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CARBON DIOXIDE CONCENTRATIONS AND MINIMUM AIR CHANGE RATES IN A HIGH-RISE OFFICE BUILDING

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The carbon dioxide concentration patterns in a large high-rise office building in Ottawa were examined experimentally using an automated data acquisition system. Daily CO_2 concentration profiles throughout the building and air change rates, using SF_6 as a tracer gas, were measured at minimum outdoor air supply rates during much of a heating season. Of particular interest was how well-mixed the indoor air was and how well the CO_2 concentrations measured in the central ventilation system's return air plenum represented the average CO_2 concentration behaviour in the building as a whole. CO_2 concentration profiles were also measured on individual floorspaces in the building to determine the range of variability in the concentration behaviour. The measurement results are presented and discussed in the context of demand controlled ventilation.

INTRODUCTION

As the public awareness of indoor air quality issues has grown, building managers have faced increasing pressures to ensure that air quality in places of work is acceptable in terms of both health and comfort. Recent changes to ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality" (1), especially its increased requirements for outdoor air supply, have exacerbated concerns that the energy costs associated with meeting these requirements will be excessive, particularly in cold climates. Demand-controlled ventilation systems, using occupant-generated carbon dioxide as the control index, have been proposed as an energy efficient approach to meet ventilation requirements. The effectiveness of this strategy applied to whole building ventilation will depend, to a great extent, upon how well mixed the occupant-generated CO_2 is in the building.

Carbon dioxide concentration patterns and air change rates in a large high-rise office building in Ottawa were examined experimentally using an automated data acquisition system. The objectives were (1) to examine the factors that may affect the use of occupant-generated CO_2 concentrations for controlling the ventilation system, and (2) to determine the feasibility of using CO_2 concentration as an index of the minimum ventilation rate. The principal factors that could have an impact on CO_2-based demand control are how well mixed the building air is, where the CO_2 sensor(s) should be located, and what concentration setpoint is appropriate.

EXPERIMENTAL APPROACH

The test building is a 22-storey office building with a total interior volume of approximately 113,700 m^3. The 22nd floor houses all the HVAC equipment. There are seven all-air constant volume supply air handling systems, and two return air handling systems. Four core supply systems provide air to the east and west interior lower zones (floors 2-11), and the east and west interior upper zones (floors 12-21). Three supply induction systems provide air to the south perimeter, east and east half of the north perimeter, and west and west half of the north perimeter zones which each include floors 2-21. There are independent supply and exhaust systems for the first floor which includes the entrance lobbies and a large cafeteria. Constant volume exhaust systems continually exhaust air from the washrooms.

The components of a CO_2-based demand controller for the ventilation systems' outdoor air supply rate are installed in the building. The CO_2 sensors are located inside the tops of the two return air shafts and connected to provide the average of their readings to the central control system.

An automated data acquisition system, identical to that described by Shaw et al (2), was installed in the building to enable tracer gas measurements of whole building air change rates and air distribution patterns, and continuous monitoring of CO_2 concentrations at various locations throughout the building, and outdoors as a reference. Sulfur hexafluoride (SF_6) was used as the tracer gas. It was injected in equal amounts into the four interior core supply systems' airstreams for air change rate measurements, or into only one of the four core supply systems to examine air distribution patterns. The decay method was used for all tracer gas tests.

All the measurements reported in this paper were made with the outdoor air supply dampers set to provide 20 percent outdoor air. This is the minimum setting used in the building at any time of the year. Higher percentage settings for outdoor air are used only during weather conditions which permit "free cooling."

Sampling locations for the automated data acquisition system were selected in the return air shaft intakes and in the occupied zones of floors 2, 5, 8, 11, 12, 15, 18, and 20. These floors were selected to represent the range of floor plans (partitioned space and open office concept) typical throughout the building. Measurements were made during the period from October 1990 to September 1991.

MEASURED RESULTS

Tracer Gas Tests

The measured results of a typical air change rate test at minimum outdoor air damper settings are shown in Figure 1. The concentrations of SF_6 measured at various sampling locations throughout the building are plotted against time elapsed since the balanced injection of the tracer gas into the supply airstreams of all four interior core supply air handlers. These results show that after 20 minutes, the tracer gas is well mixed throughout the building, and its concentration decay follows a single curve. These results suggest that CO_2 generated by occupants distributed throughout the building will be well mixed in the indoor air very quickly, with no more than a 30 minute lag time between changes in CO_2 generation or dilution locally appearing in the main return airstream.

