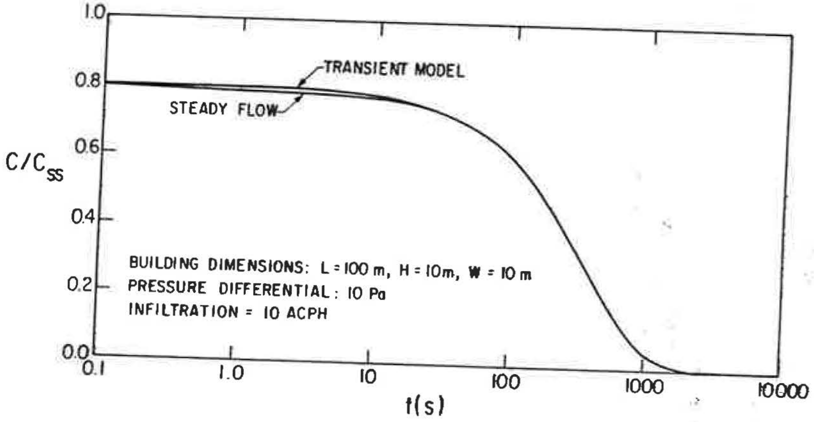

Fig. 8 Effect on concentration of a suddenly imposed pressure differential with no concentration flux.

$$\dot{m}_1 = 0 \quad t > 0$$

IMPACT OF A NEW SMOKING POLICY ON OFFICE AIR QUALITY

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A new smoking policy was implemented on a trial basis on one floor of a large modern Canadian office building. Smoking was limited to a single enclosed room which shared the same recirculating-type ventilation system with the rest of the floor. Environmental monitoring was conducted on the test floor and a control floor during three consecutive working days both before and after policy implementation. Hourly levels of respirable suspended particulate (RSP), carbon monoxide (CO) and carbon dioxide (CO_2) were monitored on the floors and in the designated smoking area throughout the workday. Temperature and relative humidity were monitored at specific sites on each floor and the quantity of outdoor air supplied to each floor was measured on a daily basis. A voluntary questionnaire was circulated to all staff to detect any changes in personal smoking habits over the course of the study.

Results of the investigation showed statistically significant reductions of RSP and CO concentrations on the test floor. After standardization to the control floor, the test floor results indicated a reduction of RSP and CO, 23% and 7.2%, respectively.

Introduction

A new smoking policy was implemented on a trial basis for a period of three months on one floor of a large modern office building in Hull, Canada, during the winter of 1985. The policy was based on the findings of an employee initiated survey on tobacco smoke in the workplace. Under the new policy, smoking was to be limited to the staff lounge.

In order to quantify the impact of the new smoking policy on office air quality, environmental monitoring was conducted on both the test floor and a control floor. Testing was conducted during three consecutive working days, approximately two weeks before policy implementation (Period 1) and two weeks following policy implementation (Period 2).

The two floors studied are situated in a 19 storey office tower which is part of a large four building office/hotel complex. The heating, ventilation, and air-conditioning (HVAC) system employed throughout the complex is based on the "compartmental system" and uses a variable air volume (VAV) distribution system. The main air handling system, consisting of filters, heat exchanger, heating coils, humidifier and supply fan, is located in the penthouse. A smaller auxiliary unit is located on the 14th floor to assist in ventilating the lower floors, which are significantly larger due to the terraced nature of the building. As part of the conditioning process, outdoor air passes through two sets of filters: one set of 20% efficient fibreglass pre-filters and another set of 60% efficient filters (based on ASHRAE Atmospheric Dust Spot Efficiency Tests)[1].

Mechanical rooms on each floor act as mixing plenums for the conditioned supply air from the penthouse and return air from the floor ceiling space. A schematic of the system is shown in Figure 1. This mixture, approximately 20% outdoor air and 80% recirculated air, undergoes further cleaning as it passes through another set of 60% efficient filters in the air handling unit. Air is then channeled through ductwork containing cooling and heating coils for perimeter zones and cooling coils only for the interior zones. Treated air is distributed by fibreglass ductwork to VAV valves and supplied through linear ceiling diffusers. Return air is directed through the ceiling space to the mechanical room where approximately 20% is exhausted. All (100%) washroom exhaust air is discharged directly to the outside.

