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INSTRUMENTATION AND DATA ACQUISITION FOR MONITORING EFFECT OF SYSTEM OPERATION ON INDOOR AIR QUALITY

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ABSTRACT

The indoor air quality of an actual variable air volume (VAV) heating, ventilation and air conditioning (HVAC) system in a building on the campus of the University of Missouri, Rolla has been analyzed, modified, and monitored. Components measured include temperature, relative humidity, CO_2, volatile organic matter (VOM), particulates, outside air flow rate, and building pressure. In addition to these parameters, the building is studied in normal operation, and for operation when the economizer damper was controlled to maintain minimum outside air. As expected, CO_2 and VOM decrease when the outside air ventilation rate increases. Additionally, several methods of controlling outside air on a VAV building were studied using computer simulation. These methods include economizer control, return air damper control, and return fan control of outside air. Results indicate that building performance can be significantly improved when an additional control loop is added for either outside air or return air damper, or both, control based on a signal related to the flowrate of the incoming outside air.

INTRODUCTION

The study of Indoor Air Quality (IAQ) in buildings has increased in recent years. Acceptable IAQ is maintained if there are no known harmful contaminants in the air, and if a substantial majority of people exposed do not express dissatisfaction. Unacceptable IAQ has led to an increased number of complaints of headaches, eye and throat irritation, and breathing difficulties. These symptoms, called sick building syndrome (SBS), have been blamed on construction materials such as insulation, carpet glues, building furniture and on undesirable ventilation air. There are two main reasons engineers and building managers are concerned about such problems. First, SBS does cause a loss in worker productivity. Second, if occupants in a building experience IAQ related problems, the designers and architects may be held financially liable for poor building design. The legal ramifications of not properly designing for IAQ has been documented by Bas (1995). Besides the legal ramifications for maintaining adequate IAQ, human productivity is also a factor. Lizardos (1993) states that the cost of conditioning building air is approximately \$2 U.S./sq ft (\$22 U.S./m^2), while the cost of maintaining a productive work force is \$150 U.S./sq ft (\$1600 U.S./m^2).

Because the symptoms of SBS are so widely defined, researchers have attempted to determine what causes IAQ problems in buildings. Jaakkola et al. (1994) cites many studies that have found that incidences of symptoms of SBS are directly related to the amount of outside air ventilation. Small air change ventilation rates allow irritants to increase in concentration. ASHRAE (1989) Standard 62-1989 provides methods of addressing this problem. This standard specifies minimum ventilation rates per occupant for different space types. For instance, office spaces require 20 cfm/person (10 L/s/person). IAQ measurements are required by this standard only when space usage changes or complaints occur. There are several problems with this approach to maintaining IAQ on VAV buildings. In particular, in peak cooling times, with a closed economizer, outside air ventilation varies with the cooling load. When a VAV building is in reheat, the reduced air supply causes the outside air ventilation to hit a minimum (Roberts (1991)). If the test and balance (TAB) engineer sets the minimum outside air damper during peak cooling, ventilation levels fall below the minimum requirements when cooling loads are small. This could result in IAQ problems because of lack of ventilation. Conversely, if the minimum outside air damper is adjusted when the building is in heating mode, extra outside air will be ventilated in peak cooling times, causing an increase in energy usage. Standard 62-1989 does, however, allow controlling of outside air via CO_2 sensors. By this method, CO_2 concentration is kept below 1000 ppm by dilution with outside air. This method would involve modulating the dampers to control CO_2 level. Energy usage could be minimized further in this method over the ventilation rate method of controlling IAQ. Schell (1995) writes that energy savings result because ventilation is controlled for actual occupancy rather than the designed maximum occupancy. This method however has been subjected to intense scrutiny. Rutkowski (1993) states that CO_2 ventilation control for IAQ does not eliminate the possibility of other building contaminants such as volatile organic compounds (VOC) and dust. Persily (1993) states that while CO_2 is the easiest indoor contaminant to measure, controlling it alone will only eliminate human generated body odors. Furthermore, while CO_2 concentration is usually taken as a single value, actual local concentrations might not be equally distributed. Finally, Persily (1993) states that CO_2 concentrations behave with a delay, so if a large number of people moved into a space, the system would not react quickly enough.

Volatile organic compounds (VOCs) are also considered detrimental to IAQ. Huza et al. (1995) describes VOCs as vaporous contaminants. VOCs are compounds that evaporate from products in which solvents or adhesives are used. Human bioeffluent is considered to be a VOC. A total VOC concentration of between 3 and 25 mg/m^3 can cause irritation such as headaches. Judson (1995) includes fumes from lacquer, cleaning solvents, perfumes, CO_2 and CO in a list of VOCs that are detectable. Furthermore, Judson argues that VOC sensors cost less than CO_2 sensors, require less maintenance than CO_2 sensors, and directly measure an aspect, rather than an indicator, of IAQ. Also, both VOC and CO_2 sensor outputs may be used to control ventilation in the state of California. But, as Schell (1995) points out, VOC sensors can not be calibrated. The output of these devices indicate a level of pollution (% of full scale output), not a level of a specific pollutant. Also, these sensors tend to be temperature and humidity affected. While this would not be a problem in a return duct of a HVAC system, outside air mounted sensors might experience problems.

Particulate concentrations are also considered important when evaluating IAQ. Huza states that the National Ambient Air Quality Standards allows exposure limits of **150 ì g/m^3** of particulate over a 25 hour period. In a study conducted by Grot et al. (1991), one parameter monitored continuously was particulate levels. For this study, particle counts were taken for six different particle size ranges. Grot mentions that in the office spaces, dust concentrations did show variation over short periods of time. Jaakkola states that some studies have linked particulate concentrations to sick building syndrome.

One accepted method of preventing IAQ problems is fresh air dilution. This is accomplished by ventilating fresh outside air into the building and exhausting contaminated return air. ASHRAE Standard 62-1989, a standard written into many building codes, requires that at least 20 cfm of outside air be ventilated 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 air flow to individual spaces is modulated to control return air temperature. Similarly, outside air flow changes with the building cooling load. So, when VAV systems without outside air controls are used, the possibility of having an IAQ problem increases.

Direct control of ventilation on VAV buildings has been successfully tried in the past. Janu et al. (1995) describes a control scheme which utilizes a supply duct mounted velocity probe and three CO_2 sensors. Outside airflow is calculated by determining what fraction of the supply air is outside air. Such a complex system was used because "Convoluted duct work limits potential mounting sites and creates poorly developed velocity profiles that make any velocity measurement difficult." Another study in which outside air was controlled (Haitas (1995)) utilized a supply duct mounted velocity probe, and three temperature sensors. Based upon the velocity signal, the exhaust fans were set to maintain minimum outside air, and a slight positive pressure.

The goals of the research reported herein have been to investigate methods of ventilation control on VAV systems, modify the building control system to achieve ventilation control, observe and analyze IAQ before and after system changes, investigate the energy saving potential of ventilation control, and develop a list of recommendations for improving IAQ and energy usage on VAV buildings. Ventilation control signifies maintaining the desired minimum amount of outside air during all occupied periods while providing for economizer operation at appropriate outside air conditions. The IAQ measuring devices used for this study include a total volatile organic matter sensor (VOM), a real time dust sensor, and CO_2 sensors. Other measurements include temperature and relative humidity at various locations, outside air flow from a hot-film anemometer and pitot tube anemometer, and space pressure.

METHODOLOGY

Constructed in 1990, Castleman Hall houses the music, theatre, and fine arts departments of the University of Missouri-Rolla (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. In this study, only the music wing VAV system was evaluated. Figure 1 provides a general view of this section of the building as well as the zone layout. VAV boxes are used for most of the 33 rooms. Most rooms in this part of Castleman Hall are exterior zones. All rooms have exterior roof area, and many of the zones have exterior walls. Only the offices have windows.

The HVAC system used for the music center 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 inches of H_2O (436 Pa). The return fan is set to turn at the same speed as the supply fan. There is no direct space pressure control in this arrangement. Because this air handler utilizes direct digital control (DDC), an outside air anemometer can be included as an input. Figure 3 displays a simple look at the arrangement of equipment used on the air handler for the music wing. Included with this figure is the location of the equipment used in this study. Because DDC is available on this building, most modifications to the control scheme were 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.

Various methods of controlling outside air were first investigated using computer simulation prior to changing Castleman Hall's control system. The simulation program, outlined in Sauer (1992) and Delp (1991), determines space pressures, duct air flows, and energy usage for fans as well as for heating and cooling. By making modifications to the program, most control schemes can be evaluated. One damper control scheme (ECONO System) utilizes the total economizer control. The maximum intake, return, and maximum exhaust dampers are all controlled by the same signal. The economizer, controlled by the outside air flow signal, opens as necessary to increase the amount of outside air to desired minimum level. If minimum ventilation requirements are being met, the economizer behaves as usual to save energy by using the appropriate balance of outside and return air as dictated by a mixed air temperature signal. However, if the outside air quantity is higher or lower than the minimum requirement during non-economizing times, the economizer dampers are modulated to maintain the desired minimum amount of outside air. Figure 4 displays of flow chart of this control scheme. When the outside air temperature is between the supply temperature and return air temperature, the economizer will open fully to reduce mechanical cooling requirements. When the outside air temperature is above return air temperature, the economizer will modulate to maintain minimum outside air. When the outside air temperature falls below the supply air temperature, the economizer modulated to maintain minimum outside air and attempts to raise the mixed air temperature to the supply air temperature.

