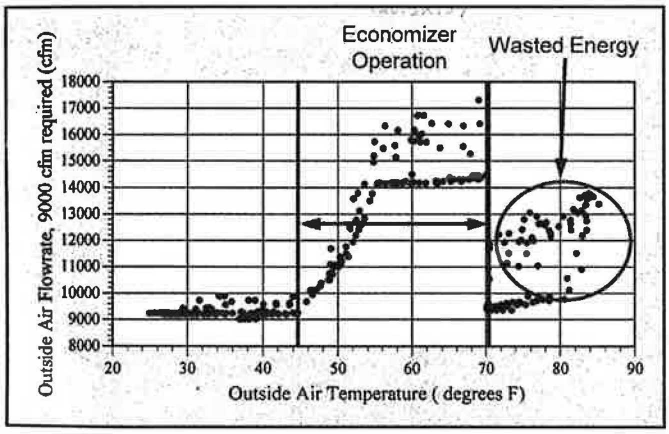

Fig. 5: Computer simulated typical ventilation trend.

damper position and outside airflow rate. *Figure 5* displays a typical ventilation trend for a VAV system. For this sample case, the economizer set point and supply air temperatures were 70°F and 55°F (21°C and 13°C), respectively. If outside air temperature is between 70°F and 55°F (21°C and 13°C), the economizer is fully open. Between 55°F and 45°F (13°C and 7°C), the economizer modulates to maintain 55°F (13°C) mixed air. At temperatures above 70°F (21°C) and below 45°F (7°C), the economizer damper is closed. Air ventilates solely through the minimum outside air damper in this temperature range. For this example, the minimum required outside air is 9000 cfm (4200 L/s). During non-economizer operation, ventilation above the minimum requirement represents wasted cooling or heating energy.

If the economizer control system is modified as outlined earlier, the trend of *Figure 6* can be obtained. With the direct ventilation control, energy is no longer wasted, as was indicated for

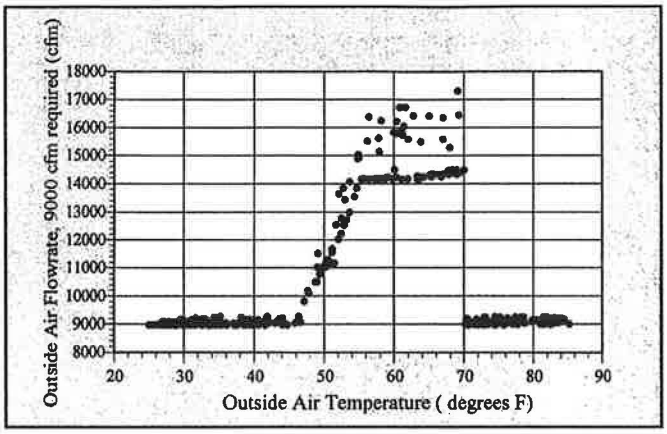

Fig. 6: Ventilation controls the economizer (computer simulation results).

the operation of *Figure 5*. Simulation results indicate that for this example, between 1.7 and 3.3% of the annual energy bill can be saved utilizing minimum ventilation control.

IAQ Measurements With and Without Direct Ventilation Control

The main purpose of instrumenting this building with IAQ measuring devices was to determine and examine any changes that occur after the building control system has been modified. Data collection took place over a two-week period. In the first week, the building control system was modified to maintain 3200 cfm (1500 L/s) (34% of the peak supply air required during this period) of outside air by modulating the economizer dampers. With the limited accuracy and stability of the electronic manometer at very low flow rates, full-range energy-saving economizer control could not be utilized.

During the second week, the system was restored to its regular control scheme with one change: the economizer was not allowed to open. This allowed for an IAQ comparison with the ventilation controlled system data. Outside air quantities during normal operation tend to be around 1800 cfm (850 L/s) (17% of the peak supply air).

The data displayed on *Figure 7* were from the week in which outside air ventilation was controlled to 3200 cfm (1500 L/s). In general, for CO_2, the concentration tracks building occupancy. After lunch and dinner breaks, there are corresponding drops in CO_2 concentration. During the evening, CO_2 concentration builds up because the building is occupied late into the night. The VOM reading is less predictable than the CO_2. However, many of the VOM peaks occur at the same time as CO_2 peaks. Because initial testing determined that CO_2 concentrations of 1000 ppm did not register on the VOM sensor, it is apparent that the VOM sensor is detecting a possible pollutant. Particulate trends do not seem to follow any occupancy-related trend. When the air handler is off, the particulate sensor does not detect particulate.

