11120

CIBSE National Conference 1997

AIR POLLUTION AND NATURAL VENTILATION IN AN URBAN BUILDING: A CASE STUDY

Vina Kukadia, James Pike and Martin White

Building Research Establishment Ltd, Garston, Watford, WD2 7JR

In recent years, increases in pollution emissions resulting from an increase in vehicular traffic have caused great public concern regarding the quality of urban air and its impact on those working in these areas. In buildings this has led to an increase in the installation of air conditioning systems to 'clean' the incoming air. However, with environmental issues in mind such as high energy costs, the related CO_2 emissions and global warming, designers are increasingly being encouraged to consider natural ventilation as the primary design option. Concern about air pollution and external noise still remain and these are perceived to be major barriers in the design of buildings located in urban areas, although there is no real data to support this. BRE is thus carrying out a study of the levels of air pollution and noise in such buildings.

This paper presents results of measurements carried out for a number of pollutants inside a naturally ventilated building located near a major road, where atmospheric pollution and noise levels are perceived to be high. The building, a recent design completed in 1994, incorporates a specially designed natural ventilation strategy with air supply intake from a courtyard away from the busy road. Ventilation rates within the building and external wind speed and direction were monitored to allow the pollution measurements to be put into context. Some noise measurements are also reported. An initial analysis of the ventilation strategy used in mitigating the effect of external pollution while providing adequate ventilation for the occupants has been made for the winter period.

1. INTRODUCTION

Historically, the improvement in urban air quality throughout the United Kingdom has been dramatic. The smogs of winter 1952 which led to the premature deaths of 4000 Londoners have been all but eliminated. This success has largely been attributed to the Clean Air Acts of 1956 and 1968, the move away from domestic coal burning and the centralisation of electricity generation in large power stations away from towns and cities.

More recently however, because of increases in pollutant emissions from vehicular traffic and other human activities, urban air quality is once more causing great public concern, especially in relation to current and projected traffic levels (1). In the UK, traffic is estimated to double by 2025 and there is real concern that even with the substantial financial investment in exhaust emission controls, urban air quality may deteriorate again.

Due to this and to a current lack of guidance on alternative low energy solutions, many investors feel that mechanical ventilation or air-conditioning is necessary in office buildings located in urban areas to clean the incoming air from external urban pollution sources. However, with environmental issues such as, high energy costs for air-conditioning and related CO_2 emissions and global warming in mind, designers are increasingly being encouraged to consider natural ventilation as the primary design option. In particular, naturally ventilated office buildings can typically consume less than half the delivered energy consumed in air-conditioned buildings, representing cost-effective energy savings of the order of 20-30%.

However, effective design for natural ventilation in urban locations needs a fundamental understanding of the way in which external air flows, pollutant sources (internal and external) and ventilation processes affect the indoor environment before practical guidance and strategies can be developed. Currently, research at the Building Research Establishment Ltd (BRE) is addressing how fundamental parameters affect the indoor air quality in naturally ventilated buildings located in urban areas. As part of this study, BRE is extensively monitoring a naturally ventilated building in London. Initial findings from this study are reported here.

2. PREVIOUS STUDIES

Previous studies (2,3,4) have shown that in urban areas, road vehicles are a major source of pollution, in particular of carbon monoxide and nitrogen dioxide. Concentrations of these pollutants are often lower internally than in the external environment although they usually follow outdoor pollutant trends. Other more localised pollutant sources such as, boiler flues and cross-contamination between ventilation exhausts and inlets, may account for higher internal concentrations of certain pollutants than those found externally.

Furthermore, internal-external air quality relationships can be a complex function of several factors including : the combination of external 'local' sources and 'background' pollutant levels (5) and their temporal and spatial variation; meteorology (wind speed, direction, weather patterns); dispersion processes around the building; permeability of the building envelope; indoor pollutant sources; pollution depletion mechanisms and ventilation processes (6). In urban locations, the surrounding structures, as well as the size, shape and the orientation of the building itself are important parameters in the building contamination process.

