VENTILATION CONTROL AND BUILDING DYNAMICS BY CO2 MEASUREMENT

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The dynamic response of CO_2 concentration in commercial buildings can be used to develope on-line strategies for HVAC control and operation. This study investigates the comfort and air quality in a commercial building under different operation conditions. The parameters measured were dry-bulb temperature and relative humidity, total dust, nicotine, formaldehyde, VOCs, and CO_2. Questionnaires were also distributed to the building occupants. All parameters and questionnaires were recorded and analyzed as the quantity of outdoor air was controlled. CO_2 concentration is a very good indicator for maintaining ventilation rates in buildings. It's profile provides a footprint of the building's dynamic characteristics, such as, outdoor air damper position, office occupancy, control and energy conservation strategies, and building time constants.

INTRODUCTION

Increased insulation and reduced ventilation of buildings to save energy, the growing use of synthetic materials and household chemical products, and the increased pollution of outdoor air are all phenomena that contribute to deterioration in indoor air quality. The number of complaints related to this deterioration continues to increase.

The new ASHRAE ventilation standard (1) introduces an option to a fixed ventilation rate. It allows modulation of the fresh air intake so long as CO_2 concentration level in any given zone does not exceed 1000 ppm. The purpose of this paper is to demonstrate the dynamic behavior of CO_2 concentration in a building and the information one can obtain as the result of the measurement.

The interest in control of building ventilation has increased as a consequence of the demands for energy savings. Ventilation control by the concentration of carbon dioxide is a means for a more cost-efficient use of ventilation air (2,3). CO_2-controlled ventilation however, depends on careful consideration of several critical aspects. Besides pollutants from occupants, pollutants from building materials, activities, and from the outdoor air must be observed.

ASHRAE, in the new ventilation standard, has applied a limit value for CO2 of 1000 ppm. Provided the occupants only perform light work, this CO2 value roughly corresponds to a need for an outdoor air flow of 10 l/s/person.

Formaldehyde is a gas reknowned for its sharp, irritating effects on eyes, nose, and respiratory system. Emanations arise from glues used for panelling and carpeting, from treated fabrics, from new materials, furniture, or renovations. Volatile organic compounds were measured next. Whether their toxicity is more or less important, it is generally associated with the central and peripheral nervous systems. The sources of organic solvents in office buildings are numerous. Some examples are printing processes, paints, glues, varnish, cleaners, and perfume. Nicotine's health effects, the source of which is tobacco smoke, are well-known. Finally, airborne dust found in office buildings is usually created by the occupants and their activities; for instance, smoking, paper shuffling, and circulation. Depending on the size, these particles are inhaled and then lodged in the alveoli of the lungs.

INSTRUMENTATION AND METHODOLOGY

The experiments were conducted during the summer months, in an office building in the southern end of Montreal, along the St. Lawrence river, Quebec. The zone area was 1060 m2, 70 people occupied it, and it was divided into open-area office space with moveable partitions. The air handler was a constant volume system with variable outdoor air supply. The air supply to the zone was through 60 diffusers supplying at constant volume, but at variable temperature, controlled by adjustable thermostats located throughout the work space.

A TSI-1620 velometer with 15 sensors measured the volumetric outdoor air supply to the zone. Additionally, an Alnor velometer was used to measure the volumetric total air supply to the zone. Automatic psychrometers measured DB temperature and WB temperature. An ADC CO2 Analyzer sensor measured the CO2 concentration. This direct-reading instrument is based on infra-red technology. Air pumps sampling at an air flow rate of 0,5 l/min were used with: 1) orbo adsorbent tubes impregnated with N-benzylethanolamine to collect formaldehyde, 2) activated charcoal tubes to collect VOC's and 3) XAD-2 tubes to collect nicotine. Air pumps sampling at an air flow rate of 2,0 l/min were used with polyvinyl chloride filters at 37 mm, and 0,8 u to collect total dust.

The total airflow supply to the space was measured three times throughout the testing period. The outdoor air dampers were modulated to offer from 0% to 100% outdoor air to the zone. At each change in damper position, the following took place:

-the outdoor airflow supply was measured;
-a questionnaire was distributed;
-18 VOC samples, 6 formaldehyde samples, 6 nicotine samples,

and 6 total dust samples were taken over a period of 2 8-hour working days; and

-10 DB temperature readings, 10 WB temperature readings, and 30 CO_2 readings were taken hourly, for 14 hours per day, for 2 days.

