OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

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The Effect of External Atmospheric Pollution on Indoor Air Quality

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ABSTRACT

This paper reports the findings of a pilot field study carried out to investigate the internal and external air pollution levels of two adjacent buildings, one naturally-ventilated and the other air-conditioned in an urban area, to investigate their relative attenuation of external pollution levels and to compare internal levels with existing air quality guidelines.

Concentration levels of sulphur dioxide, nitrogen oxides, carbon monoxide and carbon dioxide were monitored. Simultaneously, measurements of ventilation rates within the buildings and periodic video recordings of the traffic were also carried out.

As expected the concentrations of external pollutants in the buildings followed the daily external variation, but at reduced levels. Generally, pollutant levels were higher in the naturally ventilated building than in the air-conditioned building. However, on a number of occasions, combustion products from heating boilers were entrained into the air-conditioned building via the high level air intake of the ventilation system raising the levels of nitrogen oxides, sulphur dioxide and carbon dioxide inside the building to higher than those found externally.

A comparison of the results with existing air quality guidelines or standards for exposure showed that in both buildings the level of contamination was less than the relevant standard, except during a limited period at the weekend when combustion products were possibly entrained into the air-conditioned building. There is thus no clear distinction between the two types of ventilation strategies in terms of providing adequate indoor air quality to the occupants of the buildings.

1. BACKGROUND

Increased concerns over the adverse environmental impact of high energy usage required for mechanical ventilation and air-conditioning has encouraged the design and construction of energy-efficient buildings with many of them employing natural ventilation strategies. However, in urban areas and city centres where external air pollution levels are relatively high, it is usually assumed that natural ventilation may not be able to provide adequate indoor air quality. Mechanical ventilation and air-conditioning systems are thus being installed to 'clean' the incoming air, even though there is evidence that such systems do not always provide clean fresh air to the occupants of the building (1).

The air quality in non-domestic buildings has been widely studied in the context of contaminants arising from internal processes or emanating from materials within the building. However, there have been comparatively few studies of the internal air quality of a building arising from the normal occurrence of external air pollution and the supply of this air to the occupants. Furthermore, there have been few attempts to relate this internal air quality to accepted standards of exposure to known contaminants.

A number of guidelines or standards exist which deal with human exposure to contaminants which are potentially injurious to health. In the UK these are contained within the Control of Substances Hazardous to Health (COSHH) Regulations 1988 (2) and the Health and Safety Executive (HSE) Occupational Exposure Limits EH40/95 (3). The relevant standards are expressed in terms of concentrations of pollutant to which the working population may be exposed for the relevant periods, (eg. an 8-hour day, a 15-minute period or an absolute peak value) to avoid any risk to their health. Standards which deal more explicitly with air quality for the general populace are those of the World Health Organisation (WHO)(4), which deal with both indoor and outdoor air quality and those of the UK's Department of the Environment Expert Panel on Air Quality Standards (EPAQS), which has recently begun to publish reports on the health effects of certain pollutants and recommends air quality standards for these. Other more stringent guidelines are those which are included in the UK's Her Majesty's Inspectorate of Pollution (HMIP) Technical Guidance Note (5). The European Community (EC) also sets guideline or limit values for some pollutants (6).

2. CURRENT STUDY

This pilot study was carried out to investigate the following:

- internal and external pollution levels of a naturally ventilated and an air-conditioned building in close proximity to one another,
- their relative attenuation of external pollution levels, and
- a comparison of the levels recorded indoors with currently available air quality guidelines.

Previous work in this area is limited. Turner and Binnie (7) studied the CO levels in a number of naturally and mechanically ventilated buildings and found that externally produced CO was more prevalent in the mechanically ventilated buildings than those naturally ventilated. This was thought to be a consequence of ingress into the air handling units of contaminated air from underground car-parks. A study by Phillips, et al (8), of four naturally ventilated buildings, concluded that the air change rate was the determining factor for air quality; the greater the supply of external air the greater the presence of external pollutants indoors.

However, Ekberg (9) showed that it is unlikely that the relationship is related to the air change rate alone since there is the potential for sinks and sources within the building. He also showed that the effect of the rapidly changing concentrations of external pollutants was important in obtaining a more complete understanding of the relationship between indoor and outdoor air quality and that short term peaks in the concentration of external pollutants are significantly affected by the general response of the building. This is also highlighted in Treple's (10) studies of ventilation strategies in cases of external pollution events.

Although evidence from recent buildings employing natural ventilation as a design strategy (rather than simply providing openable windows) shows that acceptable ventilation rates can be achieved without resort to mechanical ventilation (11), the level of externally generated pollution experienced in these buildings has not been considered directly with reference to indoor air quality and air quality standards. Thus to enable development of suitable design guidance for low energy ventilation of non-domestic buildings in urban areas, the manner in which buildings can attenuate the effects of external pollution levels to achieve adequate indoor air quality needs to be known.