3. CURRENT STUDY

3.1 Description of building and ventilation strategy

The building (Figure 1), located on a busy high street in London, is a two-storey day care centre providing easy access to counselling, treatment and support for people who would otherwise have to attend hospital. The design of the building and its ventilation system was based on a relatively low budget together with the need to protect patient confidentiality by preventing pedestrians overhearing sensitive conversations from rooms situated on the roadside and to prevent the intrusion of external noise and air pollution.

A natural ventilation strategy (Figure 2) was developed using diaphragm cross walls to provide a series of chimneys which allow air to be drawn through the building assisted by wind and buoyancy forces. The south west side of the building, on which the therapy and interview rooms are located, faces the busy High Street and pedestrian area where air pollution and noise levels are perceived to be high. Windows on this side are unopenable. The north east side of the building backs onto an enclosed garden courtyard which also serves as the Centre's car park. During the period of the monitoring, although the car park was, in general, full during the working day, it is believed that no cars had been left running to have had any major effect on the indoor air quality in the building.

Fresh air for the building comes exclusively from the courtyard side where air pollution and noise levels are believed to be low. It enters through slots in the external ends of the diaphragm walls and is drawn into the rooms located on the High Street through low level grilles in the diaphragm wall. Fresh air for rooms on the courtyard side is purely via trickle ventilators and openable windows. 'Used' air is expelled through grilles at high level in each room and is drawn out at the chimney tops. Adjustable dampers (Figure 3) in the stacks control the air change rate in each room. In general, these are controlled centrally and are set on a fully open position in the summer to aid cooling; and an almost closed position in the winter to provide adequate ventilation while minimising energy loss. However, in the winter, if a room becomes too warm due to the heat generated by the occupants, a manually controlled button installed in each room may be pushed, to open up the dampers for a one hour period to increase the air change rate in that room and remove any excess heat. During the period of monitoring the dampers were in the winter position, ie. almost closed. Heating via thermostatically controlled radiators was in operation during the period. Double glazed panels facing the south or west (depending upon the part of the building which they service) towards the top of the chimney are intended to act as solar 'accelerators' to increase air extraction in the summer.

4. MEASUREMENTS

Table 1 lists the monitoring instruments and averaging times of the measurements used for this study. Measurements of carbon monoxide (CO), carbon dioxide (CO_2), ventilation rates, temperature and humidity were carried out continuously over a one week period during March 1997 in four offices: two on the roadside and two on the courtyard side (ground and first floor). External measurements of CO and CO_2 were also taken at a single point at a height of 4m immediately outside office 3 on the roadside. For practical reasons, measurements of noise were carried out only in the two first floor offices, 3 and 4, and measurements of nitrogen oxides (NO_x) and sulphur dioxide (SO_2) in a seminar room in another part of the building (Figure 1). Also for practical reasons it was not possible to carry out wind speed and direction measurements at the monitoring site. These were obtained from the nearest meteorological site which is based in Whitehall, approximately 10 miles away. This is sufficient to give the overall wind speeds and directions for the district, but not the more precise levels close to the building.

Ventilation rates were measured by using the conventional technique of observing the decay of an injected tracer gas (sulphur hexafluoride) seeded into the areas of interest.

Table 1: Instruments and methods used to measure internal and external parameters

Parameter	Method	Averaging period	Measurement interval
Carbon monoxide	Photo-acoustic	1 min	30 mins
Carbon dioxide	Photo-acoustic	1 min	30 mins
Ventilation rate	Photo-acoustic	1 min	-
Nitrogen dioxide	Chemiluminescence	30 secs	30 mins
Nitrogen oxide	Chemiluminescence	30 secs	30 mins
Sulphur dioxide	Pulsed Fluorescence	30 secs	30 mins
Temperature	Thermistor	spot	30 mins
Noise	Acoustic	1 min	1 hour

5. RESULTS

5.1 Pollutant concentrations

Carbon monoxide (CO)
Figures 4(a-e) show the internal and external (measured at one point on the roadside) concentrations of CO within the four offices monitored. As expected, all the offices show very similar contaminant levels because of the common air intake from the courtyard side. Low external CO levels measured over the weekend period indicate little vehicular activity in comparison with the working week. During certain periods of the working week, relatively high CO concentration peaks occurred externally reaching levels of about 12 ppm. Comparison of the contaminant levels measured inside the offices with external measurements taken at a single point on the roadside indicate that these high contaminant peaks were reduced considerably and did not occur inside any of the offices monitored. Even office 3, outside which the external measurements were carried out, does not show these peaks, indicating little pollutant infiltration through the fabric of the building.