Figure 8 (which displays data from a week in which outside air ventilation was not directly controlled) displays trends similar to *Figure 7*. The main difference between *Figure 7* and *8* is the magnitude of the peak concentration levels. The peaks during the direct outside air control case (*Figure 7*) were lower than in the non-outside air control case (*Figure 8*). This is significant because

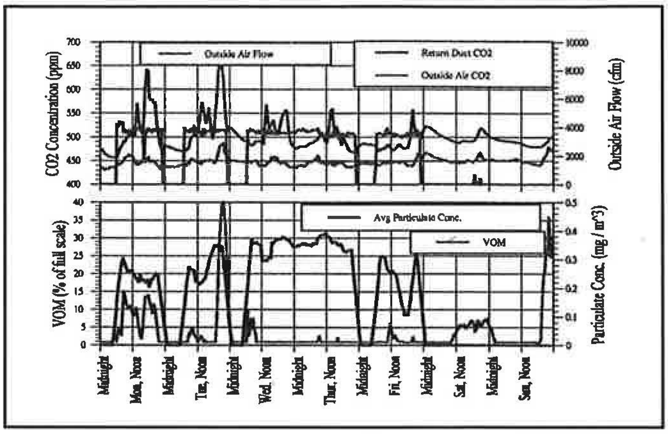

Fig. 7: Data from Sept. 25 to Oct. 1, economizer controls ventilation to 3200 cfm (1500 L/s).

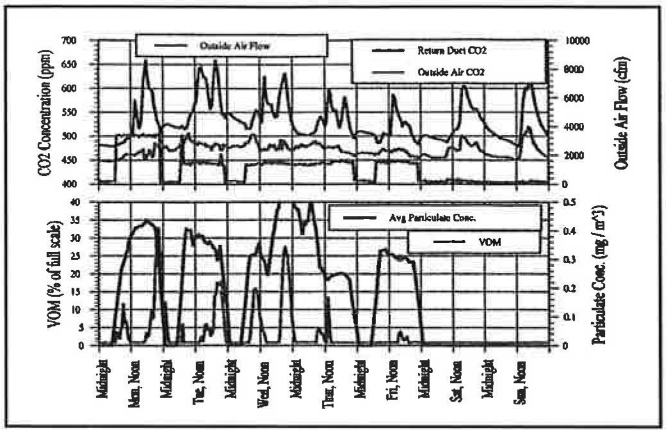

Fig. 8: Data from Oct. 9 to Oct. 15, economizer closed after Monday.