The dampers were positioned in a random order so as to ensure that the occupants were unaware of any pattern of change. The CO_2 readings were taken at three levels (0, 1, and 2 meters from the floor) so as to verify the presence of short-circuits or stagnant areas.

RESULTS & DISCUSSION

From the CO_2 concentration results, it was found that no short-circuits or pockets of stagnant air were found throughout the zone. In Figure 1, the supplied outdoor air flow rate to the zone is plotted against CO_2 concentration in ppm. These data refer to the maximum concentration level found at any particular work-station in the zone. It is quite obvious that the CO_2 is diluted as the outdoor air flow is increased.

Figure 2 shows the average formaldehyde concentration found in the zone plotted versus the amount of outdoor air flow supplied. As the amount of outdoor air was increased, a definitive decrease in formaldehyde concentration was noted.

Figures 3 and 4 show the average stoddard solvent and toluene concentrations, respectively, found in the zone plotted versus the amount of outdoor air supplied. Both stoddard solvent and toluene decreased as the outdoor air was increased. But, no correlation was established for the xylene.

No correlation was established for nicotine since very few occupants smoked, putting in evidence that the smoke was effectively removed from the zone by the ventilation system.

Figure 5 shows the average total dust concentration in the zone plotted against the amount of outdoor air supplied. Contrary to what would be expected, the amount of total dust increased with outdoor air flow rates. This could be due to a very physical factor; the location of the building itself. The office building is surrounded by a very busy thoroughfare, a heavily trafficked bridge, and two parking lots. The HVAC system was not equipped with the proper filters to collect all the dust being supplied from the outside. Therefore, as more outdoor air was supplied, the higher the interior dust concentration.

ASHRAE defines acceptable indoor air quality as being "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80 % or more) of the people exposed do not express dissatisfaction."

The distributed questionnaires were analyzed, and the results are shown in Figure 6; the percentage of occupants expressing dissatisfaction is plotted against the amount of outdoor air supplied to the zone. Surprisingly, the amount of people dissatisfied increased with the amount of outdoor air. This brings in evidence certain questions: 1) were the occupants overly sensitive to the dust? (N.B. dust being the only contaminant that did not satisfy ASHRAE 1989), and/or 2) were the occupants sensitive to something other than indoor air quality parameters, i.e. were they confusing the quality of indoor air with thermal comfort?.

Figure 7 shows the relationship between the percentage of people dissatisfied with the thermal environment and the amount of outdoor air. The same correlation is seen here as with complaints about indoor air quality. Furthermore, 76% of the respondents answered both questions identically. They might have thought the thermal environment as being equivalent to the quality of indoor air.

Figures 8 and 9 show the changes in daily average ambient air temperatures and the daily average relative humidities, respectively. As the amount of outdoor air increased, so did indoor air temperature and relative humidity. The existing HVAC system was not capable of cooling and de-humidifying the supply air to comfort demands. ASHRAE 55-1981 (4) recommends a comfort zone, for summer conditions, as the following: from 22,6 and 26°C at 16,7°C dewpoint to 23,3 and 27,2°C at 1,7°C dewpoint. These conditions were satisfied only 10% of the total testing duration, supporting the occupants' complaints of inadequate thermal comfort. This thermal discomfort probably dominated their sensitivity to changes in the indoor air quality parameters.

CONCLUSIONS & RECOMMENDATIONS

It was shown that the correlation between CO2 and outdoor air supply was similar to formaldehyde and VOC concentrations. The opposite was seen for dust concentration and for occupant satisfaction levels. Measurement of CO2 in a building can be a very good tool to determine the level of ventilation rate, provided that the HVAC system is able to clean, cool/heat, and humidify/de-humidify adequately the outdoor air being supplied to the zone, ensuring optimal air quality and comfort while conserving energy.

ACKNOWLEDGEMENTS

The researchers of this project would like to thank the occupants of the building in question for their cooperation and understanding.

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4. ASHRAE Standard; Thermal Environmental Conditions for Human Occupancy; ANSI/ASHRAE 55-1981.

FIGURE 1.

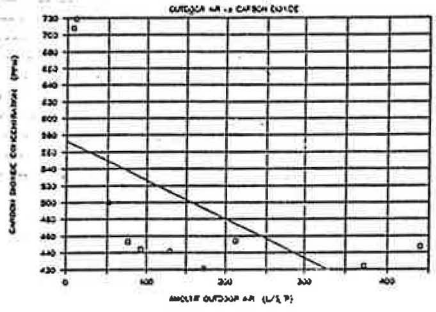


FIGURE 2.