The average of the tracer gas measurements of building air change rates at the minimum 20% outdoor air supply rate was 0.58 air changes per hour (ac/h). The ASHRAE Standard 62-1989 specifies a ventilation supply rate of 10 L/s outdoor per person. With a total population of 1100 people in the test building, and total internal volume of approximately 113,700 m^3, the air change rate required by the ASHRAE standard is 0.348 ac/h. Therefore, at its minimum outdoor air setting, the mechanical ventilation system exceeds by approximately 66%, the minimum outdoor air supply requirement set by ASHRAE.

The results of a typical air distribution test, where the tracer gas was injected into only one of the four core supply systems (the west interior upper supply) are shown in Figure 2. These results indicate that even with unbalanced injection the tracer gas is well mixed in the indoor air by the time 60 minutes have elapsed after injection, after which its decay follows a single curve. These results also show the expected source zone and target zone concentration behaviours - pure decay in the source zone (here the upper floors) and rise followed by decay in the target zone (the lower floors).

These results collectively suggest that CO_2 generated by occupants distributed throughout the building will be well mixed in the indoor air very quickly. No more than a 30 to 60 minute lag time should occur before local changes in CO_2 generation or dilution appear in the main return airstream for the whole building.

CO_2 Concentration Measurements

The measured CO_2 concentration profile for a typical working day is shown in Figures 3(a) and 3(b). As expected, the concentration profiles measured in the occupied floorspaces, Figure 3(a), display greater variability than those measured in the return air intakes, Figure 3(b). This is probably because the measurements in the return air intakes can be regarded as representing spatial averages of concentrations in the occupied zones of their respective floors.

To confirm whether or not the measurements in the return air intakes represent the spatial average of concentrations in the occupied floorspace, an automatic measurement system was used to monitor concentrations at eight locations on each of two typical floors, the 18th and 20th. The measured results for the same typical day in Figure 3 are shown in Figures 4(a) and 4(b). They indicate that the concentration profile measured at the return air intake well represents the spatial average of the concentration profiles measured at 8 locations throughout the occupied zone.

The daily average CO_2 concentrations measured at the tops of the return air shafts are compared in Figure 5 with the average of the individual daily average concentrations measured at each return air intake on the eight test floors. Daily averages were calculated from concentrations measured between 9 A.M. and 4 P.M. The regression analysis, plotted in Figure 5, indicates that the shaft top daily average concentrations underpredict by 3% the averages of the daily average concentrations at the return air intakes. The daily maximum concentrations measured at the tops of the return air shafts are compared in Figure 6 with the average of the daily maximum concentrations measured at the individual return air intakes. The regression analysis, plotted in Figure 6, indicates that the shaft top maxima also underpredict by 3% the average of the individual daily maxima at the return air intakes.

These results collectively indicate that measurements of CO_2 concentrations at the tops of the return air shafts well represent the concentration behaviour throughout the building. This suggests that the top of the return air shafts is an appropriate location for the CO_2 sensors of a demand controller for the ventilation system. The concentration setpoint however, should be adjusted to account for local variability in the occupied zones of the building, to avoid local exposures which might exceed recommended guidelines.

The average daily maximum CO_2 concentration measured in the return air of the building, at the minimum outdoor air supply was 650 ppm. This is well below the 1000 ppm CO_2 concentration limit specified in the ASHRAE Standard 62-1989.

CONCLUSIONS

1. The building is well mixed as indicated by the SF_6 test results. With balanced injection into all four interior core supply systems, mixing throughout the building is complete within 20-30 minutes.

2. The CO_2 concentrations measured at the tops of the two return air shafts well represent the average of the CO_2 concentrations measured at the return air intakes on all the test floors in the building.

3. The CO_2 concentrations measured at the return air intakes well represent the average of concentrations throughout the occupied floorspace on the test floors measured.

4. The CO_2 concentrations measured at the tops of the two return air shafts, therefore, well represent the average of the concentrations throughout the occupied floorspace in the building.

5. Demand control of the ventilation system using CO_2 concentrations measured at the top of the return air shafts as the control index, does offer a feasible approach to control the supply of outdoor air to the building to provide acceptable indoor air quality.

REFERENCES

1. ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality." American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

2. Shaw, C.Y., Magee, R.J, Shirtliffe, C.J. and Unligil, H. 1991. "Indoor Air Quality Assessment in an Office-Library Building: Part I - Test Methods." ASHRAE Transactions, Vol.97, Pt.2.