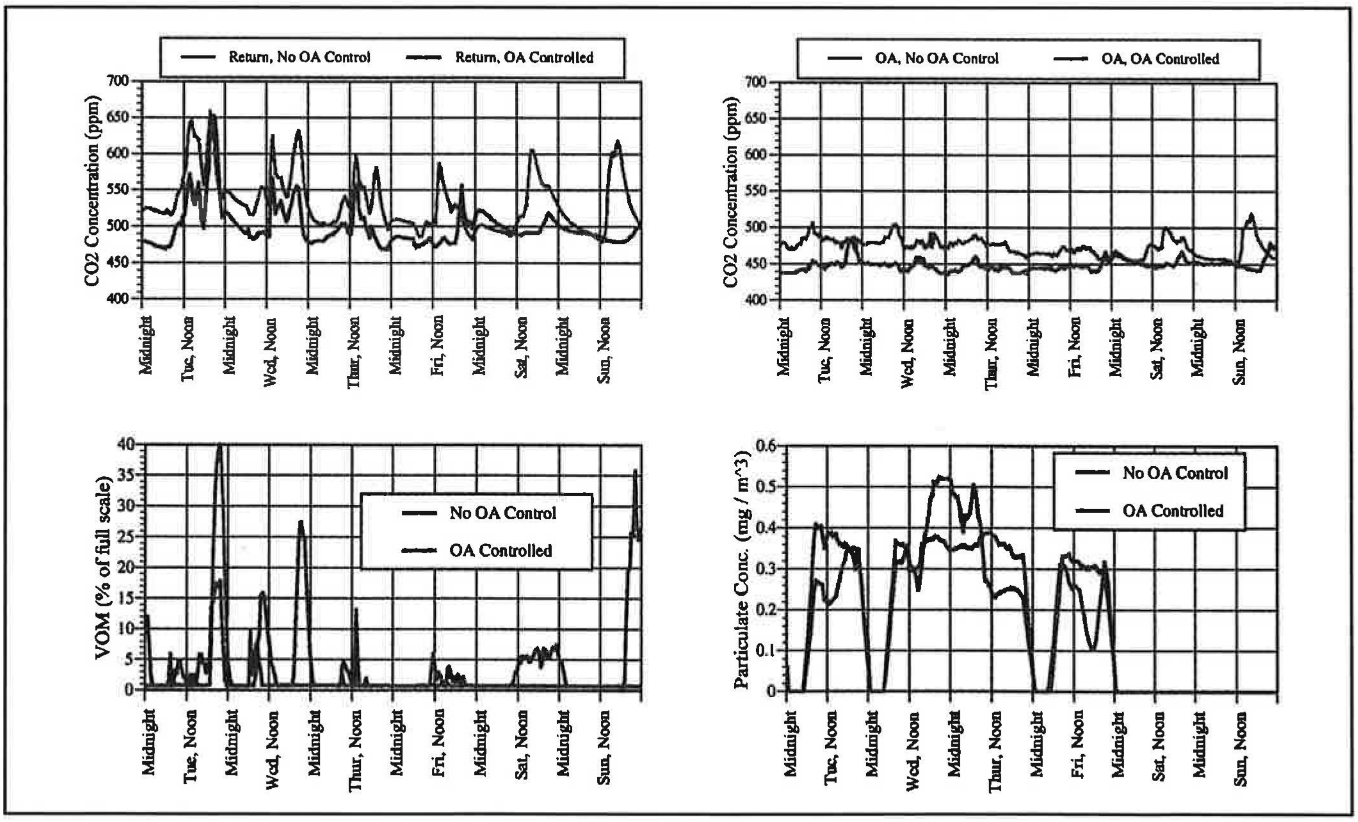

Fig. 9: Direct comparison of IAQ with and without ventilation control.

the scheduled occupancy during both periods was the same.

A closer look at CO_2 concentration on *Figure 9* reveals another noteworthy trend. The outside air duct CO_2 concentration was higher during the non-outside air control case. This was not expected because the ambient level of CO_2 does not vary by amounts seen on these figures. Further investigation revealed that this resulted from a reverse airflow condition in the common outside air plenum that serves both the music wing system and the alumni center system.

Apparently, the alumni center HVAC system (also a VAV system) was *exhausting* through its minimum outside air *intake. Figure 11* displays pictures of the outside air intakes. Air streamers illustrate the air exhausting from the alumni center intake. Because both outside air intakes are located within 10 ft (3 m) of each other, some return air from the alumni center vents into the music wing system. This certainly can cause a potential IAQ problem. This flow can be attributed to interactions among the six air handlers with many open connecting corridors acting as common return plenum.

If the outside air concentration was subtracted from the return air concentration, the return air CO_2 concentration was 7.3 +/– 2.9 ppm higher on average (95% confidence) when ventilation was not

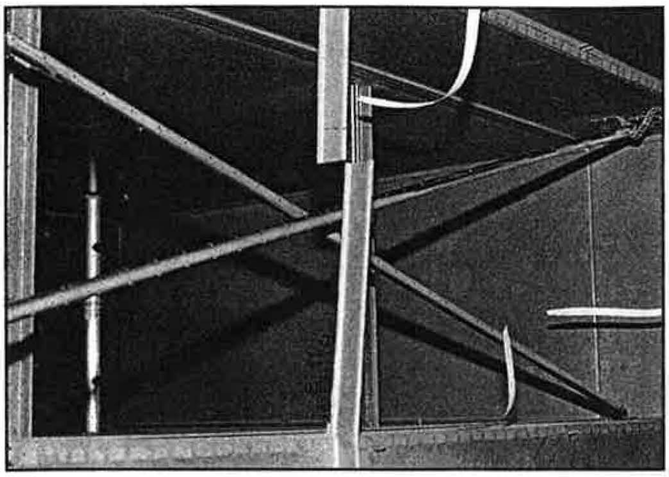

Fig. 10: Outside air intakes for the Music Wing (above) and the Alumni Center (left).

controlled. This trend was expected because the higher ventilation rate associated with the direct outside air control case provides more dilution. This indicates that IAQ improvement is achievable with the modified control system.