When outside CO concentrations were very low (less than 0.5ppm) the internal levels often exceeded external roadside levels. It is possible that contamination levels were higher on the courtyard side in these cases or that the building retained the contaminant dispersing it slowly whilst the external concentration dispersed more rapidly. However, since the external measurement point was not in the courtyard near the inlet to the offices monitored, it is not possible at this stage to make any firm conclusions on the quality of the air on this side of the building. In fact these studies show that a single external measurement point is not fully representative of the overall exposure levels experienced around the building and highlights the need to carry out a range of lateral and vertical measurements externally on both sides of the building. Nevertheless, it is clear that by using supply air from the courtyard side the high concentration peaks of CO (12ppm) in the external environment appear to have been reduced to values around a mean of about 0.3 ppm inside the building. This is well below recommended air quality guidelines as given in Table 2.

Oxides of nitrogen (NO_x)

The measurements of nitrogen dioxide (NO_2) and nitric oxide (NO) are shown in Figure 5. Due to practical constraints only internal measurements could be made and it is not therefore possible to make any comparison with concurrent external concentrations. However, comparison of hourly concentration means of these pollutants with standard air quality guidelines (Table 2) shows that levels were low in the building. In general, NO_2 is a product of a variety of combustion processes including traffic. However, there were no other known sources of NO_2 in the area apart from the road traffic on the High Street. It can therefore be assumed that the low levels measured in the building indicate that air intake from the courtyard side away from the road traffic gave acceptable concentrations.

Table 2. Measured mean concentrations over the monitoring period inside the offices compared with recommended air quality guidelines.

Measured gas	Measured mean concentrations	Recommended air quality guidelines		
		Expert Panel on Air Quality Standards	World Health Organisation	European Community
CO (ppm)	0.3^1	10^1	10^1	-
CO_2 (ppm)	400	-	-	-
NO (ppb)	22^2	-	-	-
NO_2 (ppb)	43^2	150^2	80^1	105^1
SO_2 (ppb)	2^2	100^3	122^2	94^2

1 8-hour mean
2 1-hour mean
3 15-min mean

Sulphur dioxide (SO_2)

Internal levels of SO_2 (Figure 6) are typical of levels found in previous studies (2,3) and were below recommended air quality guidelines. This is as expected, since in general, external trends of SO_2 concentrations in London show that background levels have decreased by almost 60% since 1970 and by 45% since 1980 (7). This is largely attributable to the relocation of power stations away from city and urban areas and the growing use of natural gas and lower sulphur content fuel oils in combustion plant.

Carbon dioxide (CO_2)

Increased levels of CO_2 within buildings are usually occupant generated. CO_2 results for office 1 are shown in Figure 7. These are typical of levels obtained in all the offices monitored. As expected, the high concentrations (with peaks of about 1100 ppm) correspond to periods during the working week when the office was occupied. The levels reduced to a background of about 400 ppm during the weekend and at night. In general the occupancy in each room was variable on each day and this is shown by the varying degree of CO_2 levels. A background value of about 400 ppm is also seen in the external environment where there are no known sources and is in agreement with previous work (4).

5.2 Temperature and humidity

The issue of overheating arises in the summer months. However, the monitoring described here was carried out during a relatively warm winter period with external temperatures reaching values of about 16°C. Mean internal daily temperatures varied between 17.5 - 21°C and at night between 16 - 19°C in the four offices monitored. This is in good agreement with an average winter temperature internally of 18°C for which the offices in the building were designed.

Relative humidity levels varied between about 40-60% in the offices monitored which is in agreement with general levels quoted in CIBSE Guide A (8).