The first goal of the data collection was to observe whether or not the system was operating properly prior to modifying the control strategy. The next step in the data collection was after the change in the building control system. Figure 5 displays a schematic of the new control scheme. The control scenario is similar to the economizer control scheme mentioned previously. Basically, the economizer modulates to maintain minimum desired outside air. The last part of the data collection involved studying the effect of changing the control system on space pressure. For both the standard operating system and the ventilation controlled system, building pressure was measured with a simulated full load (VAV boxes fully open) and with a heating load (VAV boxes closed to 50% of maximum flow). Additionally, pressure is monitored extensively over a full day for the standard operation system and the ventilation controlled system. These results are compared with computer simulation results of the same situations.

The economizer controlled outside air scenario (ECONO System) provides a constant ventilation rate by opening and closing the economizer damper. As previously mentioned, the logic for this scenario is displayed in Figure 4. For the ECONO System, there are two ways of approaching component changes. One such method is to close up the minimum outside air damper, thereby making the economizer damper the sole path for intaking outside air. A second method of making component changes for the ECONO System is to increase the return air damper size only. An increase in the return damper size translates into more outside air controllability.

DATA ACQUISITION

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Carbon Dioxide Measurements. Carbon dioxide is measured in the return air stream and the outside air stream (see Figure 3) continually. These devices provide an analog current output that corresponds to the 0 - 1000 ppm of CO_2. This sensor utilizes infrared absorption which allows for continuous monitoring. For a recently calibrated sensor, accuracy can be expected to be +/- 20 ppm. These sensors are mounted outside the duct in a sealed aspiration box that draws air across the sensor by use the pressure difference between dynamic and static pressure ports.

VOM Sensor. VOM sensor provides an output that corresponds to the total level of VOC in the air. This device consists of a probe that is placed into the return duct air stream (see Figure 3). The manufacturer claims this device measures propane, ethylene, chlorine, CO_2, CO, ammonia, formaldehyde, acetone, as well as many gases. The voltage output on this device can be adjusted for different data acquisition systems. For this application, the maximum voltage is set at 5 volts. Another feature of this sensor is adjustable sensitivity. A dial on this sensor can be turned to increase or decrease the sensitivity of the sensor. The sensor also includes a removable electronic filter which stabilizes the output. This electronic filter was used for all VOM measurements in this study.

Particulate Sensing. Particulate sensing for this study is accomplished with ASHRAE Standard 62-1989 in mind. The sensor used, an industrial dust sensor, provides a continuous concentration reading of particulate in the return duct of the system (Figure 3). This sensor works by detecting light scattering. Particles of the 0.1 to 10 μm range are detected by this sensor. Furthermore, the mass concentration measured by this sensor enables it to measure between 0.01 and 100 mg/m^3 of particulate. Air movement through the sensing chamber is accomplished by a method similar to the CO_2 sensor. A dynamic pressure probe is inserted into the duct facing the air stream. Air then flows through tubing into the sensing chamber. From the sensing chamber, air is drawn back into the return duct through a static pressure port.

Hot-Film Anemometer. The hot-film anemometer was placed near the front of the outside air duct (Figure 3). For this device, air flow velocity is related to the rate of heat transfer from the heated hot-film. Three probes, with two hot-film anemometers each, are placed across the duct cross section. Electronics on each of the three probes give an analog voltage output that corresponds linearly with the velocity. A separate device averages the three outputs and gives an analog 4-20 mA output that is linearly related to the average duct velocity. The measurable velocity range of this device is from 0-2500 fpm (0-12.7 m/s). For Castleman Hall, the lowest velocity achieved in normal operation is around 200 fpm (1 m/s). With the economizer fully open, air velocity is around 1000 fpm (5 m/s). There are disadvantages to using a hot-film anemometer. George (1993) states that thermal anemometers are affected by variations in temperature, pressure, and humidity. An advantage of using the hot-film anemometer is the stable analog output with the electric outputs of this device providing a smooth (non-noisy) signal at low and high velocities.

Pitot Tube Anemometer.Pitot The pitot tube anemometer is a very simple device for measuring duct flows. The device used in this study, the X-Flowgrid, consists of two pipes with an arrangement of ports. On the dynamic pressure probe, a row of ports lie normal to the direction of flow. The static pressure probe has two rows of ports that are arranged to provide a static pressure. Both probes are located near the front of the outside air duct (Figure 3). With these two probes placed across the duct, an average airflow is determined. Because the velocity in the duct varied from 200 to 1000 fpm (1 to 5 m/s), a pressure sensor which reportedly measures pressure differentials as low as 0.0006 inches of H_2O (0.15 Pa) was used. The electric output from this unit is 4-20 mA and was fed to the computer data acquisition system.

EXPERIMENT RESULTS AND ANALYSIS

The experimental results are presented in several parts. First, the building IAQ is analyzed before modifying the building outside air control scenario. Next, IAQ is compared for the outside air control case and the standard operating case. Finally, the building pressure measurement results are investigated.

Initial Data Collection. Before taking data for outside air control evaluation, data were taken to characterize the operation of Castleman's HVAC system and IAQ. As expected, much of the data displayed a time dependent trend. Figure 6 displays the trends for one week in September. The return temperature and humidity trend show large fluctuations throughout the week. What is interesting however is the CO_2 trend. As the week progresses, the peak amount of CO_2 fell. The daily shapes of the profiles were as expected however. Also important is the trend of VOM. Peaks on the VOM corresponded to peaks in CO_2. This is significant because in testing the VOM was not sensitive to CO_2 concentrations under 1000 ppm.

A closer look at an individual day is given in Figure 7. CO_2 concentration seems to build up through the day and into the night. This was expected because Castleman is occupied in the evening hours for band and choral practice. CO_2 drops around 5 p.m. when a dinner break was taken. Also interesting about this plot is the VOM reading. It behaves much like the CO_2 sensor, but without the extreme peak values. Like the CO_2, around 5 p.m., the VOM level drops. One confusing result however, is the particulate concentration. Particulate levels fall when the HVAC system is turned off during night time and weekend hours. Occupancy and building load do not seem to cause a trend.

Actual System Performance Comparison with and without Outside Air Control. Economizer operation for "Free Cooling" was not utilized during this experiment. This allows data from two different weeks to be compared because the system was not purged of contaminants during fully open economizer operation.

The data displayed on Figure 8 was from the week in which outside air ventilation was controlled to 3200 cfm (1510 L/s). CO_2, VOM and particulate all trended similar to the initial data collection. Figure 9, which displays data from a week in which outside air ventilation was not directly controlled, displays similar trends. The one main difference between Figures 8 and 9 was the magnitude of the peaks. The peaks during the direct outside air control case (Figure 8) were lower than in the non-outside air control case (Figure 9).

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] has been documented by [illegible] [illegible] that the cost of continuing training [illegible] is approximately [illegible] while the cost of maintaining a productive work force is [illegible]

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<u>VOM Sensor.</u> VOM sensor provides an output that corresponds to the total level of VOC in the air. This device consists of a probe that is placed into the return duct air stream (see Figure 3). The manufacturer claims this device measures propane, ethylene, chlorine, CO_2, CO, ammonia, formaldehyde, acetone, as well as many gases. The voltage output on this device can be adjusted for different data acquisition systems. For this application, the maximum voltage is set at 5 volts. Another feature of this sensor is adjustable sensitivity. A dial on this sensor can be turned to increase or decrease the sensitivity of the sensor. The sensor also includes a removable electronic filter which stabilizes the output. This electronic filter was used for all VOM measurements in this study.

<u>Particulate Sensing.</u> Particulate sensing for this study is accomplished with ASHRAE Standard 62-1989 in mind. The sensor used, an industrial dust sensor, provides a continuous concentration reading of particulate in the return duct of the system (Figure 3). This sensor works by detecting light scattering. Particles of the 0.1 to 10 μm range are detected by this sensor. Furthermore, the mass concentration measured by this sensor enables it to measure between 0.01 and 100 mg/m^3 of particulate. Air movement through the sensing chamber is accomplished by a method similar to the CO_2 sensor. A dynamic pressure probe is inserted into the duct facing the air stream. Air then flows through tubing into the sensing chamber. From the sensing chamber, air is drawn back into the return duct through a static pressure port.

<u>Hot-Film Anemometer.</u> The hot-film anemometer was placed near the front of the outside air duct (Figure 3). For this device, air flow velocity is related to the rate of heat transfer from the heated hot-film. Three probes, with two hot-film anemometers each, are placed across the duct cross section. Electronics on each of the three probes give an analog voltage output that corresponds linearly with the velocity. A separate device averages the three outputs and gives an

analog 4-20 mA output that is linearly related to the average duct velocity. The measurable velocity range of this device is from 0-2500 fpm (0-12.7 m/s). For Castleman Hall, the lowest velocity achieved in normal operation is around 200 fpm (1 m/s). With the economizer fully open, air velocity is around 1000 fpm (5 m/s). There are disadvantages to using a hot-film anemometer. George (1993) states that thermal anemometers are affected by variations in temperature, pressure, and humidity. An advantage of using the hot-film anemometer is the stable analog output with the electric outputs of this device providing a smooth (non-noisy) signal at low and high velocities.

Pitot Tube Anemometer.Pitot The pitot tube anemometer is a very simple device for measuring duct flows. The device used in this study, the X-Flowgrid, consists of two pipes with an arrangement of ports. On the dynamic pressure probe, a row of ports lie normal to the direction of flow. The static pressure probe has two rows of ports that are arranged to provide a static pressure. Both probes are located near the front of the outside air duct (Figure 3). With these two probes placed across the duct, an average airflow is determined. Because the velocity in the duct varied from 200 to 1000 fpm (1 to 5 m/s), a pressure sensor which reportedly measures pressure differentials as low as 0.0006 inches of H_2O (0.15 Pa) was used. The electric output from this unit is 4-20 mA and was fed to the computer data acquisition system.

EXPERIMENT RESULTS AND ANALYSIS

The experimental results are presented in several parts. First, the building IAQ is analyzed before modifying the building outside air control scenario. Next, IAQ is compared for the outside air control case and the standard operating case. Finally, the building pressure measurement results are investigated.