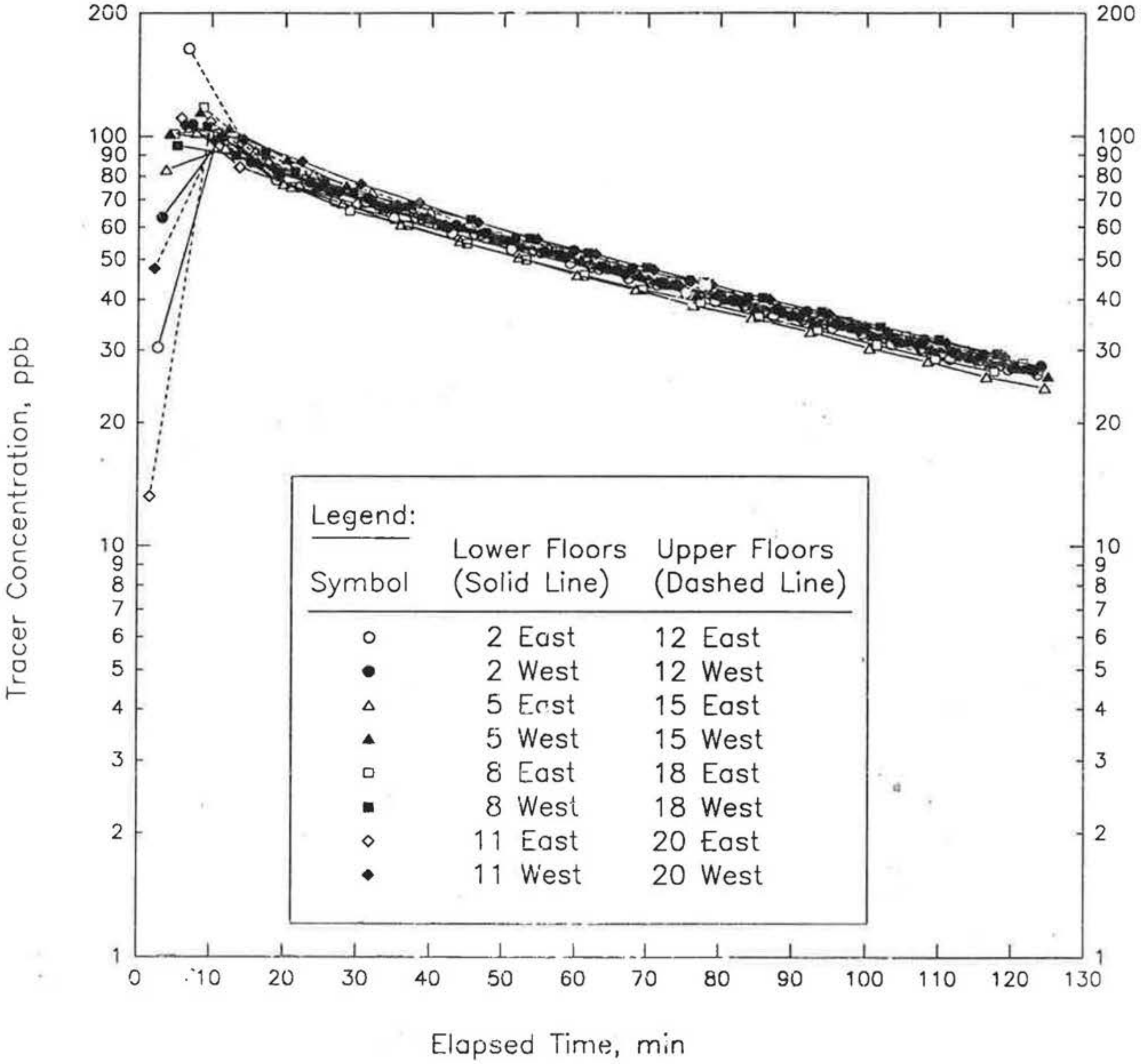

Figure 1 - Concentration Data from a Typical Tracer Gas Measurement of Building Air Change Rate

