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Concentration Variations of Pollutants in a Work Week Period of an Office

Y. K. CHUAH*
Y. M. FU†
C. C. HUNG†
P. C. TSENG†

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Indoor air quality problems for a typical office space were investigated. Continuous monitoring of concentrations was carried out for CO_2, CO, formaldehyde, and total hydrocarbons. It was found that the CO_2 concentration was at times above 2000 ppm and that for CO above 14 ppm. In addition, concentration levels of formaldehyde and total hydrocarbon were found to peak at midnight and indicated non-human sources. Partial opening of windows resulted in CO_2 concentration levels of 800 ppm or below. Ventilation rate measurements using trace gas decay method found that the air change rates were well below one air change per hour. © *1997 Elsevier Science Ltd.*

INTRODUCTION

There have been several studies in which air quality or ventilation effectiveness was measured in buildings. Among the recent studies, Chiang and Wang [1] studied the factors that influenced the indoor air quality. Pollution sources were studied for the different seasons in a year. The correlation between indoor and outdoor air pollution was analyzed. Yoshizawa [2] measured the concentrations of CO_2, CO, NO_x and biological particles in some Japanese buildings. High pollution levels were measured in cases in which there was insufficient ventilation or poor air distribution. Yoshino *et al.* [3] measured the ventilation effectiveness in an airtight house with a mechanical ventilation system; it was a two storey detached wooden house. They found that, depending on the location of measurements, air age could range from 60 to 120 minutes.

There has been some literature on indoor air quality measurements. Chuah *et al.* [4] presented the results of CO_2, CO, and particle concentration measurements in an apartment building and found CO_2 concentration in the bedroom to be higher than 1000 ppm during most of the night. Reardon and Shaw [5] measured the concentration variation of CO_2 and used trace gas method to study the minimum air change rates in a high rise building. Also by using the trace gas method, Shaw *et al.* [6, 7] studied the indoor air quality as a function of air movement control design, such as diffusers.

There are many types of buildings these days that have air quality problems that should be evaluated seriously. From the above literature, measured data can be found for indoor air quality in some types of buildings, however there is still a lack of measured data for indoor air quality for many buildings. Measured data of ventilation rates and from continuous monitoring will help in the search to find solutions to indoor air quality problems using building or mechanical designs. Therefore, it is important to identify the problems by measuring the indoor air quality data for various kinds of buildings with different air-conditioning designs.

This study focuses on the measurement of indoor air environment for a high rise office building. The concentrations of CO_2, CO, formaldehyde, and total hydrocarbons were monitored continuously for a period of four and a half days. Also, the effectiveness of ventilation in terms of air exchange rate was measured. The office under study was located on the thirteenth floor of a high rise building in the city center of Taipei. The air-conditioning system consisted of floor-standing fan coil units (standing about 82 cm from the ground with air flowing upwards) distributed in different parts of the office and had no proper means of ventilation. Fresh air intake was primarily by infiltration and opening of doors and windows. The office consisted of many rooms and the layout of the office is shown in Fig. 1. Measurements were done for six rooms of the office, of which rooms A and D had multiple occupancy and the rests were used by managerial officials and had only one occupant.

THE AIR QUALITY MEASUREMENT

Measurement of the air quality was carried out with conditions in the office maintained as usual in order to obtain realistic data. The concentrations of CO_2, CO, formaldehyde, and total hydrocarbons were measured and monitored continuously. The equipment used included a multi-gas monitor made by B & K, an air quality monitor made by Metrosonics, two set of CO_2 sensors made by Telaire, and a Fluke data logger.

*Department of Mechanical Engineering, Chang Gung College of Medicine and Technology, Taoyuan, Taiwan, R.O.C.
†Energy and Resources Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan, R.O.C.