Initial Data Collection. Before taking data for outside air control evaluation, data were taken to characterize the operation of Castleman's HVAC system and IAQ. As expected, much of the data displayed a time dependent trend. Figure 6 displays the trends for one week in September. The return temperature and humidity trend show large fluctuations throughout the week. What is interesting however is the CO_2 trend. As the week progresses, the peak amount of CO_2 fell. The daily shapes of the profiles were as expected however. Also important is the trend of VOM. Peaks on the VOM corresponded to peaks in CO_2. This is significant because in testing the VOM was not sensitive to CO_2 concentrations under 1000 ppm.

A closer look at an individual day is given in Figure 7. CO_2 concentration seems to build up through the day and into the night. This was expected because Castleman is occupied in the evening hours for band and choral practice. CO_2 drops around 5 p.m. when a dinner break was taken. Also interesting about this plot is the VOM reading. It behaves much like the CO_2 sensor, but without the extreme peak values. Like the CO_2, around 5 p.m., the VOM level drops. One confusing result however, is the particulate concentration. Particulate levels fall when the HVAC system is turned off during night time and weekend hours. Occupancy and building load do not seem to cause a trend.

Actual System Performance Comparison with and without Outside Air Control. Economizer operation for "Free Cooling" was not utilized during this experiment. This allows data from two different weeks to be compared because the system was not purged of contaminants during fully open economizer operation.

The data displayed on Figure 8 was from the week in which outside air ventilation was controlled to 3200 cfm (1510 L/s). CO_2, VOM and particulate all trended similar to the initial data collection. Figure 9, which displays data from a week in which outside air ventilation was not directly controlled, displays similar trends. The one main difference between Figures 8 and 9 was the magnitude of the peaks. The peaks during the direct outside air control case (Figure 8) were lower than in the non-outside air control case (Figure 9). This is significant because the scheduled occupancy during both periods was the same.

A closer look at CO_2 concentration reveals two interesting trends. First, the outside air duct CO_2 concentration was higher during the non-outside air control case. Figure 10 displays the CO_2, VOM, and particulate trends of the two weeks together. Further investigation revealed that this unexpected performance resulted from a reverse air flow in the common outside air plenum shared by the Music Wing and the Alumni Center HVAC systems. Streamers attached to the outside air dampers clearly showed that the Alumni Center system was exhausting through its minimum outside air intake, probably due to interaction among the six air handlers with corridors with open doors serving as unintended intercooonecting ducting.

The second and most significant trend was the increased CO_2 concentration in the return duct with the original system. This trend was expected because the higher ventilation rate associated with the direct outside air control case provides for more dilution. This performance provides another indication that improvement in IAQ performance was achieved with the new control scheme.

Comparison of the two VOM trends produces less conclusive results. VOM spikes do not appear to be as time dependant as CO_2 (Figure 10). 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 the desired IAQ improvement was achieved.

Particulate trends remain puzzling. During the hours when the system was not running, the particulate concentration falls to 0.0. During the occupied time, the concentration rose to levels that are unacceptable based on ASHRAE Standard 62-1989. Like VOM, particulate concentration is lower on average during the direct outside air control situation (average 0.24 vs average 0.26 mg/m^3).

During the building pressure testing, space pressure was measured every ten minutes throughout a 24 hour period for the directly controlled outside air and non-controlled outside air cases. Figure 11 shows data from a non-controlled outside air day. Because space pressure varied erratically, a running average was used to show the general trend of space pressure. In general, the space pressure trend was very similar to CO_2. As the building occupancy and cooling load increase, so does space pressure. This trend was predicted by the VAV simulation program.

The actual performance for the direct controlled outside air case is shown in Figure 12. This trend did not match the computer predicted trend. One possible explanation for this is the difference in weather for the two measurement days. Additionally, the data was taken on different days of the week, when scheduled occupancies were not the same. The same trend for the rise and fall of pressure does occur for the two graphs however (Figures 11 and 12).

CONCLUSION

Outside air ventilation control is achievable on present VAV buildings that do not have direct ventilation control schemes. In general, independent control of either the return air damper or economizer damper can be used to maintain the desired minimum supply of outside air (without oversupplying) during non-economizer operation as well as provide for "free cooling" with economizer operation at appropriate outside air conditions. Furthermore, as previously reported [Sauer (1995)], these control schemes can be utilized to save significant amounts of energy while conforming to the requirements of ASHRAE Standard 62-1989.

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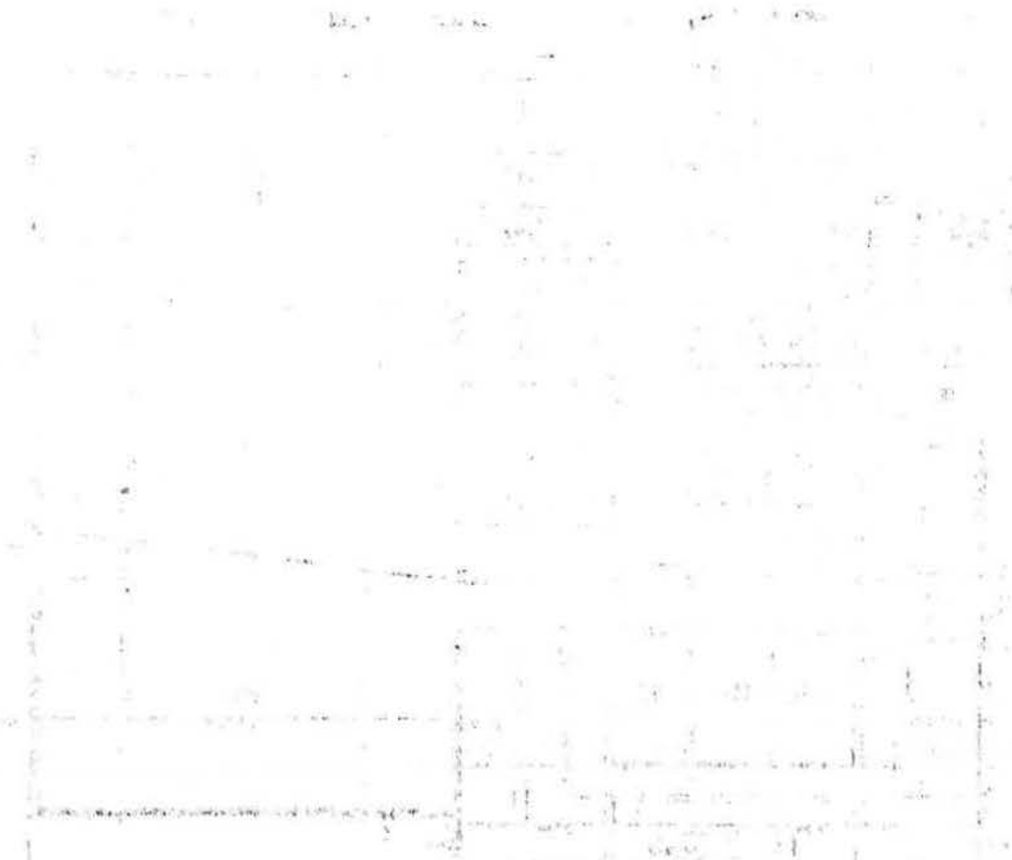
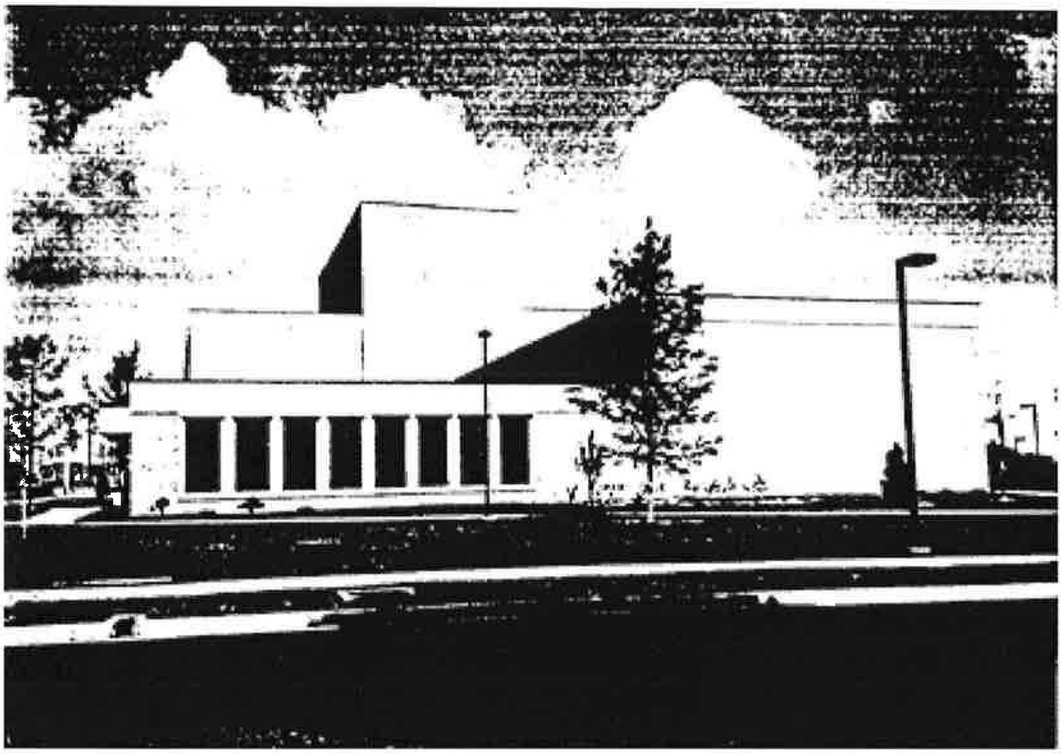
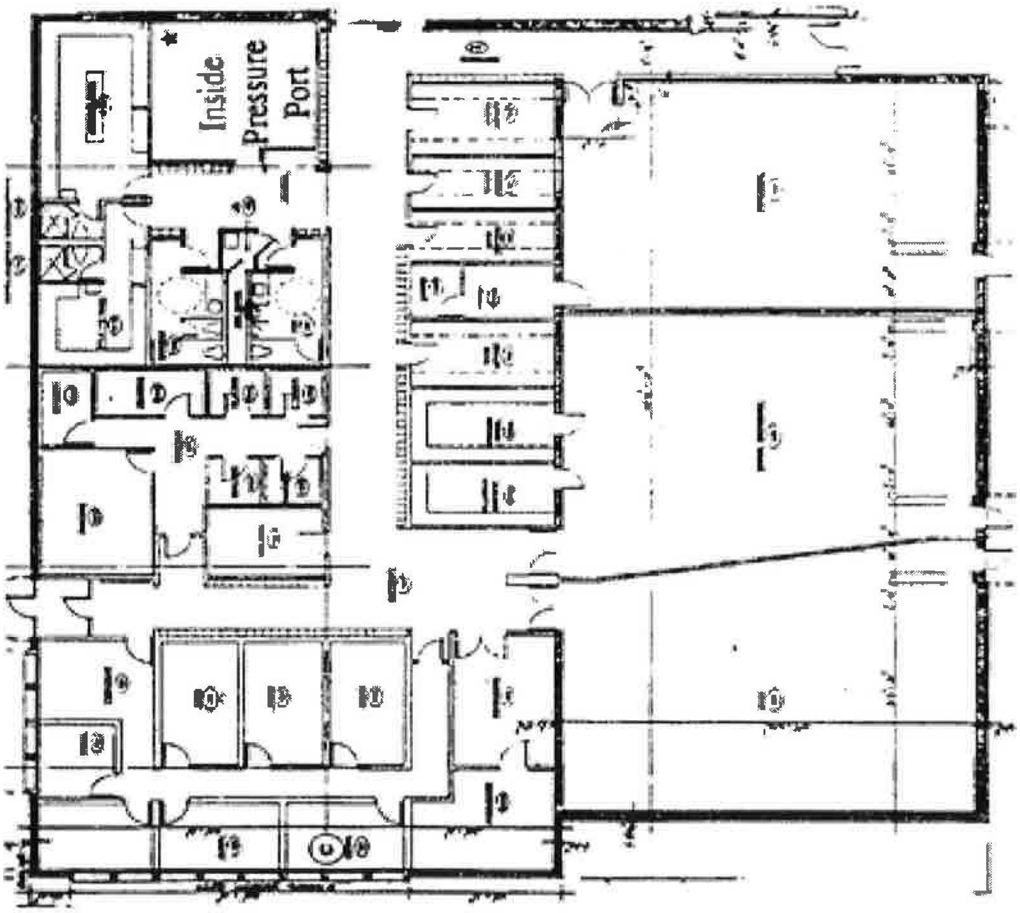