3. EXPERIMENTAL SETUP

3.1 Buildings

Two buildings, one naturally-ventilated and the other air-conditioned and located adjacent to each other on an eight-lane major road in a major urban centre (Figure 1) were selected for investigation. The naturally-ventilated building was a four storey building with openable vertical sash windows and secondary glazing. The measurements were made in a ground floor office with windows facing onto the main road on one side and an internal court-yard on the other.

The air-conditioned building was ten storeys high with a facade which was mostly sealed although there was a limited number of unused openable windows. The third floor open-plan office was chosen for monitoring because the lower floors were recessed from the road and shielded by the access stairs to a foot-bridge. The mechanical ventilation system drew external air from the tenth floor level via the roof-top plant room. The air was then filtered and heated prior to distribution to the ceiling voids for terminal re-heat and cooling. There was no heat recovery. A radiator system also provided heating to the offices. The mechanical ventilation system was taken as found and there were no reported problems. Its performance was assessed by the measurement of the air change rate as part of this pilot study.

The offices in both buildings were in normal use with variable occupancy and normal office activities. Both offices had a no-smoking policy and there were no gas appliances or any other significant internal sources of the measured pollutants apart from metabolic CO_2 from the occupants.

3.2 Measurements

Measurements of the following were made:

- sulphur dioxide (SO_2)
- carbon monoxide (CO)
- oxides of nitrogen (NO_x)
- carbon dioxide (CO_2)
- building air change rates
- traffic density

Each building was provided with a set of high quality gas analysers and the outputs from these instruments were recorded at five minute intervals for the whole of the monitoring period (13 to 20 February 1996) using a data-logging system. By using a switchable pump sampling system, the instruments in the naturally ventilated building were also used for measuring the external levels of the pollutants. They were calibrated immediately prior to the monitoring and the instruments 'zeroed' on alternate days by using a supply of uncontaminated air. The building air change 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. During unoccupied periods, the decay of CO_2 generated by the occupants previously in the building, was also used as a measure of the air change rates. Traffic densities on the main road were taken by periodic direct observation and by using video recording. The wind speed and direction were obtained from the local meteorogical site.

4. RESULTS

4.1 Pollutant Concentrations

Measurements were carried out for a seven day monitoring period (12). However, for clarity of presentation, and to show interesting events which occurred over the weekend period concentration results for the various gases for Friday to Monday inclusive of a weekend only are shown in Figures 2-6.

Over the complete monitoring period, there were times when no significant levels of pollutants were recorded - either outside or inside the buildings. The buildings appeared not to retain the external pollutants for long periods. The ability of the buildings to attenuate the external pollutants is shown in most cases by the peak internal concentrations being lower than that recorded externally. Furthermore, it is apparent that neither building reacted to the rapid and sudden fluctuations seen in the external levels. The buildings tended to smooth out the external pollution levels over a time period of about an hour.

For occupants, the period of interest is the occupied day of 08:30 to 17:30, during the working week. Table 1 shows the ratio of the internal to external pollution concentration for this period. As a first approximation, it is suggested that this can be used as a measure of the effectiveness of each of the buildings in attenuating the external pollutants.

Table 1. Concentrations of Measured Gases for the Occupied Periods for Monday to Friday.

Measured gas	External		Internal							
			Naturally ventilated				Mechanically ventilated			
	Peak	Mean	Peak	Mean	Internal/External Ratio		Peak	Mean	Internal/External Ratio	
					Peak	Mean			Peak	Mean
CO (ppm)	9.6	1.8	4.1	1.7	0.4	1.0	3.0	0.9	0.3	0.5
CO_2 (ppm)	478	366	1197	650	1.5	1.8	800	646	1.0	1.8
NO (ppb)	798	114	241	97	0.3	0.9	256	78	0.3	0.7
NO_2 (ppb)	70	31	33	28	0.5	0.9	45	25	0.6	0.8
SO_2 (ppb)	40	11	10.6	4.4	0.3	0.4	13.4	3.9	0.3	0.4

Generation of metabolic CO_2 by occupants of the buildings indicated a internal/external ratio greater than one. However, it is important to note that for the pollutants, the levels indoors are always less than those outdoors.

4.2 Air change rates

Average air change rates obtained for the two buildings over the monitoring period were as follows:

Naturally ventilated building:	Occupied	- 1.6 ach^{-1}
	Unoccupied	- 0.8 ach^{-1}
Mechanically ventilated building:	Occupied	- 1.2 ach^{-1}
	Unoccupied	- 0.4 ach^{-1}

In the mechanically ventilated building, the air change rate varied little whilst the system was operating. However, as expected, the air change rate in the naturally ventilated building was more variable and was dependent upon the circumstances of operation and weather conditions. Over the period of the tests, wind speeds were recorded at the nearby Meteorological site as being higher than normal, ranging from 5 ms^{-1} to 10 ms^{-1} with gusts of about three times the mean wind speed (Figure 7).