The HVAC system was designed to provide 0.7 lps/m^2 (0.15 cfm/ft^2) outdoor air. Based on an average occupant density of 7 persons/100 m^2 this is equivalent to 10 lps/person (20 cfm/person). These specifications are in accordance with ASHRAE ventilation guidelines for general office areas where smoking is permitted.[2]

All VAV valves were set to assure a minimum 40% open position at all times and the HVAC system is operated continuously 24 hours per day. Both of these actions are the result of employee complaints throughout the complex regarding air quality.

The staff lounge is approximately 8m x 5m, carpeted, and furnished with laminated tables and upholstered chairs and sofas. It shares the same recirculating type ventilation system with the rest of the floor.

Consequently, it is equipped with two air supply and exhaust units in accordance with its floor area. The lounge, whose door is normally left open, is located across the corridor from the washrooms and is appproximately 17m from a mechanical room and the general exhaust for the floor.

The control floor, located one floor above the test floor, is occupied by the same government department, performing tasks of a similar nature. The floor plans and office design of the two floors are not identical; however, they are similar in that both contain private offices and open office areas with moveable partitions. Their major characteristics are summarized in Table I and shown in Figure 2.

Survey Design and Methodology

No special arrangements had been made to accommodate smokers or non-smokers on either floor. Hence, for the purpose of the present investigation, it was assumed that smokers were located in a random fashion throughout the floor.

The occupiable area of each floor was divided into 7.6 x 7.6 m (25 x 25 ft) zones. This provided 57 zones on the test floor and 42 on the control floor. Eight sampling sites were then selected on each floor using tables of random numbers. In addition, measurements were taken in the staff lounge on the test floor which was designated to be the smoking area in Period 2.

Environmental monitoring was conducted for respirable suspended particulate (RSP), carbon monoxide (CO) and carbon dioxide (CO_2). Temperature and relative humidity were monitored, and the quantity of outdoor air supplied to each floor was also measured.

RSP was measured to give a quantitative assessment of levels of tobacco smoke particulate. Knowledge of RSP levels also permits a rough estimation of the risk of lung cancer attributable to tobacco smoke in the air of the workplace.

Employees, being aware that carbon monoxide is a major toxic component of tobacco smoke,[3] requested that CO also be measured. Carbon monoxide is a component of the gaseous phase and would not be removed by passage through the filters when recirculated throughout the floor. On the other hand, some respirable suspended particulate would be removed by the 60% efficient fibreglass filters that are part of the air handling unit on each floor.

Outdoor air supply rates to each floor were measured to verify that ventilation design specifications were being met, and that they did not vary over the course of the investigation. Indoor CO_2 levels were also monitored to give some estimate of the adequacy of quantity and degree of uniformity of supplied outdoor air.[4,5] Temperature and relative humidity were measured throughout the survey on both floors to reduce the possibility of their being confounding factors.

All survey monitoring was conducted between 8:00 A.M. and 6:00 P.M. RSP of aerodynamic diameter 0.01 - 3.5 micrometers was measured using a piezobalance (TSI Model 3500). Measurements of two minute duration for RSP were taken at two hour intervals sequentially at each sampling site.

The hour time weighted-average air samples were collected in gas sampling bags at each sampling site using low flow air sampling pumps. These were analyzed on site for carbon monoxide (Thermo Electron CO Monitor) and carbon dioxide (Horiba Model APBA-210 CO_2 Analyzer).

The volume of outdoor air supplied to each floor was measured daily using a Pitot tube with a micromanometer (Air Instrument Resource Ltd. Model MP3KDS). Temperature and relative humidity were recorded using thermo-hygrographs.

Two statistical methods were adopted to detect the differences of values of RSP, CO and CO_2, between floors and between periods. The independent sample t-test was applied to test the difference of mean values[6]. The Wilcoxon matched-pairs signed-ranks test was utilized to examine differences in their hourly distribution.[7]

A questionnaire on personal smoking habits was distributed to all staff on both floors before and after the implementation of the new smoking policy. The intent was to monitor any change in tobacco consumption and smoking patterns which might have occurred over the course of the investigation.