5.3 Ventilation rates

During the monitoring period (in winter) air change rates agreed with winter design values for the building of about 1-2 ach. Ventilation rates in the four offices varied between about 8 ls^{-1} per person to 20 ls^{-1} per person over the monitoring period. Again, this is in reasonable agreement with an average design value for the building of 12 ls^{-1} per person and a recommended value of 10 ls^{-1} per person (9).

From the results of the CO_2 and temperature measurements, it is apparent that the air change rates that were reached during the monitoring period were successful in removing metabolic CO_2 from the offices and in keeping temperatures in the offices to values for which they were designed.

5.4 Wind speed and direction

Wind speed and direction from the nearby Meteorological site are given in Figure 8. Wind speeds varied between about 1 to 9 ms^{-1} over the monitoring period. Some initial analysis of wind speed and direction showed no simple relationship with the internal and external CO concentrations measured.

5.5 Noise Levels

Noise measurements taken for an earlier monitoring period in October 1996 gave average external noise levels of 75 dBA. It was found that, in general, average noise levels were lower in office 4 (courtyard side) at 40 dBA than in office 3 (roadside) at 50 dBA and higher during peak periods of traffic. These are in reasonable agreement with acceptable values of about 45-50 dBA for offices (10, 11, 12).

6. CONCLUSIONS

Although investigations are continuing at the building (to include the summer period) on the effectiveness of the natural ventilation strategy, some initial conclusions can be made from the results of the short period of monitoring during the winter (March 1997) reported here. It is known that the main source of carbon monoxide in the vicinity of the building was vehicular traffic. As such this study has shown that 'fresh' air intake from the courtyard side has been successful in damping the relatively high concentration peaks which occurred in the external measurements on the roadside. Furthermore, internal concentrations of all the pollutants measured, were well below recommended air quality guidelines indicating little health risk in the building.

Ventilation measurements showed adequate air change rates for removal of metabolic CO_2 and keeping the temperature at acceptable levels. Noise levels were also found to be acceptable. Initial analysis of wind speed and direction showed no simple relationship with the internal and external carbon monoxide concentrations or the air change rates measured.

Finally, we may conclude from this short winter monitoring period that a natural ventilation strategy is possible in an urban location where external traffic pollution is perceived to be high. Acceptable pollutant levels for health and ventilation rates for respiration were achieved during the period of monitoring.

ACKNOWLEDGEMENTS

This research was supported by the Department of the Environment (DoE) and carried out under the DoE Construction Sponsorship Directorate's Energy-Related Environmental Issues (EnREI) programme. The research team would like to express their gratitude to the owners and occupants of the buildings, in particular N Morris, M Osbourne and M Strachan as well as I Logan and P Bellow and J Grace for assisting with the project. Appreciation is also tendered to Colin Craggs for all his help and guidance during the monitoring period.

REFERENCES

1. '*Urban Air Quality in the United Kingdom*', First report of the Quality of Urban Air Review Group, DoE, January 1993.

2. V Kukadia and J Palmer, '*The Effect of External Atmospheric Pollution on Indoor Air Quality*'. 17th Annual Air Infiltration and Ventilation Centre Conference, Sweden September 1996.

3. V Kukadia, J Palmer, J Littler, R Woolliscroft, R Watkins and I Ridley. '*Ventilation in urban areas and city centres*'. Proceedings of CIBSE/ASHRAE Joint National Conference, Harrogate, October 1996.

4. JL Phillips, R Field, M Goldstone, GL Reynolds, JN Lester and R Perry. '*Relationship between Indoor and Outdoor Air Quality in Four Naturally Ventilated Offices in the United Kingdom.*' Atmospheric Environment Vol 27A No. 11 pp.1743-1753, 1993.

5. DJ Hall, AM Spanton, V Kukadia and S Walker, '*Exposure of Buildings to Pollutants in Urban Areas - A Review of the Contributions from Different Sources*'. BRE Report CR 209/96, 1996.

6. JE Yocum, '*Indoor-outdoor air quality relationships. A critical review.*' Journal of Air Pollution Control Ass., Vol 32, pp500, 1982.