Inside Pressure Port

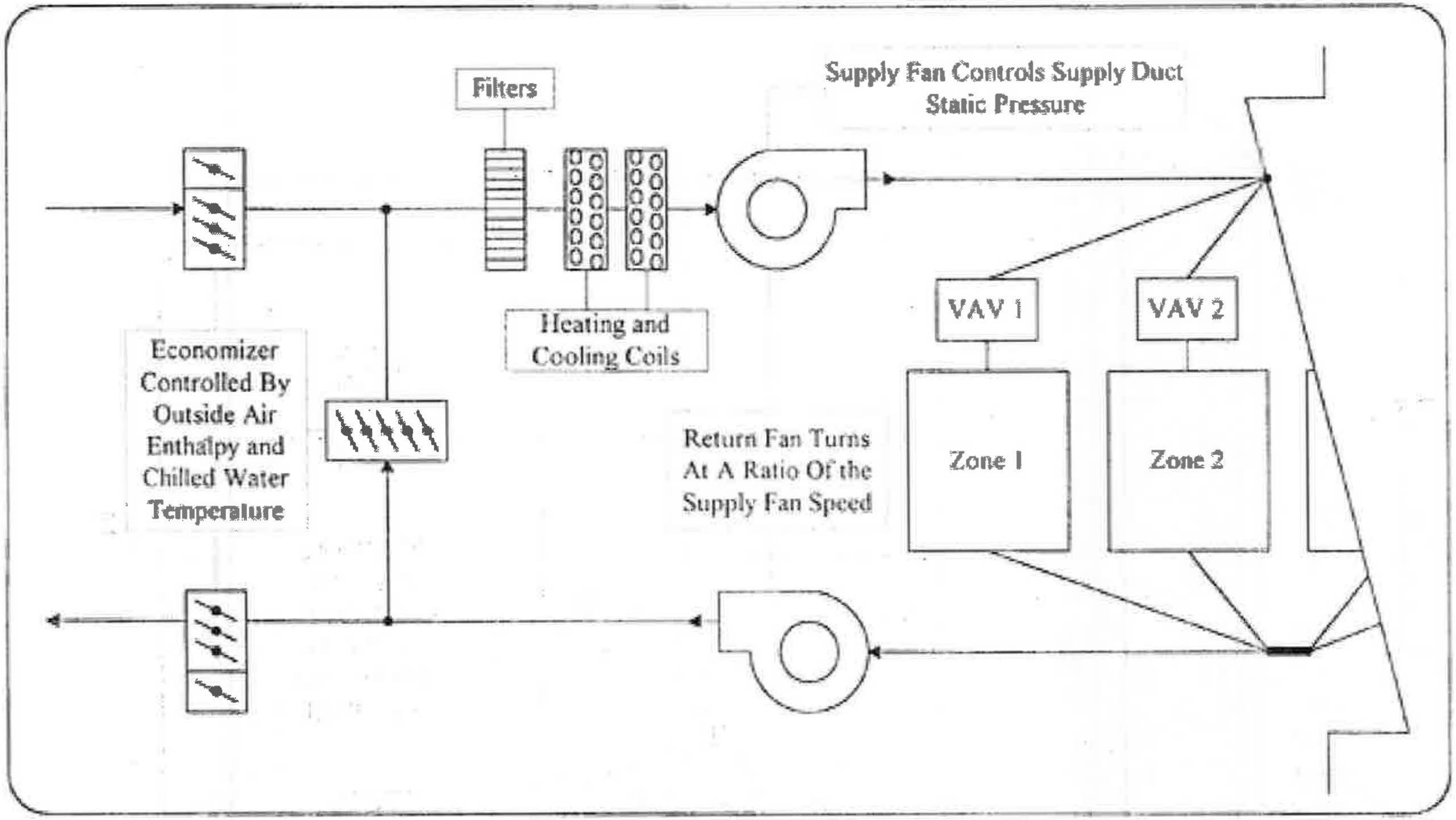


Fig. 2 - Basic Control Method for Castleman Hall HVAC System

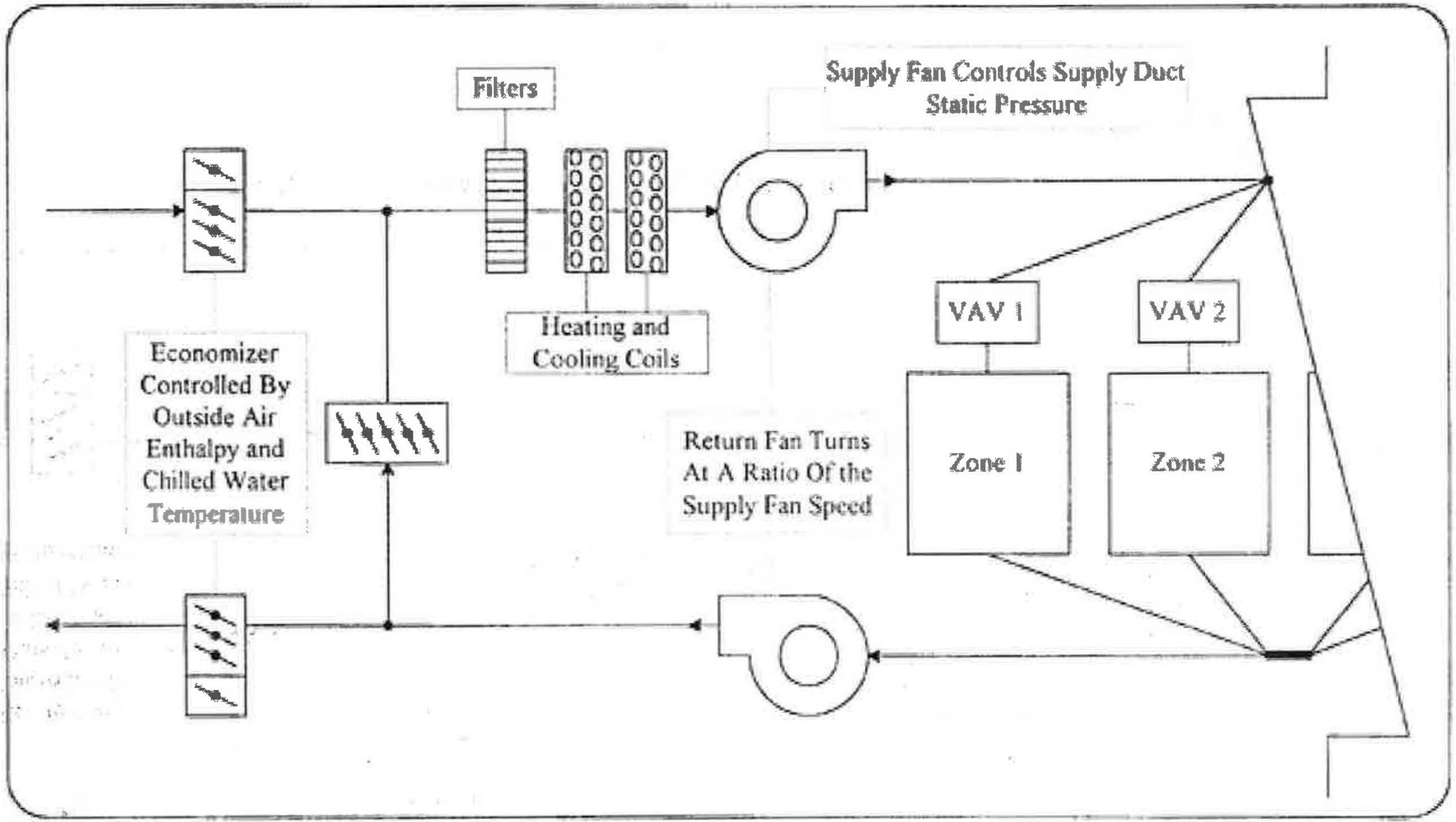


Fig. 2 - Basic Control Method for Castleman Hall HVAC System

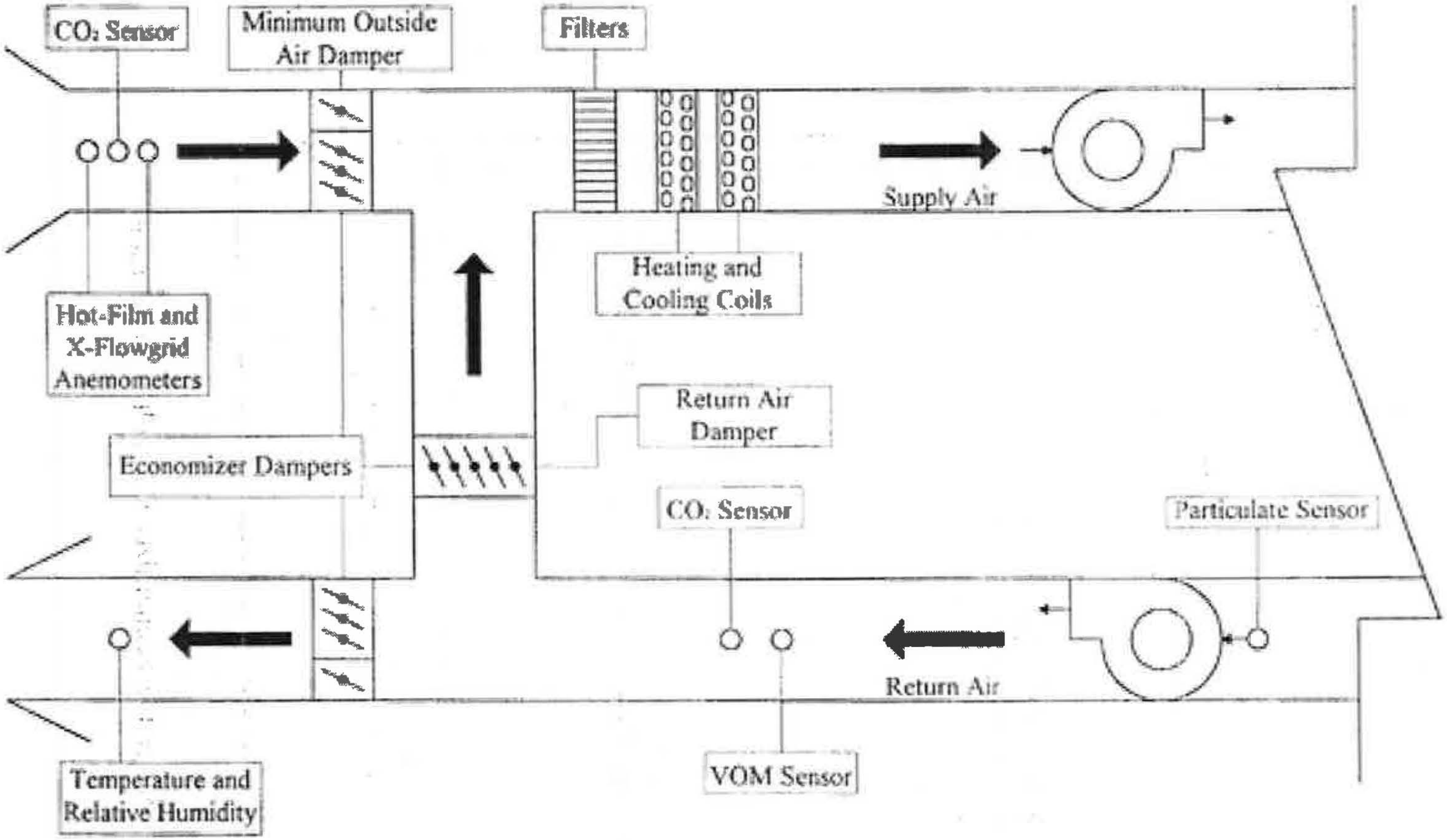


Fig. 3 - Castleman Hall Mechanical Equipment Layout