Results

The hourly variations of RSP levels on the test floor and the control floor averaged over the three days before (Period 1) and after (Period 2) the implementation of the new smoking policy on the test floor are shown in Figure 3. The corresponding hourly variations of CO and CO_2 levels during the same periods are also shown in Figures 4 and 5, respectively.

The daily mean levels of RSP, CO and CO_2 over both the test and control floors were calculated during Periods 1 and 2 respectively, using the General Linear Model[8]. The results are shown in Table II.

Shown in Figure 6 are the mean levels of RSP, CO and CO_2 on the test floor and the control floor during the three day periods before and after the implementation of the new smoking policy. These results are summarized in Table III.

The interpretation of their statistical significance, determined by independent sample t-tests are as follows:

Before the new smoking policy was implemented, the average RSP level of the control floor was 3 $\mu g/m^3$ higher than that of the test floor. After the new smoking policy was implemented, this difference increased to 9 $\mu g/m^3$ (statistically significant, $p<0.01$). When the Period 2 level difference was standardized to Period 1 level difference, the net difference decreased to 6 $\mu g/m^3$, but still remained statistically significant, ($p<0.01$).

Before the new smoking policy was implemented, the CO level of the control floor was 0.08 ppm higher than that of the test floor. After the new smoking policy was implemented, this difference increased to 0.20 ppm (statistically significant, $p<0.01$). When the Period 2 level difference was standardized to the Period 1 level difference, the net difference decreased to 0.12 ppm and became marginally statistically significant, ($p<0.07$).

Before the new smoking policy was implemented, the CO_2 level of the control floor was 23 ppm lower than that of the test floor (statistically significant, $p<0.01$). After the new smoking policy was implemented, this difference was reduced to 21 ppm, yet remained statistically significant, ($p<0.01$.) When the Period 2 level difference was standardized to the Period 1 level difference, the net difference decreased to 2 ppm (not statistically significant, $p>0.1$).

The Wilcoxon matched-pairs signed-ranks test was utilized to detect the hourly distribution difference of the three substances between floors and between periods. The test showed a similar pattern to that of the independent sample t-test; the observed statistically significant differences between mean values also existed uniformly through their hourly distribution values.

The environmental effects of restricting smoking to the lounge area on the test floor with respect to the remainder of the floor are presented in Table IV. The mean floor concentration of RSP and CO decreased from Period 1 to Period 2 by 30% and 35%, respectively. In comparison, the mean levels of RSP and CO measured in the lounge increased from Period 1 to Period 2 by 271% and 21%, respectively. The mean CO_2 levels were little changed showing a 9% decrease on the floor and a 1% increase in the lounge from Period 1 to Period 2. These effects are evident in spite of the fact that some smokers on the test floor were observed to have altered their smoking patterns to conform with the new policy prior to its implementation.

On a Sunday morning when the building was unoccupied, RSP and CO_2 levels were measured on the test and control floors (18 measurements). Measurements of outdoor air were also taken at rooftop level adjacent to the air intake (five measurements). Mean levels are shown in Table V as indoor and outdoor background levels, respectively.

The mean levels of outdoor air supply, temperature and relative humidity for Period 1 and Period 2 of the test and control floors are presented in Table VI. These parameters did not vary greatly throughout the course of the investigation. Hence it is assumed that they had little or no effect on the changes in RSP, CO and CO_2 levels that were observed.

The total number of employees on the test floor and the control floor who received the questionnaires, and the number of smokers and nonsmokers who responded to the questionnaires are chronologically listed in Table VII.

Discussion

After the new smoking policy was implemented, levels of RSP, CO and even CO_2 showed statistically significant reductions on the test floor. Among them, RSP is seen to be the most sensitive indicator of change in tobacco smoke levels. The RSP values of the test floor, after being standardized to the values of the control floor, decreased 23% from Period 1 to Period 2. In comparison, the corresponding decrease for CO was 7.2%.