7. Department of the Environment, '*The United Kingdom National Air Quality Strategy: Consultation Draft*', 1996.

8. CIBSE 'Environmental Criteria for Design' CIBSE Guide Volume A, 1988.

9. BRE 'Natural ventilation in non-domestic buildings', BRE Digest 399, Building Research Establishment, October 1994.

10. British Standard 8233: 1987 '*Sound Insulation and noise reduction for buildings*'.

11. Building Research Establishment BREEAM, '*An Environmental Assessment for Existing Office Designs*', BRE Report 4/93, 1993.

12. Building Research Establishment BREEAM, '*An Environmental Assessment for New Office Designs*', BRE Report 1/93, 1993.

Figure 1: Plan view of first floor

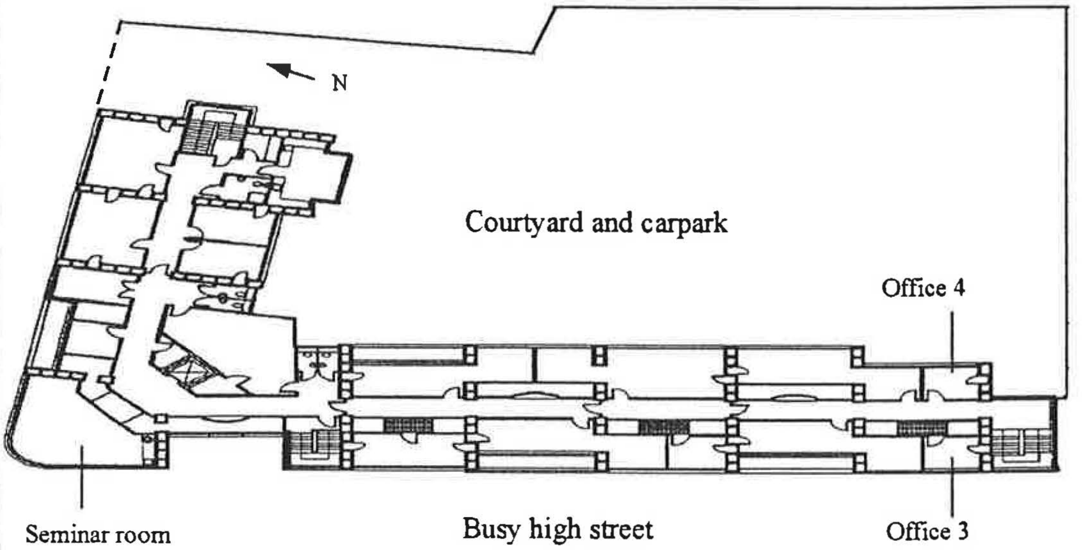


Figure 2. Natural ventilation strategy

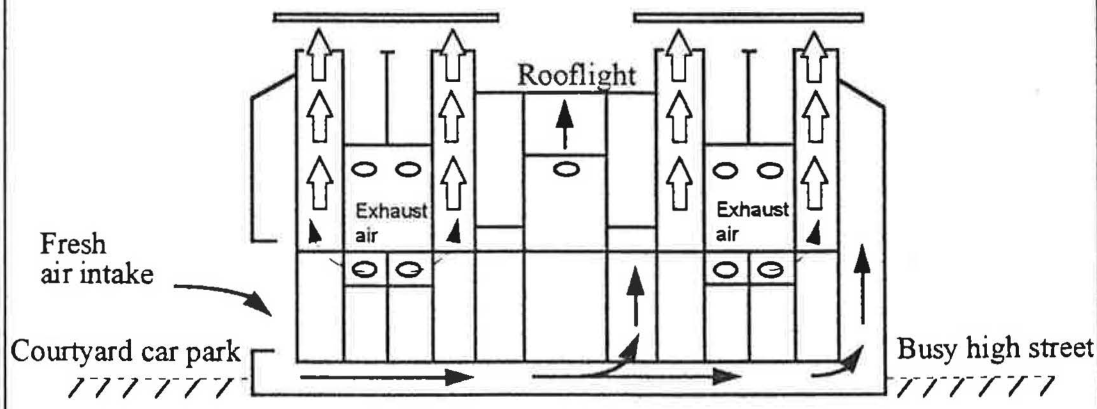


Figure 3: Wind tower natural ventilation scheme

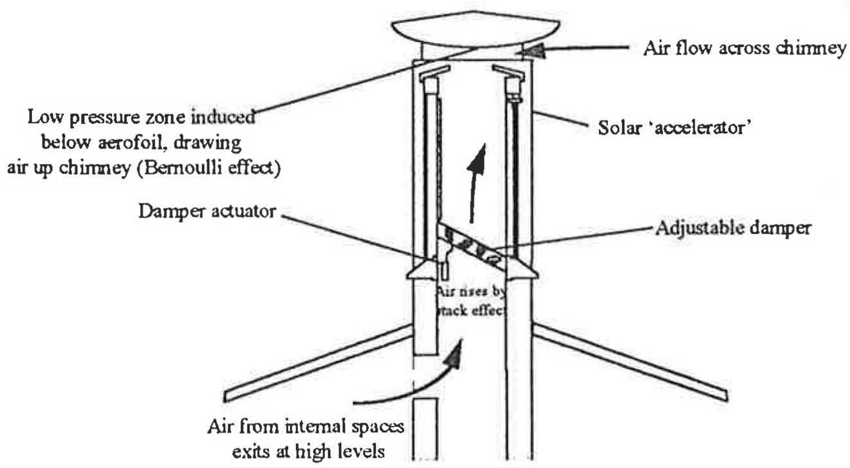
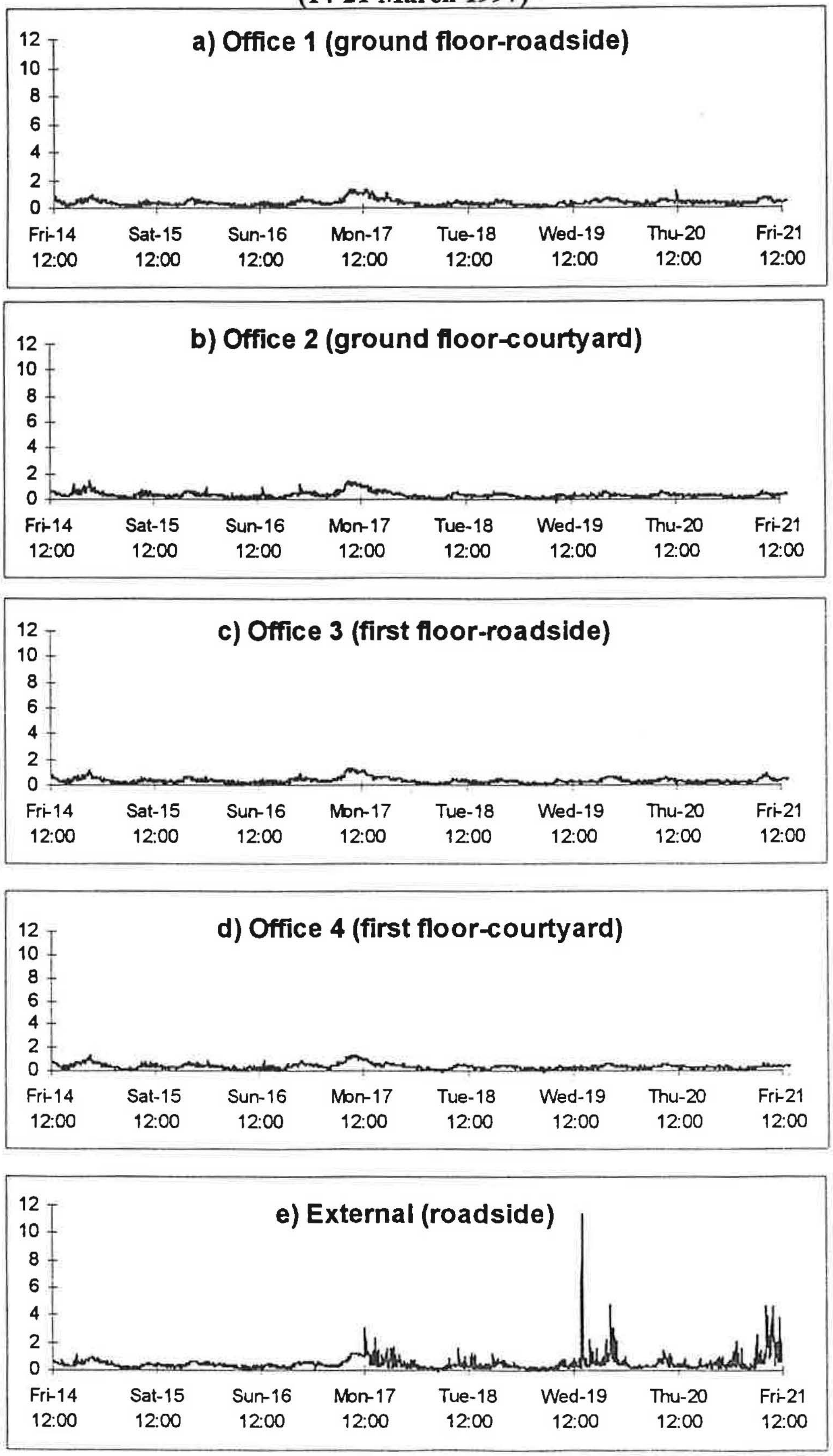