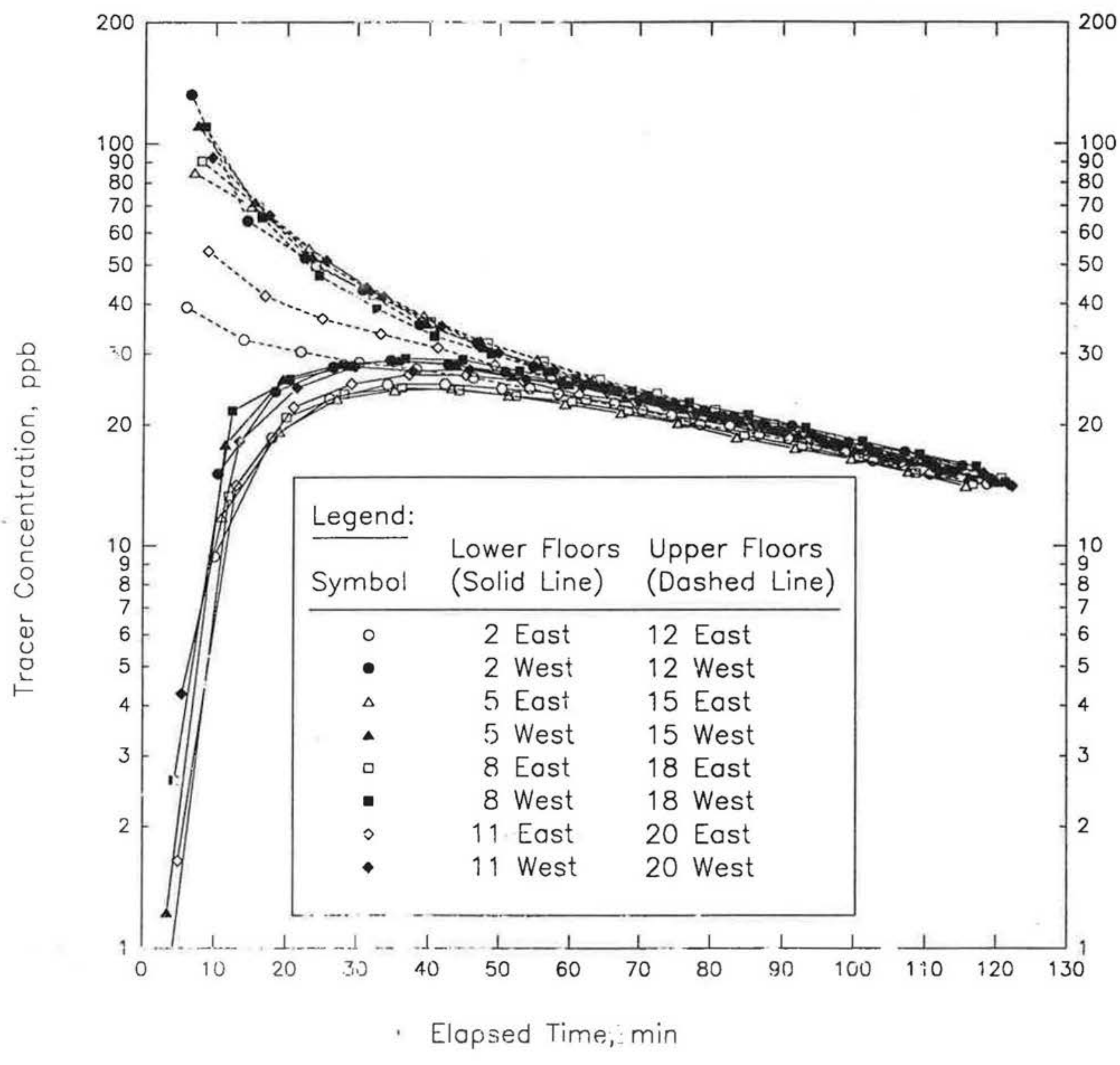

Figure 2 - Concentration Data from a Typical Tracer Gas Measurement of Air Distribution in the Building