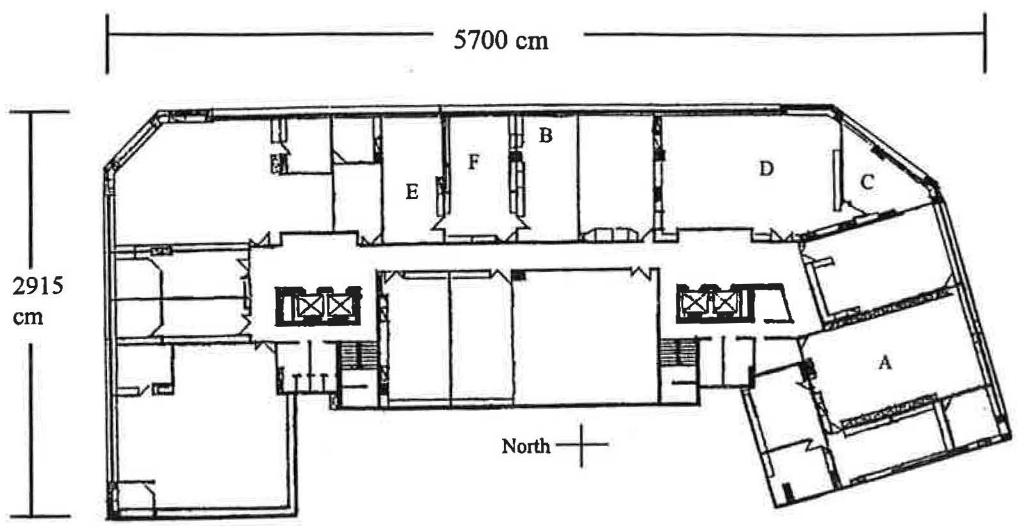

Fig. 1. The layout of the office under study and the rooms for which air quality was measured.

For comparison, different conditions of the windows were experimented with. The experiments lasted four and a half days. The windows were totally closed for the first two days and one quarter opened for the rest. This was done by the occupants at times on non-windy days. It was noted that there was no rain and only breezes during the days of measurement. In all cases, continuous monitoring of the pollution sources was carried out. Altogether, data were taken for six different rooms in the office as shown in Fig. 1. To avoid local concentration, sampling was done by tube connection to collect air samples from different positions in the rooms, as shown in Fig. 2. The air samples were then pumped into the measuring equipment after mixing. Therefore, the measurements represent the average conditions in each of the rooms.

To further study the problem, the ventilation rates were measured by a trace gas method. The concentration of a trace gas, SF_6 in this case, was continuously monitored after it was released into the space. The concentration decay of SF_6 with time was used to calculate the ventilation flow rates. The measurements were carried out in the month of October while the day tempe was still high and air-conditioning necessary.

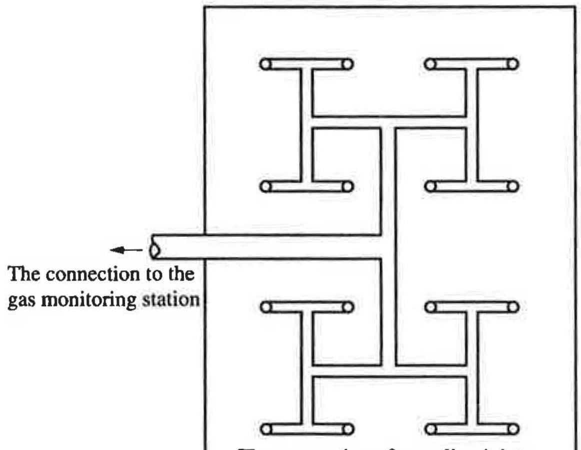

Fig. 2. The sampling tube connection of gas samples from the rooms.

RESULTS AND DISCUSSION

During the measurements, two kinds of windo ditions were used. Before 14 October 1995, i requested that windows be totally closed all the And after that it was requested that windows were one quarter open during office hours, from 8:30 to hours. This was done to study the effects of the wi conditions as adjusted by the occupants to achieve a tolerable air quality. At the same time, data on air q can be obtained under this type of air-conditi arrangement.

Figure 3 shows the variations of the concentrati CO_2 during a four and a half day period, with da shown, in 1995. Before 14 October, it was requeste the windows be closed all the time. As shown in F the concentration of CO_2 went above 1800 ppm d the day, especially for rooms with multiple occup However, when the window conditions returned to conditions, the CO_2 concentration dropped to b 800 ppm, mostly in the range of 600–800 ppm. The i erable conditions in the office are verified. The r show that infiltration and occasional opening of doo not bring in sufficient amounts of fresh air. A mecha means of ventilation is necessary for office spaces.