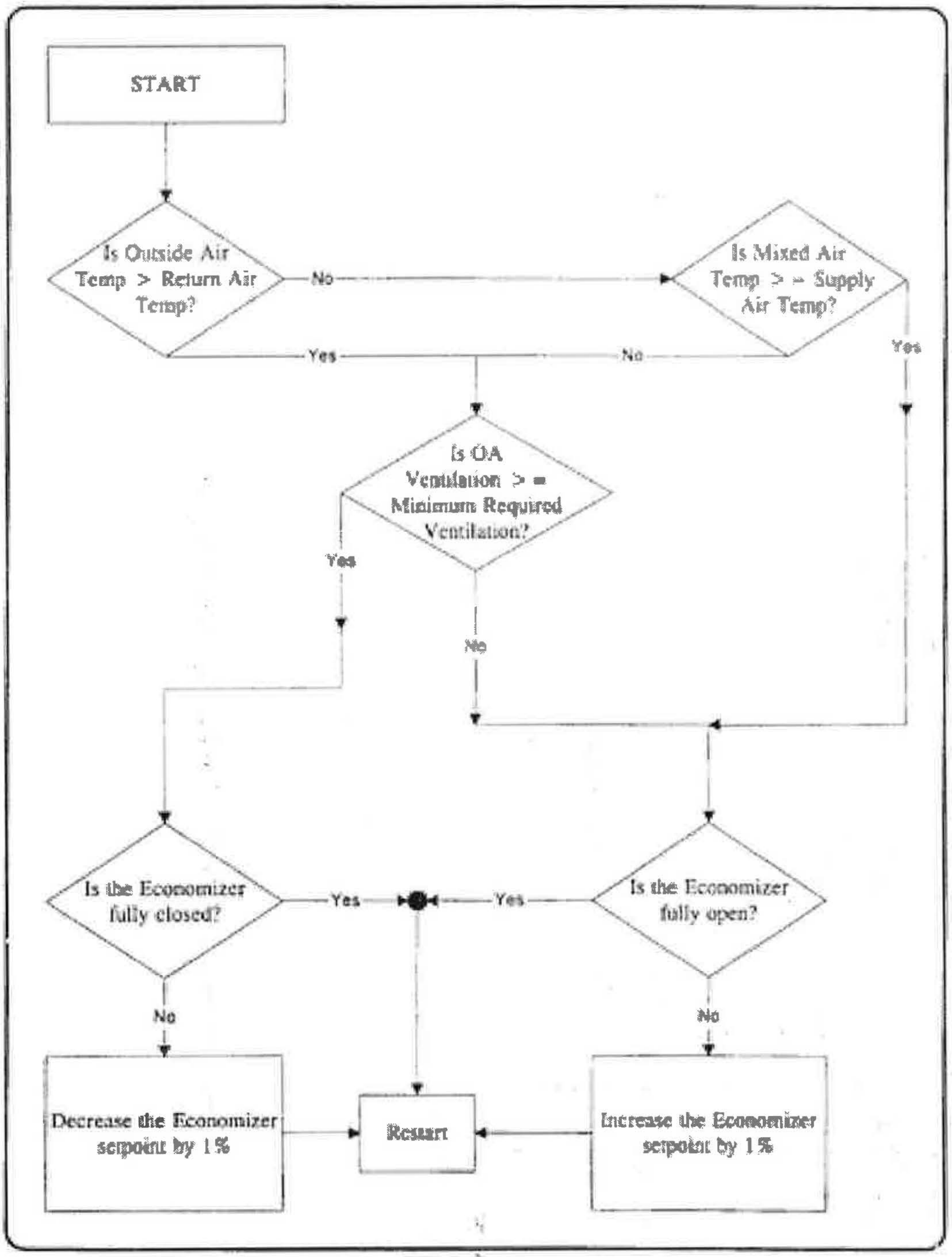


Fig. 4 - Control Scheme for the Economizer Controlled Ventilation

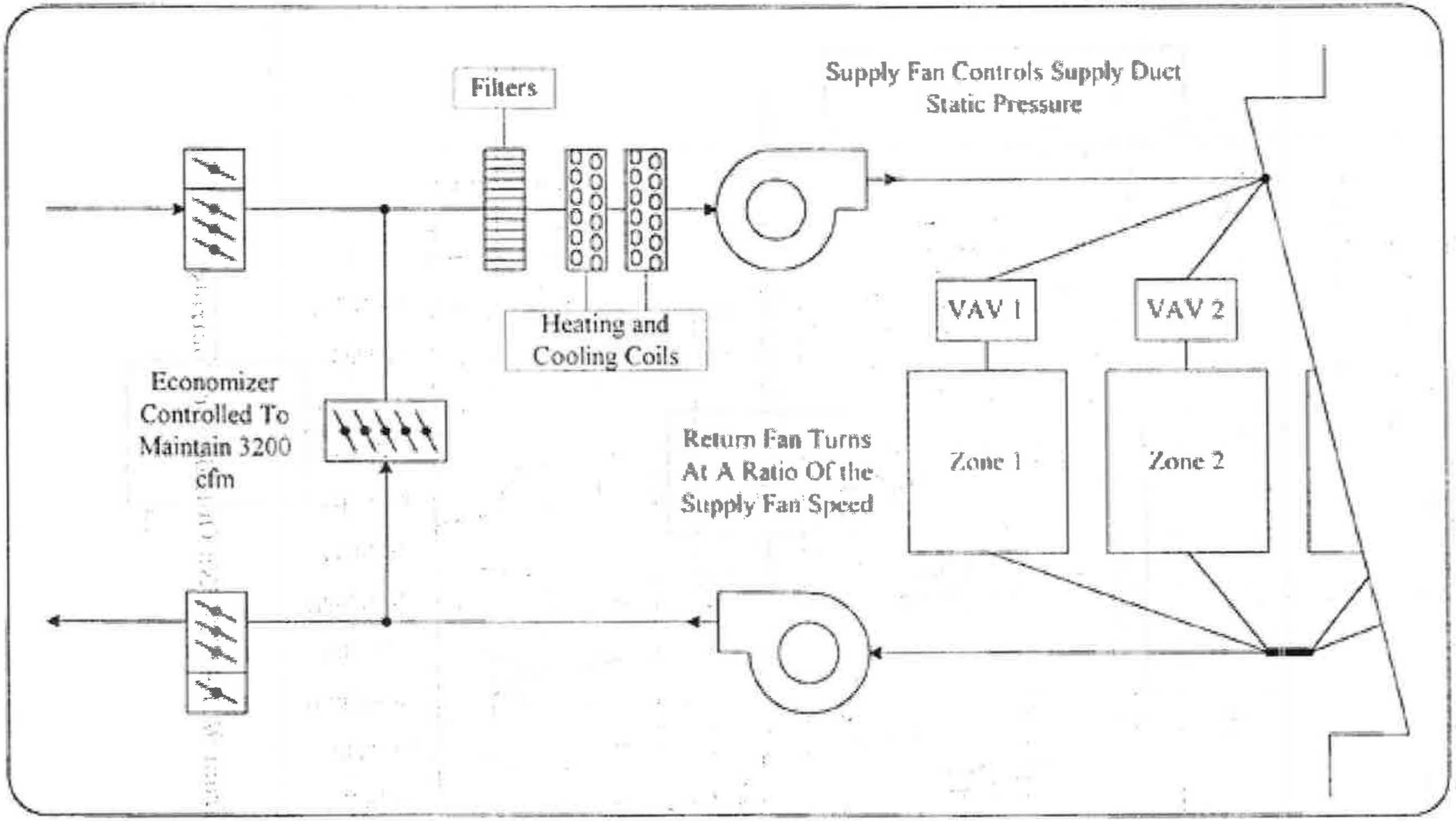


Fig. 5 - Castleman Hall Modified HVAC System Control Method

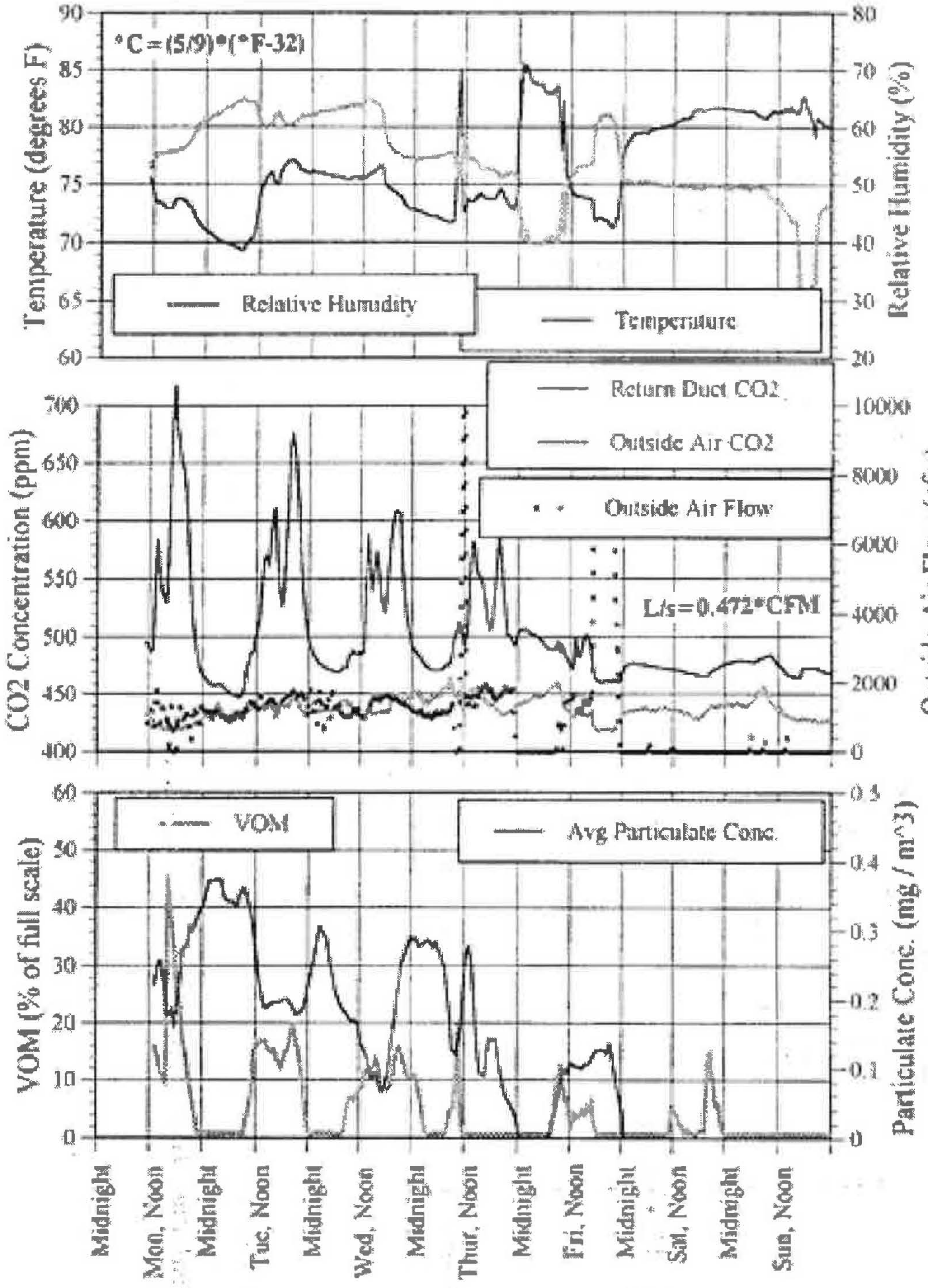


Fig. 6 - Data from 9/11 - 9/17, No Outside Air Controls