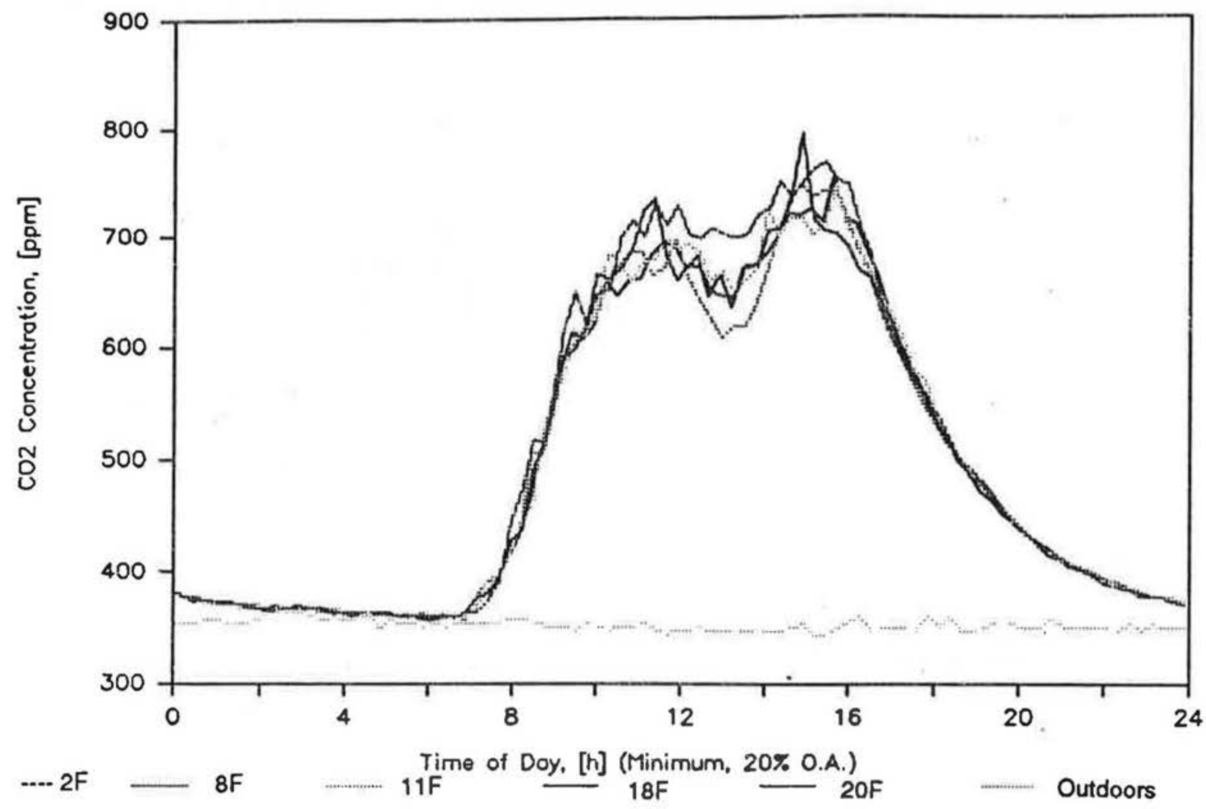

Figure 3(a) - Typical CO_2 Concentration Profiles in Occupied Zones

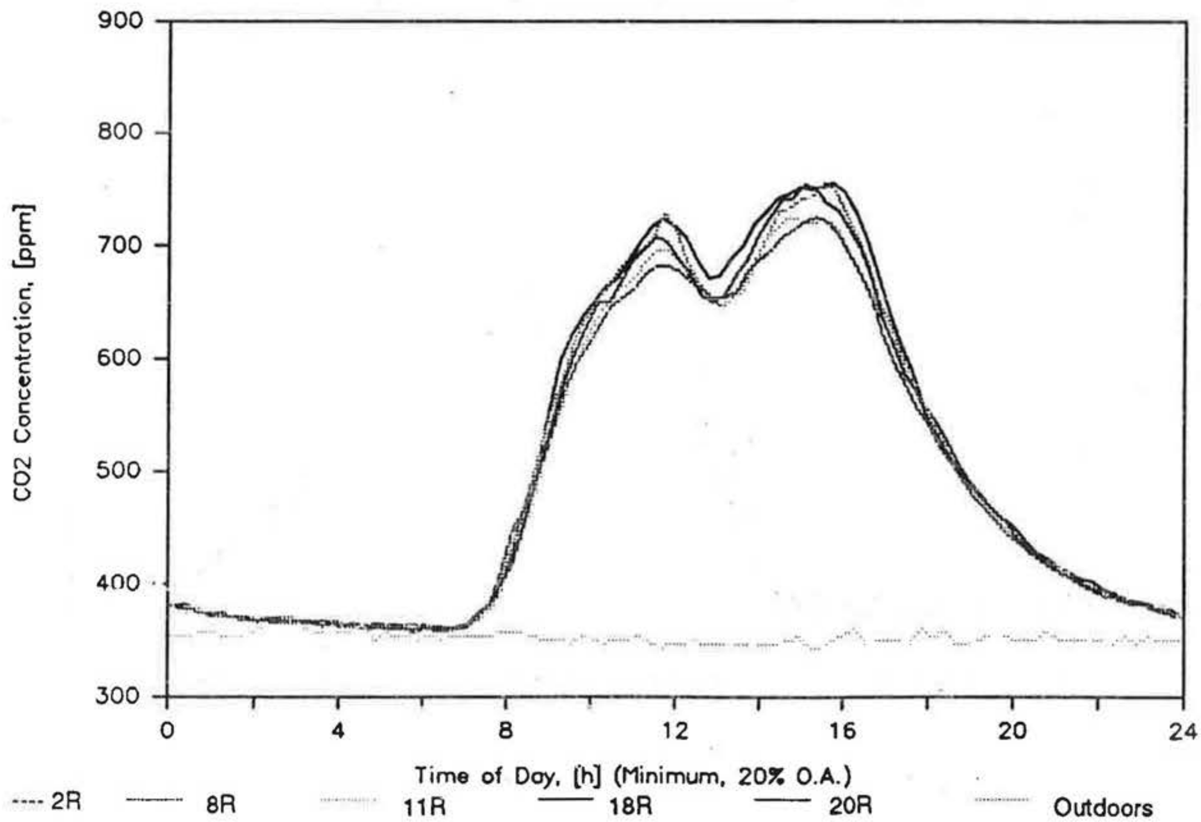