Figure 4 shows the variations of CO. The sour CO was not well understood. However, when the dows were closed for the first two days, CO level high and seemed to accumulate after working h When the windows were partly opened to allow mo exchange, the concentration of CO dropped to a le 4 ppm or below most of the time. CO pollution o originate from vehicles running on the streets. How the results of measurements as shown contradicted conjecture as the concentration increased during office hours when the windows were closed. CO centration was found to reach 10 ppm at times peaked at 14 ppm, especially on days when the win were closed. However, the CO concentration peak

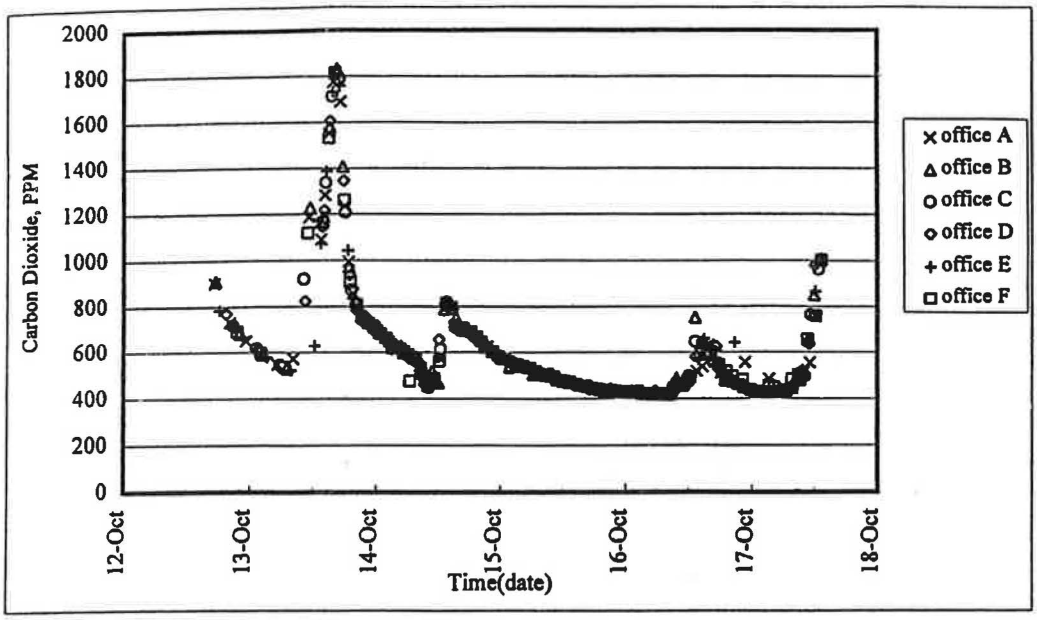

Fig. 3. Time variation of CO_2 concentration in the different rooms.

midnight when there was little office activity. It was known that there was no kitchen or any combustion activity in the office. The sources of CO were not known and this is a subject worthy of further investigation.

Figure 5 shows the variations of the concentration of formaldehyde. Contrary to the previous results, the concentration level was lower for the first two days and the last day. Also, all the rooms showed the same trends of concentration variations. Concentration of formaldehyde was found to reach 5 ppm at times. For most of the time, the concentration level of formaldehyde was more than 0.4 ppm. It appears that the pollution due to formaldehyde concentration is a matter of concern and requires further study. It also appears that a higher level of concentration occurs after working hours.

Figure 6 shows the concentration variation of total hydrocarbons. No particularly high level of concentration appeared, but the patterns resembled those of the variations of formaldehyde. Therefore, it appears that formaldehyde and total hydrocarbons originated inside the building and accumulated fast after working hours. It was known that there was no chemical cleaning activity in the building after working hours during the duration of measurements. The results could be due to release from the furniture or the decoration materials of the office.

For both CO and formaldehyde, the concentration levels lowered during office hours, probably due to the ventilation effects of occasional opening. So, both CO and formaldehyde were probably from non-human sources and were not directly due to human activities.