The reduction in RSP levels observed during Period 2 could be attributed to either of two reasons: (1) removal or exhaust of RSP from the office air by the ventilation system, or (2) the reduction in the amount of tobacco products consumed.

The proximity of the smoking lounge to both the washroom exhaust and the general floor exhaust was probably responsible for the reduction in the RSP levels observed. In addition, passage of recirculated office air through 60% efficient filters would result in some particulate removal.

Many employees mentioned that some of the smokers had changed their smoking habits while measurements were in progress. A number of unsolicited comments to the same effect appeared on responses to the questionnaire administered before the implementation of the new smoking policy. Therefore it was interesting to observe that, before the new smoking policy was implemented, there were consistent reductions in levels of RSP, CO and CO_2 as the days progressed from Day 1 to Day 3 (Table II). Furthermore, it was noted that reductions also occurred in levels of RSP, CO and CO_2 on the control floor where no smoking policy change was introduced (Table III). These could be interpreted as an impact of survey activities alone on smoking habits of the occupants of both floors during the survey period. Such an alteration in smoking habits might have lessened the observed effects of the new smoking policy on the office air quality.

Measuring RSP in order to estimate mean levels on each floor presented problems. The major difficulty was the random distribution in space and time of point sources, each point source being a smoker. It is possible that smokers consciously or unconsciously altered their position on the floor when smoking, either avoiding the measuring instrument or alternatively approaching it. The approach taken was to sample at randomly selected fixed sites, uninfluenced by the location of smokers. Practical considerations limited the number of sampling sites to eight on each floor, which may or may not be sufficient to generate true mean values. In retrospect, a better space-time average RSP level might have been obtained by continuously moving the piezobalance throughout the floor area during an extended measurement period.

The questionnaire concerning smoking habits was circulated to all employees on both floors. Completion of the questionnaire was voluntary and its success was dependent on the cooperation of the employees. However, low response rates as shown in Table VII did not permit accurate interpretation of the amount and pattern of smoking.

Conclusions

1. After smoking was limited to the staff lounge, there were significant improvements in the air quality of the test floor as illustrated by a 23% reduction in RSP concentration. If the smoking lounge air were directly exhausted to the outside, even greater improvements would be expected.

2. The measurement of RSP proved to be an appropriate and practical tool in assessing changes in the extent of tobacco smoke contamination of indoor air.

3. There were indications that the presence of survey activities influenced tobacco consumption and smoking patterns in the survey areas. Careful consideration and planning are recommended in future studies to minimize such factors.

Acknowledgements

The authors would like to express their gratitude to Dr. Y. Mao of Laboratory Centre for Disease Control, Health and Welfare Canada for his advice and substantial contribution in statistical data analysis.

Participation of Health and Welfare Canada employees, Miss L. Vance, and Messrs. R. Phillips, B. Frenette and R. Farmer in the air quality measurements, and Mr. P. Tierney in the data analysis, are also gratefully acknowledged.

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Table I Major characteristics of the test and control floor

	Occupiable Floor Area m^2 (ft^2)	Number of Employees	Population Density per 100 m^2
Test Floor (Floor 8)	3,289 (35,400)	149	4.5
Control Floor (Floor 9)	2,299 (24,750)	75	3.3

Table II Daily mean levels of RSP, CO and CO_2 over both test and control floors

		RSP ($\mu g/m_3$)	CO (ppm)	CO_2 (ppm)
Period 1	Day 1	30	2.21	632
	Day 2	28	1.65	616
	Day 3	25	1.30	591
Period 2	Day 1	21	1.34	552
	Day 2	24	1.10	589
	Day 3	23	1.12	598

Table III Mean values of RSP, CO and CO_2 levels on the floors before and after the new smoking policy

		RSP ($\mu g/m^3$)	CO (ppm)	CO_2 (ppm)
Period 1	Test Floor	26	1.67	624
	Control Floor	29	1.75	601
Period 2	Test Floor	18	1.09	590
	Control Floor	27	1.29	569