Figure 3(b) - Typical CO_2 Concentration Profiles in Return Intakes

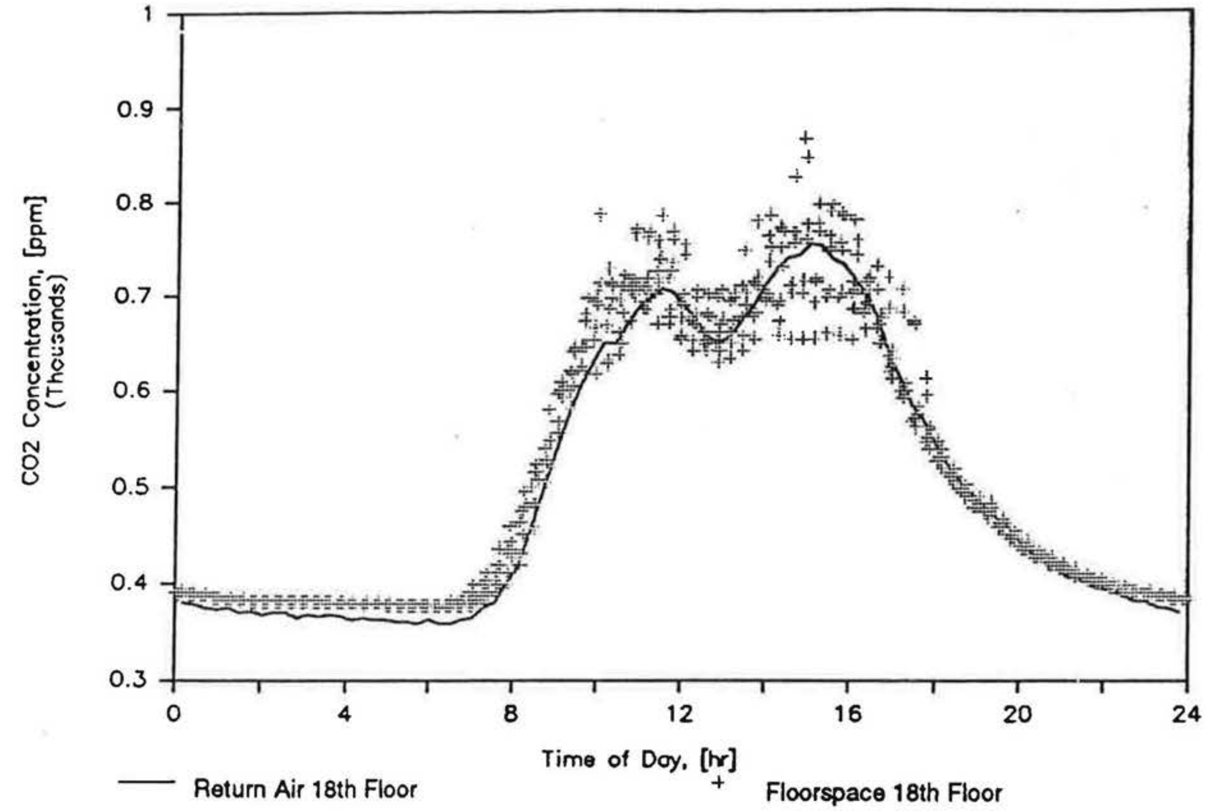

Figure 4(a) - CO_2 Measured in the Occupied Zones and in Return Intake, on the 18th Floor