As the measurement and verification of pollution sour-

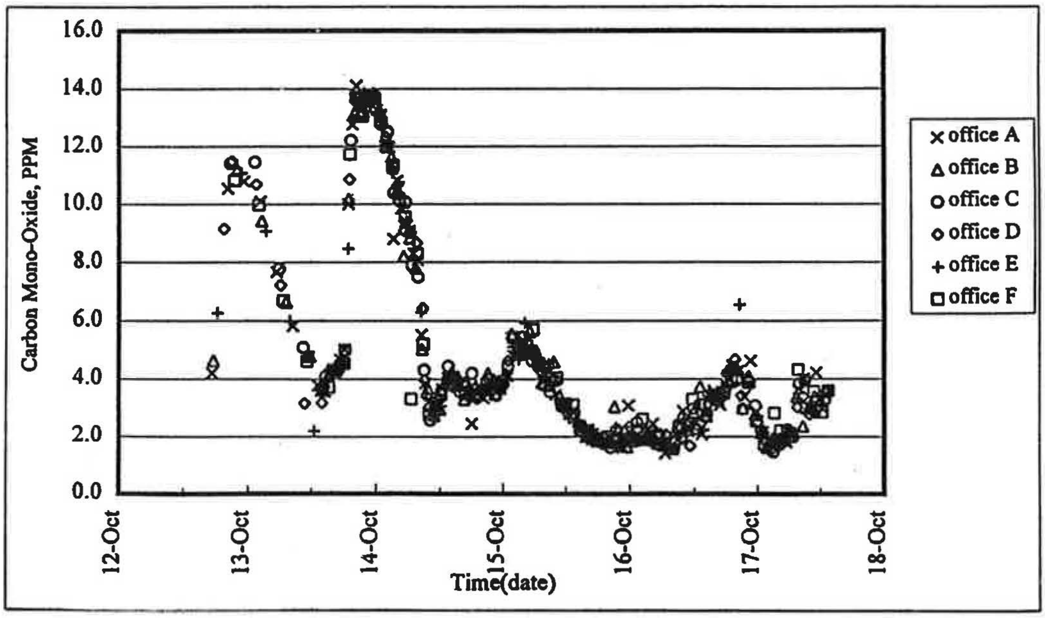

Fig. 4. Time variation of CO concentration in the different rooms.

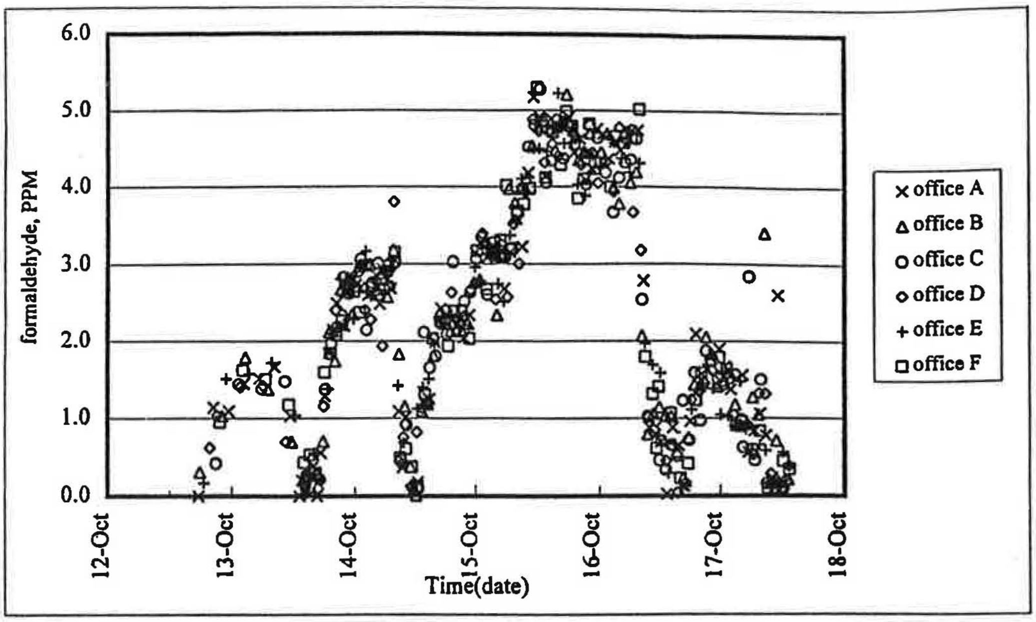

Fig. 5. Time variation of formaldehyde concentration in the different rooms.

ces requires elaborate instrumentation it is not easy to be certain of all the pollution sources. As it is shown in Fig. 6, the total hydrocarbon concentration reached 30 ppm at times and was maintained at 20 ppm levels most of the time. This shows that there were other sources of pollution due to hydrocarbon compounds and some of the levels of pollution may be higher than healthy conditions. This again verifies the importance of ventilation in maintaining a good air quality.

SF_6 was used as a trace gas to study the ventilation effectiveness of the office. After it was released into the office, its concentration decay was continuously monitored. The rate of decay indicated the rate of air exchange and the exchange rate can be calculated using the following equation:

$$\mathrm{ACH} = \frac{\ln C(0) - \ln C(ti)}{ti}, \qquad ($$

where

ACH = air change per hour (time/hour)
ti = total time of measurement, hr
$C(0)$ = the initial concentration, measured when tl concentration becomes well mixed after releas of the tracer gas is stopped, m^3/m^3
$C(ti)$ = concentration of SF_6 at time ti, m^3/m^3.