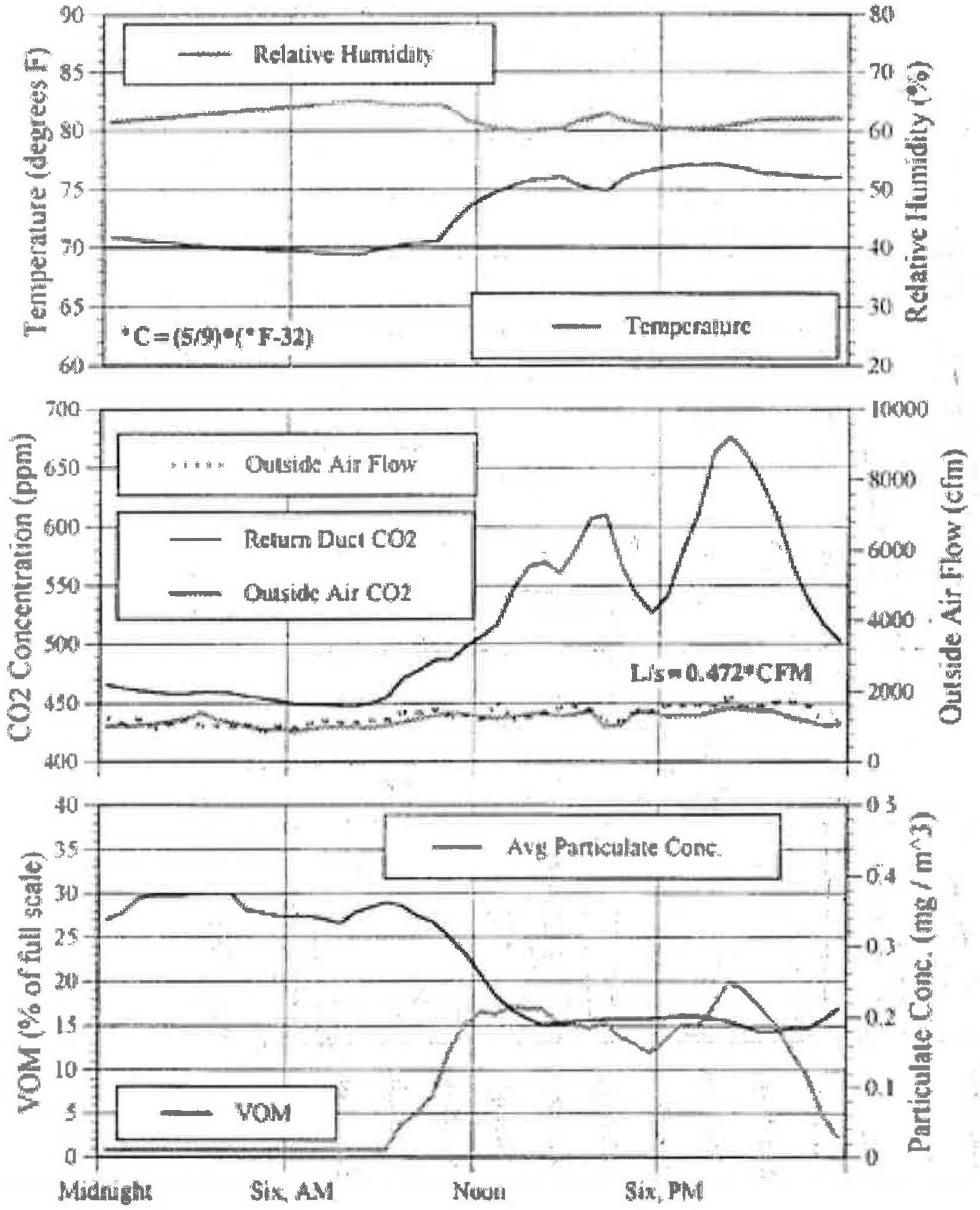


Fig. 7 - Data from Tuesday 9/12, No Outside Air Controls

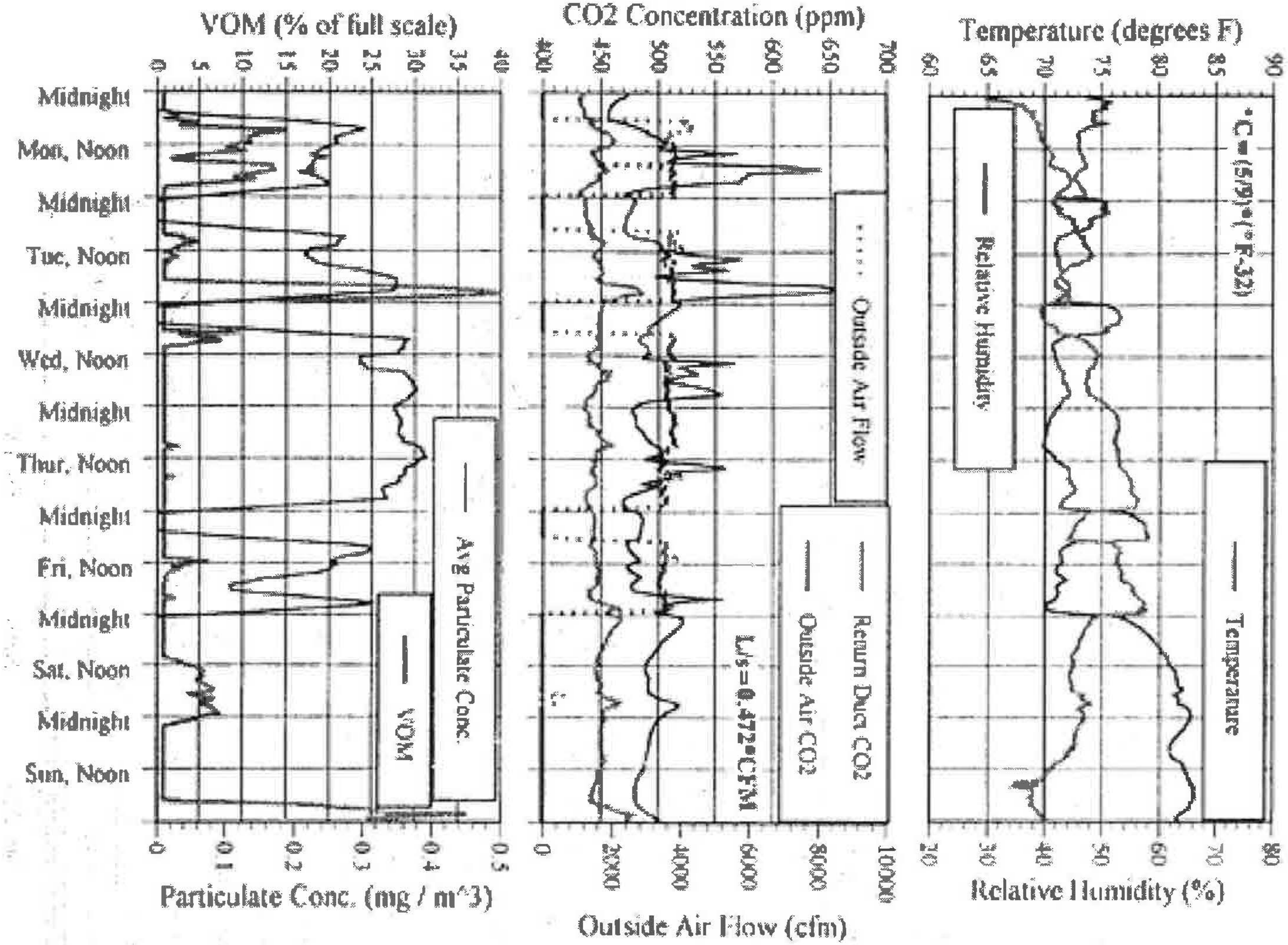


Fig. 8 - Data from 9/25 - 10/1, Outside Air Controlled Economizer

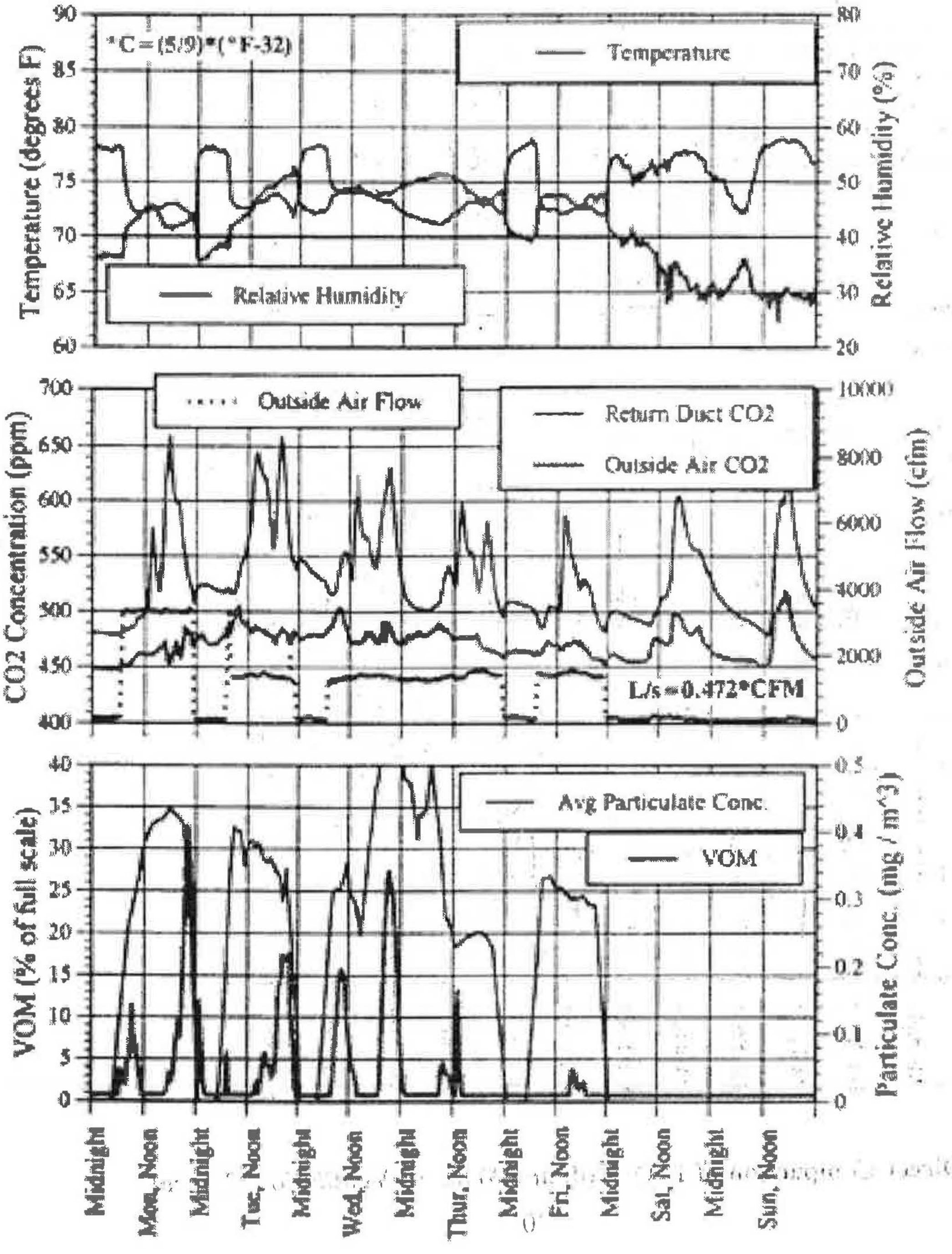


Fig. 9 - Data from 10/09 - 10/15, Economizer Closed After Monday