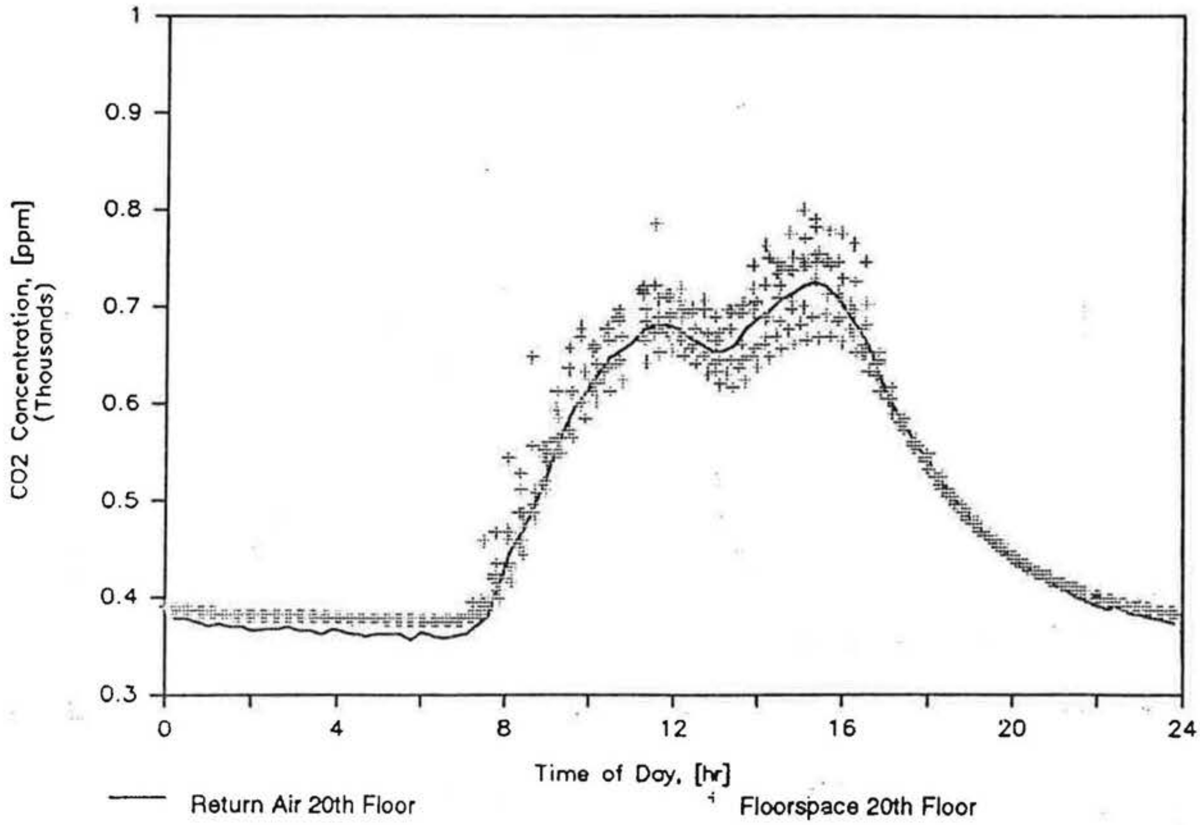

Figure 4(b) - CO_2 Measured in the Occupied Zones and in Return Intake, on the 20th Floor