The trace gas concentration method was applied t room D to measure the ventilation rates. Figures 7 an 8 show the decay of the concentration of SF_6 in room I with time. Obviously, the decay was slower when th

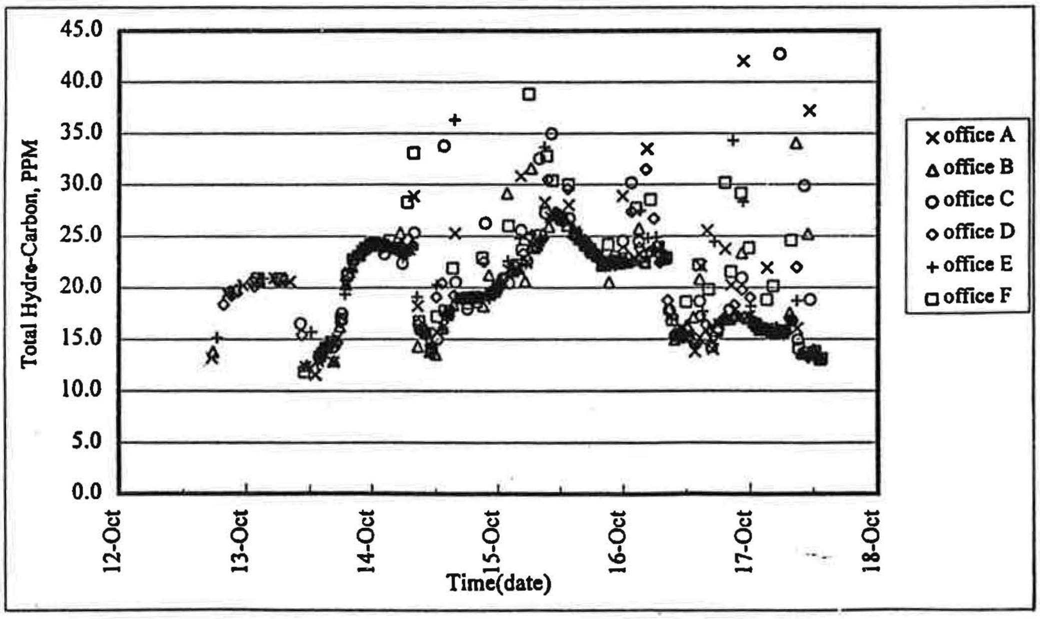

Fig. 6. Time variation of total hydrocarbon concentration in the different rooms.

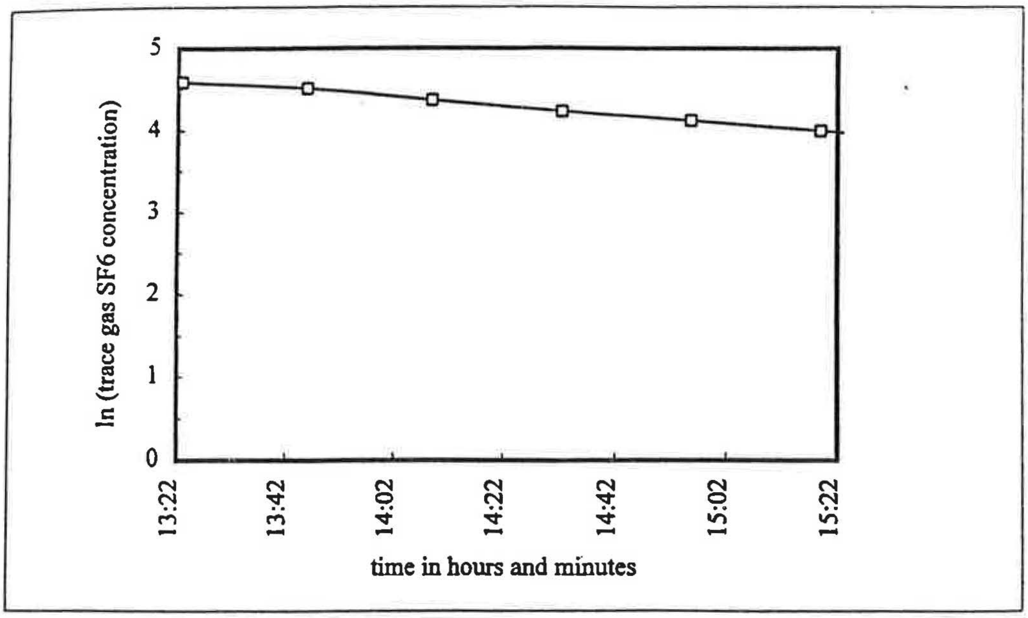

Fig. 7. The concentration decay of the trace gas (SF_6) in room D when the windows were totally closed.