Table IV Mean RSP, CO and CO_2 levels measured on the test floor

		RSP ($\mu g/m^3$)	CO (ppm)	CO_2 (ppm)
Period 1	Floor	26	1.67	624
	Lounge	51	1.98	642
Period 2	Floor	18	1.09	569
	Lounge	189	2.40	650

Table V Indoor and outdoor background RSP and CO_2 levels

	RSP($\mu g/m^3$)	CO_2(ppm)
Indoor	10	352
Outdoor	6	330

Table VI Ventilation, temperature and relative humidity measurements

		Outdoor Air Supply lps/person (cfm/person)	Temperature °C (°F)	Relative Humidity %
Period 1	Test Floor	14 (30)	23 (73)	33
	Control Floor	19 (40)	23 (73)	37
Period 2	Test Floor	13 (28)	24 (75)	29
	Control Floor	19 (40)	23 (73)	26

Table VII Questionnaire responses

Date	Floor	Respondents (Smokers/Nonsmokers)	No Response	Total
July 9/84	Test	131(20/111)	25	156
Dec. 10/84	Test	117(21/96)	30	147
	Control	14(14/-)	61	75
Jan. 16/85	Test	96(14/82)	55	151
	Control	34(8/26)	41	75

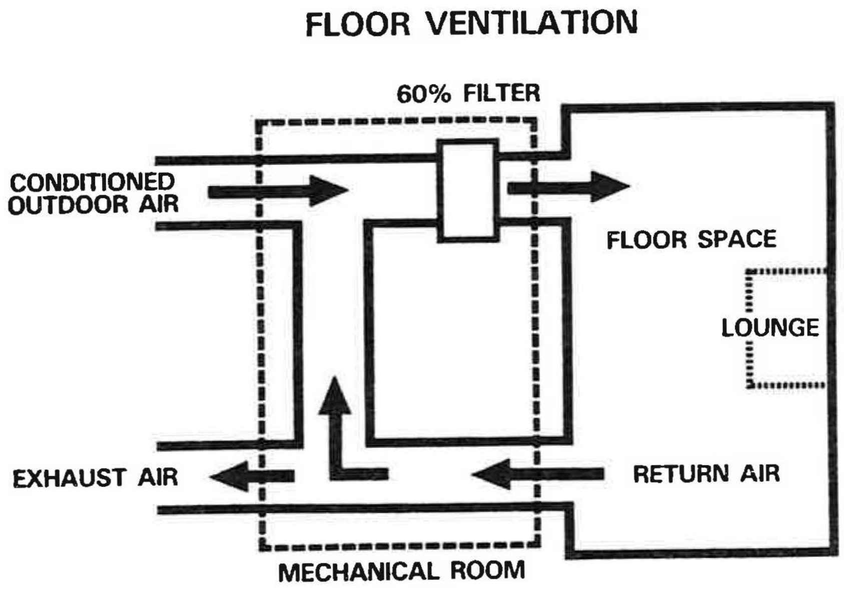

Figure 1. Schematic diagram of floor ventilation system.