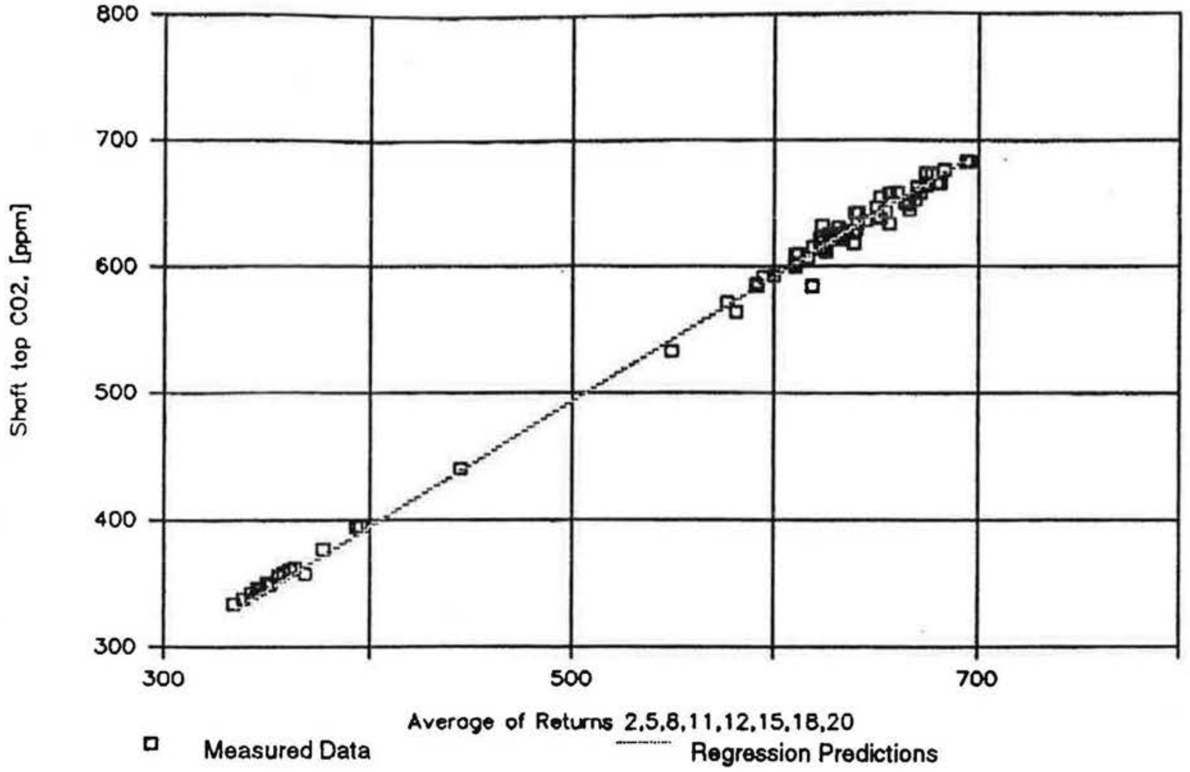

Figure 5 - Daily Average CO_2 Concentrations Measured at the Return Air Shaft Tops Compared with Average of Daily Average CO_2 Concentrations Measured at Return Air Intakes on Individual Test Floors

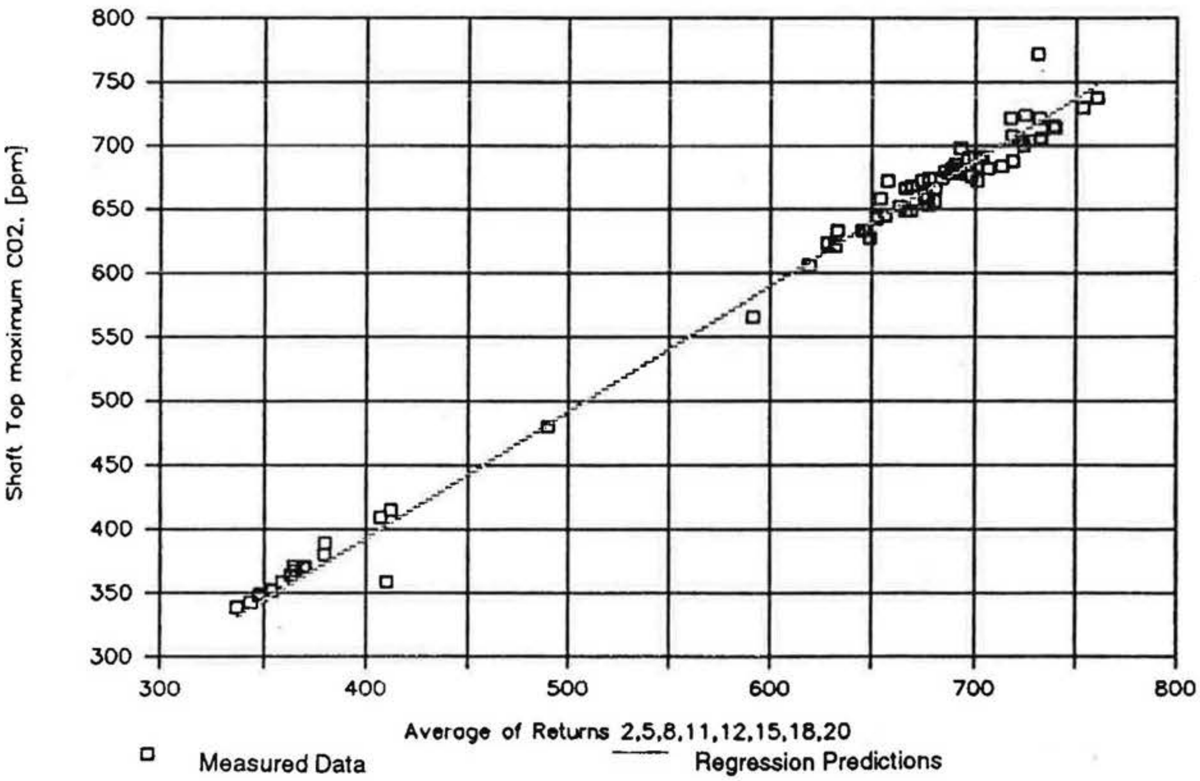

Figure 6 - Daily Maximum CO_2 Concentrations Measured at the Return Air Shaft Tops Compared with Average of Daily Maximum CO_2 Concentrations Measured at Return Air Intakes on Individual Test Floors