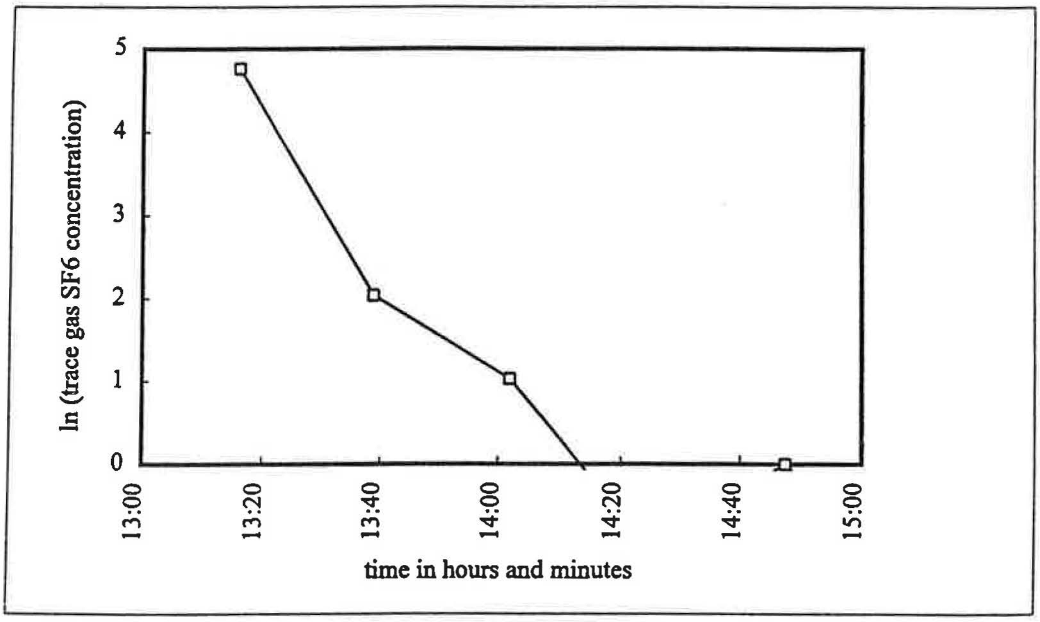

Fig. 8. The concentration decay of the trace gas (SF_6) in room D when the windows were partly opened.

windows were totally closed. For room D, the floor area was about 211.94 m^2 and the occupancy was 20 persons. The air change rates resulting from the concentration decay measurements were calculated using the equation presented above and are shown in Table 1.

According to the above results, the air exchange was quite low when the windows were closed. According to the ASHRAE Standard 62-89 [8], 20 cfm of fresh air is needed per person; the room had about 20 persons at one time, therefore at least 676 cmh of fresh air was needed for this room. The ventilation rate was measured to be 0.33 air changes per hour without opening of windows and indicated exceedingly high air age.

The above case is quite typical for many older office buildings that were not designed with proper ventilation. Research work on the improvement of the air quality is

Table 1. Measurements of air change using SF_6 as the trace gas

	Windows totally closed	Windows quarter opened
Air change, per hour	0.333	2.75
Ventilation rate, cmh	71	582
ASHRAE Standard: 20 persons * 20 cfm (ft^3/min) = 400 cfm = 676 cmh (m^3/hr)		

important, especially on the application of new technology such as the total heat exchanger to save energy while introducing more fresh air into rooms.

CONCLUSION

An office building that did not have proper means of ventilation was studied to determine its indoor air quality. Concentrations of CO_2, CO, formaldehyde, and total hydrocarbon were monitored 24 hours a day for four and a half days. The ventilation rate of the office was also measured using a trace gas decay method. It was found that the concentrations of the above sources of pollution went above some recommended standards at times, with CO_2 concentration reaching 1800 ppm. However, for CO, formaldehyde and total hydrocarbon, the highest (centrations was recorded during non-office hours indicated non-human origins of these pollution sour(

Ventilation rate was found to be excessively low, (about 0.33 air changes per hour. For this office, the o(pants at times opened the windows for more fresh The windows were opened one quarter in the l measurements for comparison. It was interesting to ı that the air quality returned to healthy levels, with (concentration reaching only about 800 ppm. The res presented prove that a mechanical means of ventila that supplies the minimum required fresh air is impera in maintaining a good indoor air quality.

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