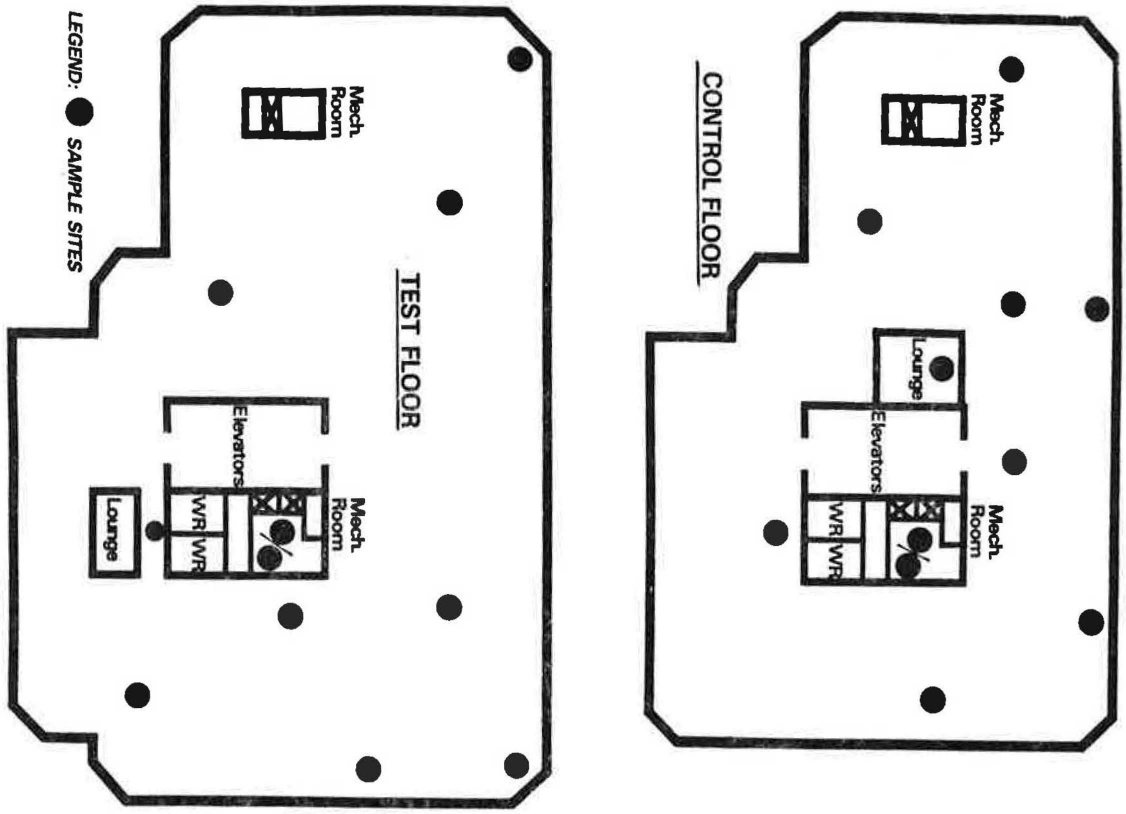

Figure 2. Sampling site locations on control floor and test floor.

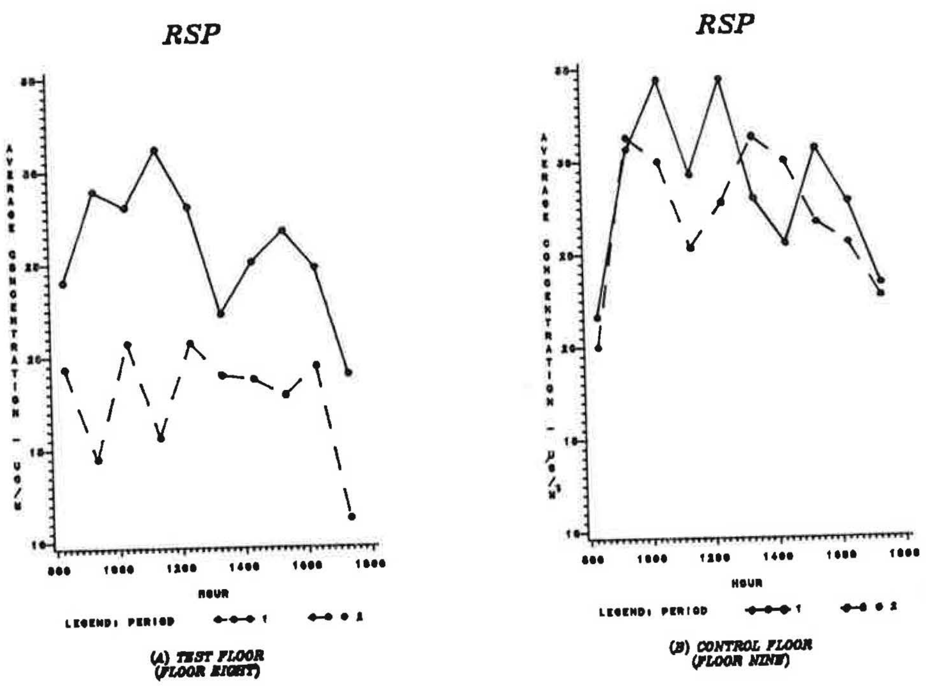

Figure 3. Hourly variations of RSP levels averaged over three day measurement periods.