Comparison of the two VOM trends produces less conclusive results. VOM spikes do not appear to be as time dependent as CO_2 (*Figure 9*). Comparing data from the period between Tuesday and Friday (both outside air control schemes), more VOM was detected during the non-outside air control case (average 3.3% versus average 2.5% of full scale). This indicates that some IAQ improvement was achieved.

Particulate trends remain puzzling. During the occupied time, the concentration initially rose to levels that are unacceptable based on Standard 62-1989 and then decreased during the afternoon. Particulate concentration was indicated as zero during the hours when the system was not in operation and there was no airflow past the sensor. As with VOM, particulate concentration was lower on average during the direct outside air control situation (average 0.24 vs average 0.26 mg/m^3).

Space Pressure Measurement

Space pressure was measured in the interior room. The outside pressure port was shielded to minimize the effects of wind. During this test, space pressure was measured every ten minutes throughout a 24-hour period while the economizer was used to directly control ventilation. *Figure 11* is a graph from this data collection. Because space pressure varied erratically, a running average was used to show the general trend of space pressure. The space pressure trend was similar to the pattern for CO_2 concentration.

It should be emphasized that the HVAC control system contains no provision for direct control of building pressure. What building pressure control there is results from the control of the return air fan speed as directly proportional to the supply fan speed.

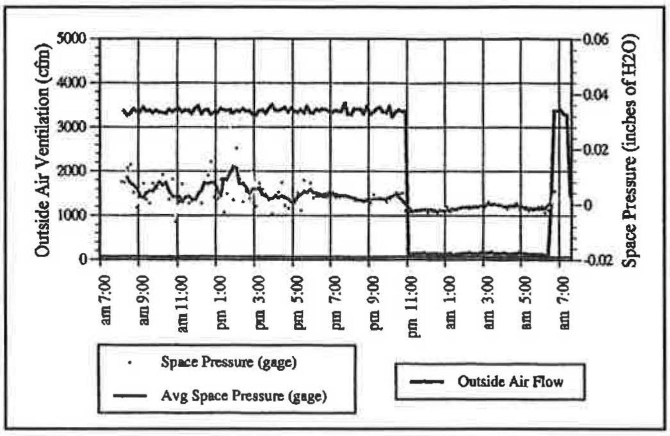

Fig. 11: Space pressure when the economizer controls ventilation.

Conclusions

With relatively simple and inexpensive hardware modifications, outside air ventilation control is achievable on present VAV buildings that currently do not have direct ventilation control schemes. In general, the economizer damper can be used to maintain a constant supply of outside air at all times. Furthermore, this control scheme can be used to save significant amounts of energy while conforming to the requirements of Standard 62-1989.

Castleman Hall displays regular predictable trends for IAQ components. While the VOM sensor appears to detect contaminant on a semi-regular basis, the output is not directly traceable to any human irritant. Although the results of this study are not conclusive in this regard, the use of this device to control ventilation is highly suspect at this time.

Acknowledgments

The authors wish to acknowledge with thanks the support provided to the first author by an ASHRAE Graduate Grant-In-Aid. The authors are also grateful to the university's physical facilities department for their permission and assistance in modifying, instrumenting and monitoring the HVAC system in Castleman Hall.

References

1. ASHRAE, "Ventilation for Acceptable Indoor Air Quality," ASHRAE Standard 62-1989.

2. Janu, G., Wenger, J., Nesler, C., "Outdoor Air Flow Control for VAV Systems,"*ASHRAE Journal*, April 1995, p. 62

3. Graves, Larry R., "VAV Mixed Air Plenum Pressure Control," *Heating, Piping, Air Conditioning*, August 1995, p. 53. ■