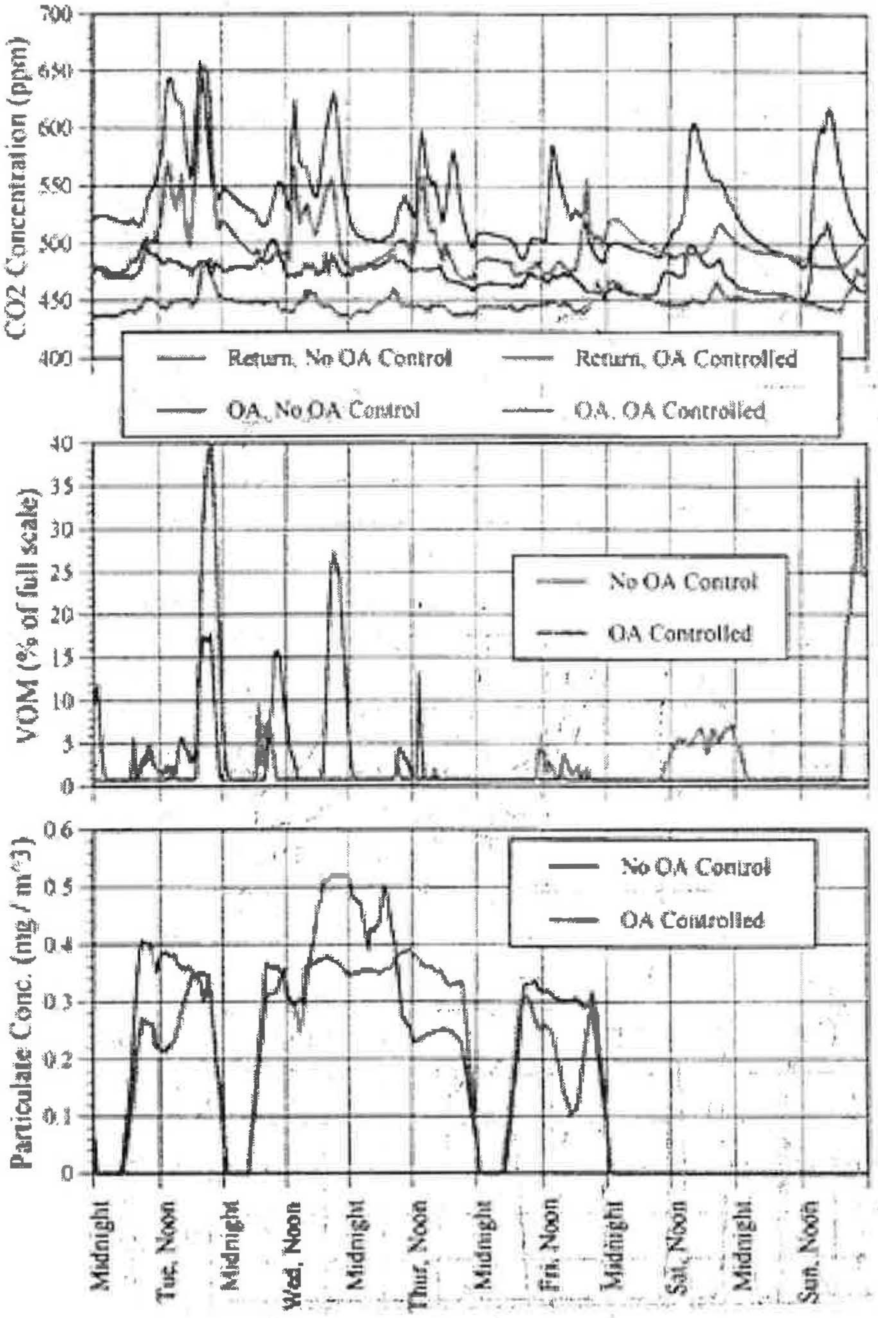


Fig. 10 - Direct Comparison of IAQ With and Without Ventilation Control

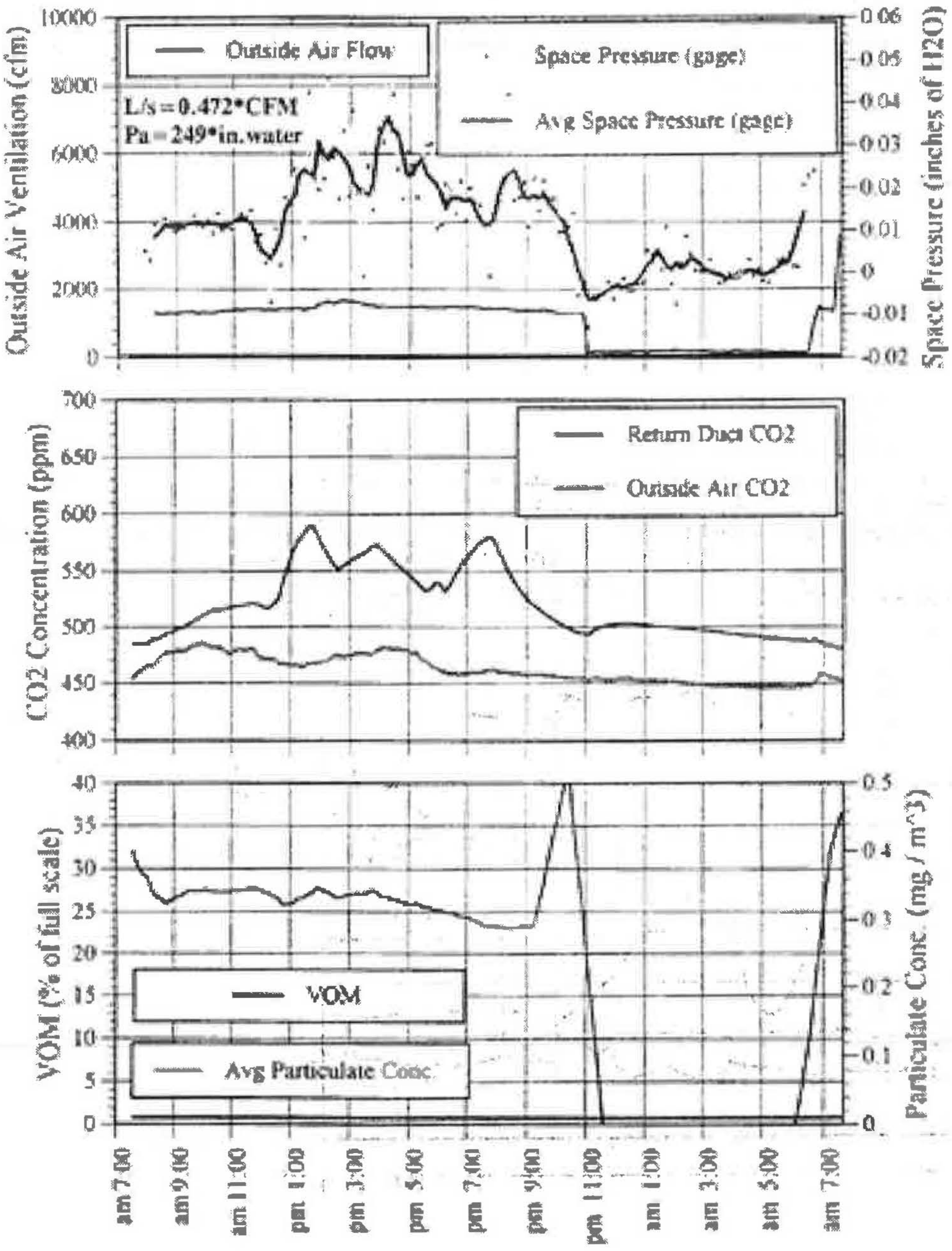
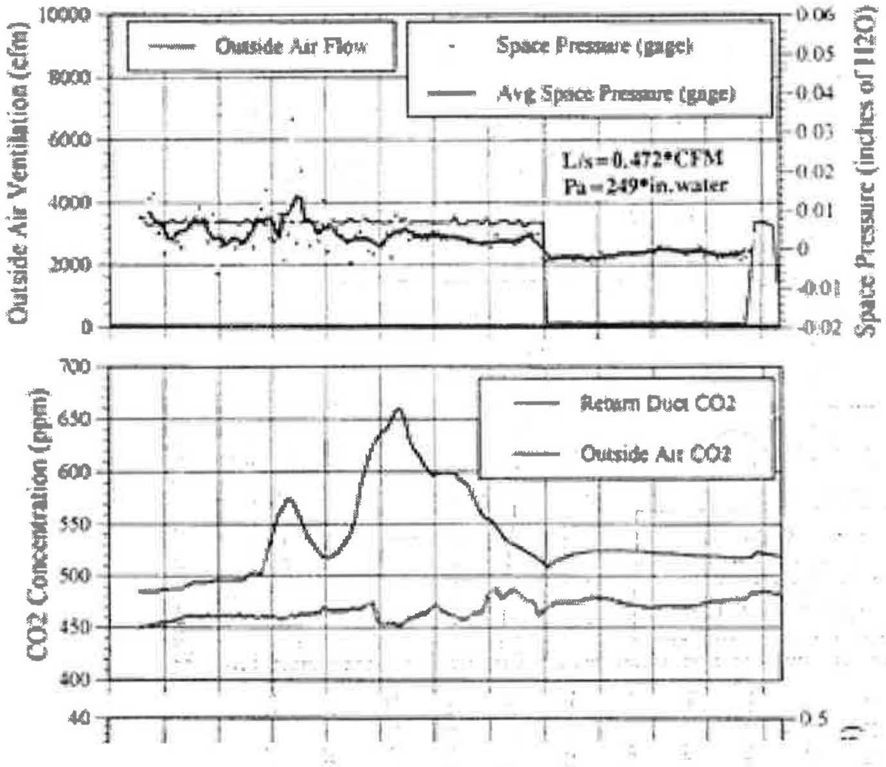


Fig. 11 - Space Pressure Data from 10/05 - 10/06, No Outside Air Controls


Outside Air Flow
Space Pressure (gage)
Avg Space Pressure (gage)
L/s=0.472*CFM
Pa=249*in.water
Outside Air Ventilation (cfm)
Space Pressure (inches of H2O)
10000
8000
6000
4000
2000
0
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
Return Duct CO2
Outside Air CO2
CO2 Concentration (ppm)
700
650
600
550
500
450
400
40
0.5