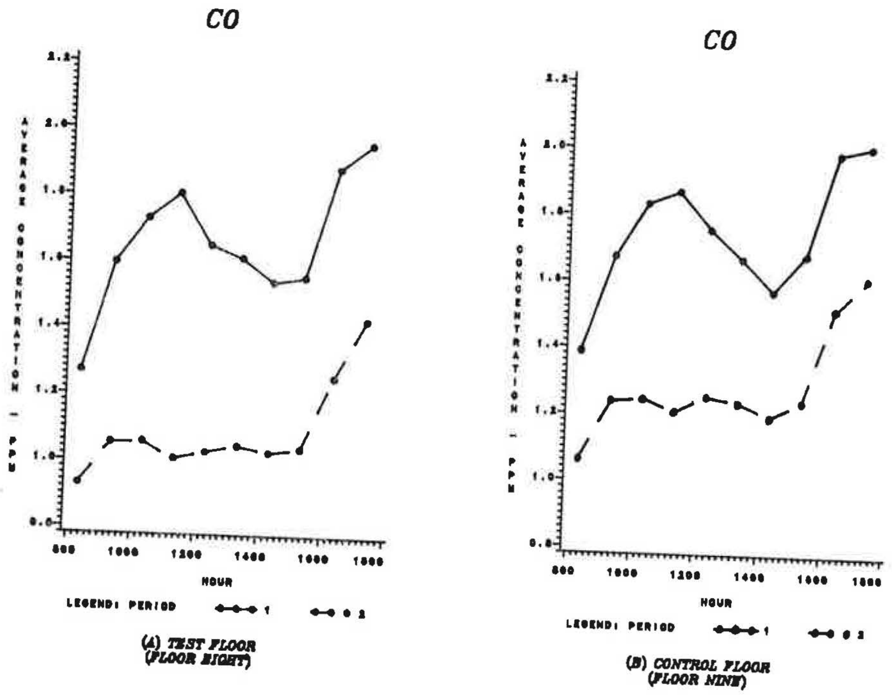

Figure 4. Hourly variations of CO levels averaged over three day measurement periods.

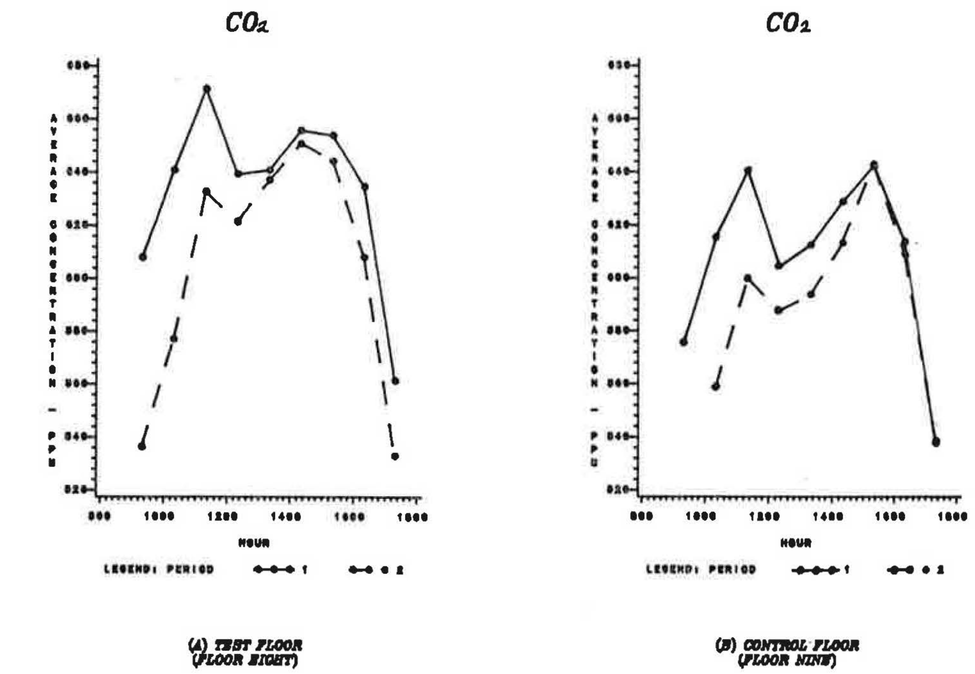

Figure 5. Hourly variations of CO_2 levels averaged over three day measurement periods.