Figure 4: Carbon monoxide concentrations (ppm) vs Time of day (14-21 March 1997)



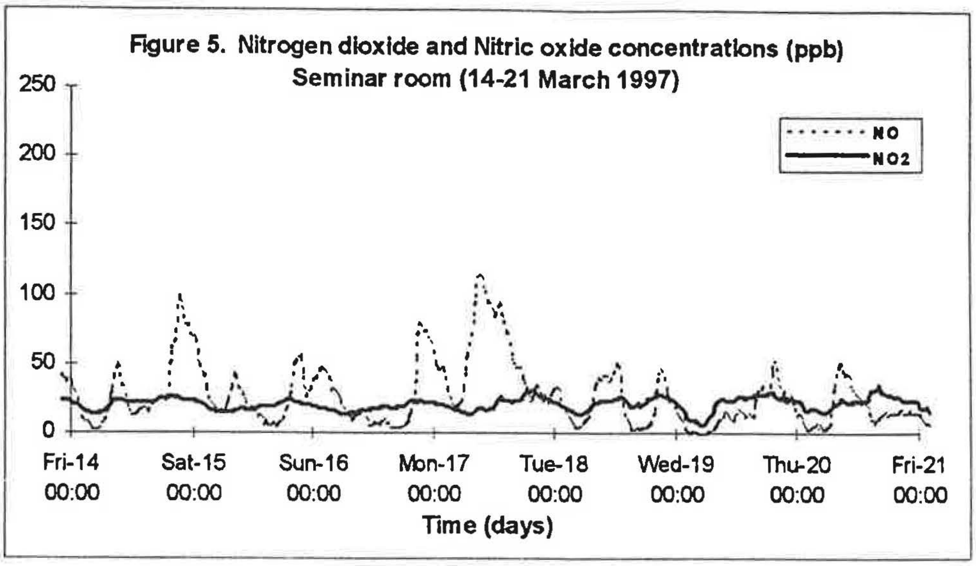


Figure 5. Nitrogen dioxide and Nitric oxide concentrations (ppb)
Seminar room (14-21 March 1997)
NO
NO2
250
200
150
100
50
0
Fri-14 00:00
Sat-15 00:00
Sun-16 00:00
Mon-17 00:00
Tue-18 00:00
Wed-19 00:00
Thu-20 00:00
Fri-21 00:00
Time (days)