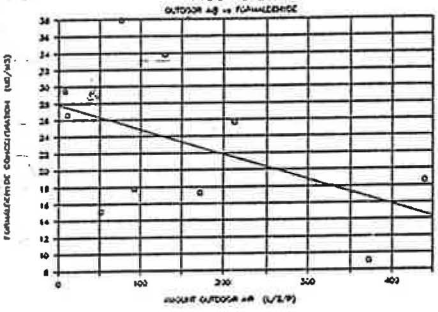
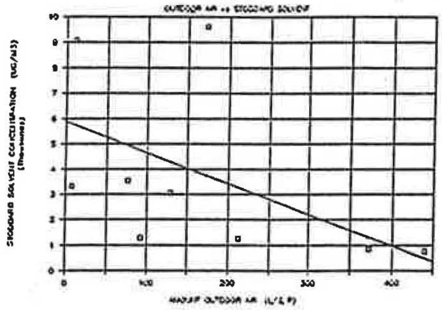


FIGURE 3.



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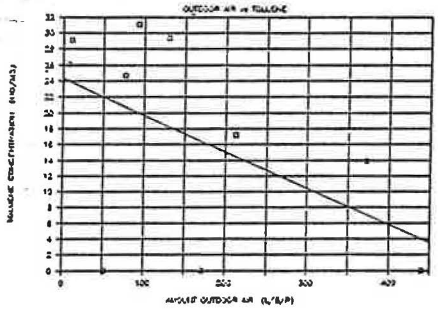


FIGURE 5.
OUTDOOR AIR vs TOTAL DUST

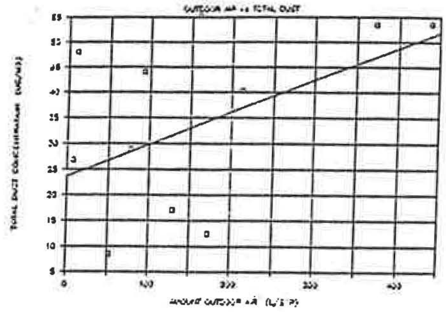


FIGURE 6.
OUTDOOR AIR vs COMPLAINTS

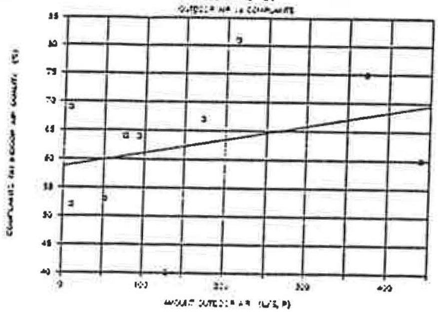


FIGURE 7.
OUTDOOR AIR vs COMPLAINTS

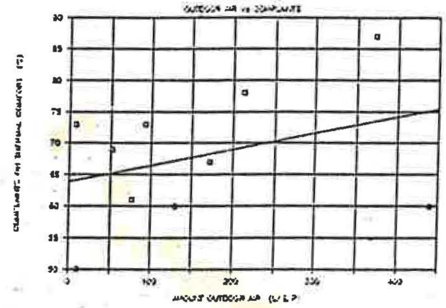


FIGURE 8.
OUTDOOR AIR vs TEMPERATURE

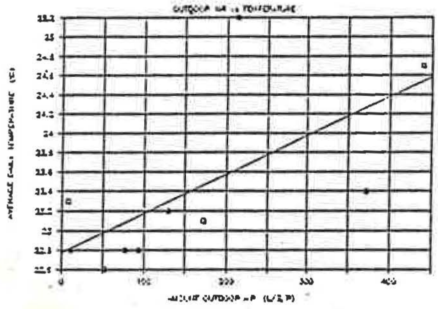
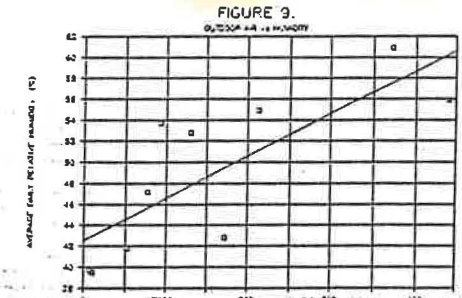


FIGURE 9.
OUTDOOR AIR vs HUMIDITY



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