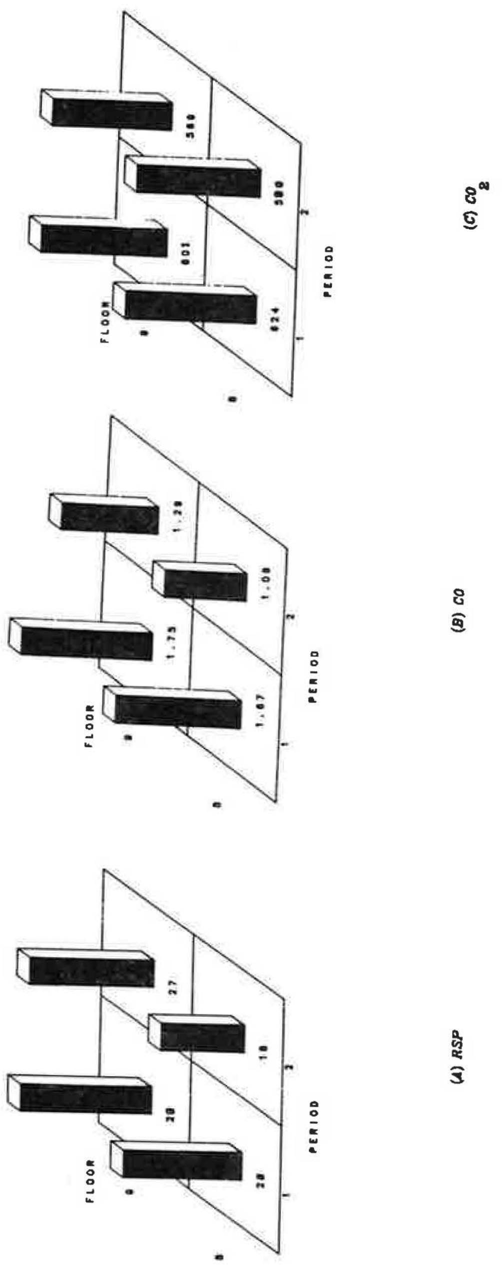

Figure 6. Mean RSP, CO and CO_2 levels on the test floor (Floor 8) and the control floor (Floor 9), before and after the new smoking policy.

OFFICE ENERGY CONSERVATION: THE EFFECT ON AIRBORNE PARTICLES AND THEIR CHEMICAL CONSTITUENTS

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Energy conservation is a prime consideraton in the operation of telephone office buildings. Following the soaring cost of energy in the mid-1970s, an energy saving program based on a larger permissible range for indoor temperatures was initiated. Whereas the previous practice was for air handling fans to run continuously, under the new program fans operated only when necessary to bring the temperature within allowable limits. The effects of fan operation on indoor airborne particles and the chemicals associated with those particles were monitored at several representative telephone offices. During the tests the building fans were cycled between 2-week intervals of continuous fan operation and 2-week intervals of intermittent fan operation.

Results indicate that filtration of recirculated air is a major factor determining the average indoor concentration of airborne particles. When the fans are off the concentration of airborne particles increases, primarily because of the lack of recirculation/filtration. The concentrations of most of the chemical constituents of the indoor particles increase by the same relative amount that the concentration of the particles increases. The major exceptions are organic compounds that are associated with airborne particles through an adsorption process. Their concentrations do not scale in a simple way with particle mass, sometimes increasing by a much larger factor. This is due to both an increase in the fraction of such compounds attached to particles (as the surface area/unit volume of air increases) and to a greater overall concentration of such compounds (as the dilution with outside air decreases).

An expression has been derived for the relative increase in airborne particles when the building fans are turned off. Among other factors, the relative increase is directly proportional to the efficiency of the building filters and to the rate at which air is recirculated through them.