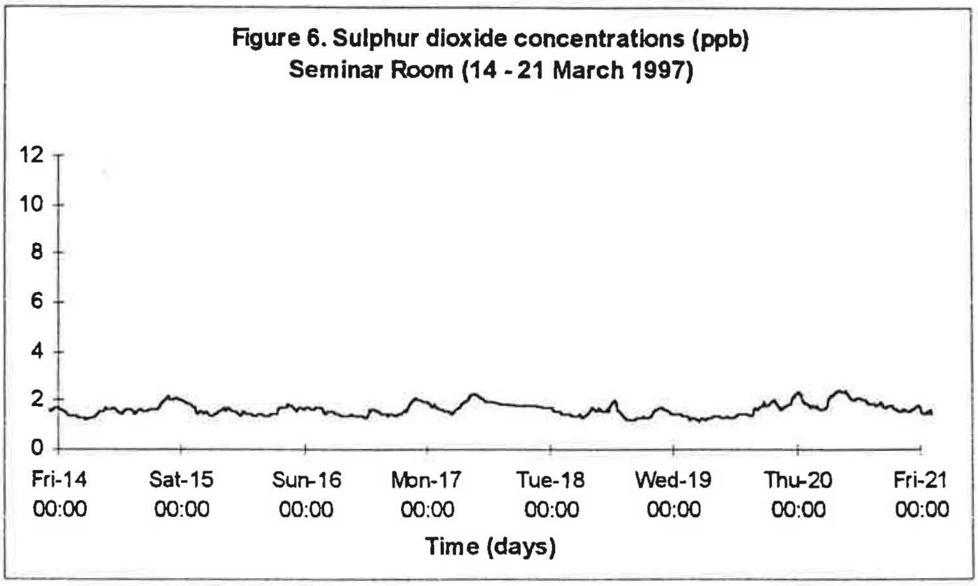


Figure 6. Sulphur dioxide concentrations (ppb)
Seminar Room (14 - 21 March 1997)
12
10
8
6
4
2
0
Fri-14 00:00
Sat-15 00:00
Sun-16 00:00
Mon-17 00:00
Tue-18 00:00
Wed-19 00:00
Thu-20 00:00
Fri-21 00:00
Time (days)

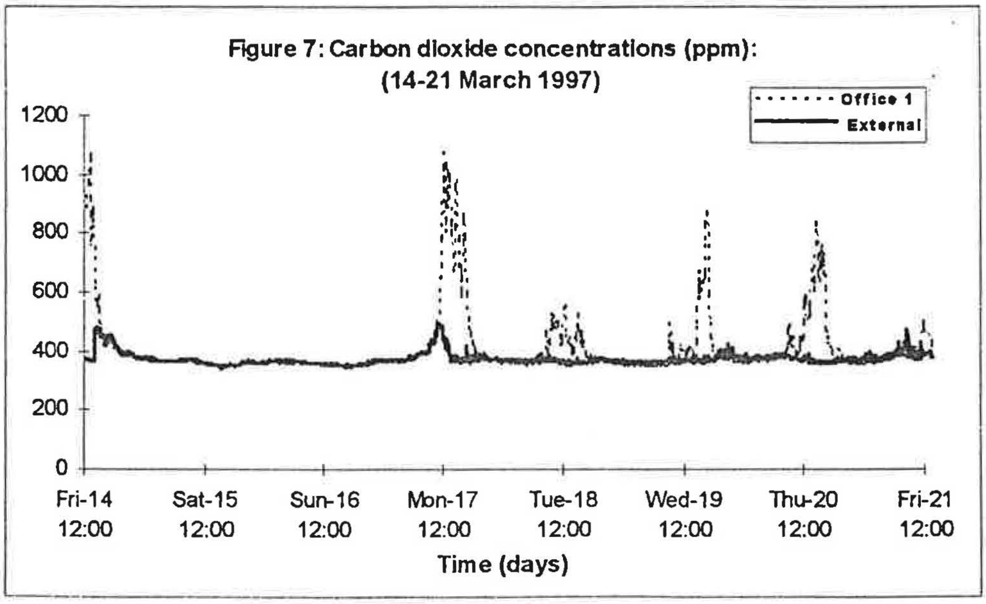


Figure 7: Carbon dioxide concentrations (ppm):
(14-21 March 1997)
Office 1
External
1200
1000
800
600
400
200
0
Fri-14 12:00
Sat-15 12:00
Sun-16 12:00
Mon-17 12:00
Tue-18 12:00
Wed-19 12:00
Thu-20 12:00
Fri-21 12:00
Time (days)

Figure 8. Wind direction and wind speed
(15-21 March 1997)