5. DISCUSSION

The short period of monitoring in this pilot study allowed only a limited scope for investigation of the performance of the buildings with regard to the indoor and outdoor air quality. However, a number of useful observations were made with regard to comparison with guidelines on exposure levels of the contaminants studied.

5.1 Sources of Pollution

In this study traffic appeared to be the major source of CO and NO_x. The concentrations of these pollutants varied with the traffic density on the main road. However, SO_2 concentrations were not so clearly associated with the traffic as can be seen from the low levels which occurred on the Saturday evening (Figure 6) when the high levels of other pollutants suggest a considerable flow of traffic.

The most prominent feature of the data is the exceptionally high levels of CO_2, SO_2, NO and NO_2 in the mechanically ventilated building on the Saturday morning from 06:00 to 12:30 - coincident with the period between the start-up and shut-down of the building's ventilation system. Levels were well in excess of the external concentrations and not seen inside the naturally ventilated building. The obvious source for these gases in such high concentrations was either cross-contamination from the ventilation exhaust or high level discharges from boiler plant being drawn into the ventilation inlet. There are a number of boiler flues close to the building which may have been responsible for this, if not those on the building itself. A similar event on the Monday morning suggests that this was not an isolated incident.

5.2 Health risk from external air pollutants

Table 2 shows the measured daily mean concentrations for the working week taken from Table 1 and compares them with some of the most appropriate guidelines for air quality. It can be seen that for all of the gases measured there was little risk in either of the buildings when these standards were applied. However, if the results from the weekend (Figures 2-6) are compared then the NO concentration, for a limited period, does exceed the HMIP guideline and the NO_2

Table 2. Measured mean concentrations inside the buildings for the working week compared with existing air quality guidelines.

Measured gas	Measured mean concentrations		Air quality standards/guidelines				
	Naturally ventilated	Mechanically ventilated	DoE*	HSE**	WHO#	HMIP##	EC~
CO (ppm)	1.7	0.9	-	50	10[1]	50	-
CO_2 (ppm)	650	646	-	5000	-	-	-
NO (ppb)	97	78	-	25000	-	830	-
NO_2 (ppb)	28	25	<50	3000	80[1]	100	105[1]
SO_2 (ppb)	4.4	3.9	<60	2000	122[2]	170	94[2]

* Department of Environment - very good air quality
** Health and Safety Executive 8-hour exposure TWA (time weighted average)
# World Health Organisation
UK's Her Majesty's Inspectorate of Pollution short-term exposure limit
~ European Community guidelines
1 8-hour mean
2 1-hour mean

concentration exceeds almost all the guidelines. The possible cause for this is discussed in section 5.1. These results suggest that for this particular building there may be a cause for concern if these occurred when the building was occupied.

5.3 Attenuation of Pollutants
The results show that the buildings significantly attenuated the concentration of the external pollutants. The ratio of the internal/external peak values in the occupied periods (Table 1), indicate that the levels of the external pollutants monitored inside the buildings were generally less than 50% of the peak external concentrations. This was consistent over the period of monitoring and shows that this damping of the fluctuations of external pollutant levels would be valuable in reducing short-term exposure levels. There was less attenuation of the mean concentration but both buildings show better air quality indoors than outdoors in terms of the externally generated pollutants. The attenuation of the CO in the mechanically ventilated building was greater than in the naturally ventilated building. However, for the other pollutants the difference was less marked.

5.4 Correction for building air change rates
In order to allow for the fact that they experienced different air change rates and sources of external air, a form of correction procedure is required. Investigations into suitable techniques for performing this 'correction' are currently being carried out. When a building is to be located in an urban area it would be desirable if the ventilation system designer could predict the internal air quality from records of external pollution events for that site. The development

of the proposed correction procedure should enable such a prediction to be carried out.

6. CONCLUSIONS

From the measurements made in this pilot study a number of conclusions can be drawn about the attenuating capability of the buildings and the comparison of the internal measured concentrations with existing air quality guidelines.

1. In both the naturally and mechanically ventilated buildings the indoor air quality followed the trend of that of the external air to which they were exposed. However, the concentrations of the external pollutants were attenuated by the building and the transient peak concentrations measured externally were approximately halved in value.

2. The possibility of drawing combustion products into buildings at high level has been shown to exist in the mechanically ventilated building. The building was chosen only for its location with respect to traffic density. However, the findings highlight the real danger of cross-contamination between ventilation exhausts and inlets at roof level and contamination from other sources.

3. The indoor air quality in both buildings over the main occupied period did not exceed any of the main health standards. However, most of the NO_2 guideline values were exceeded over the weekend when combustion products were possibly drawn into the air conditioned building.

4. In terms of indoor air quality it is not clear which guidelines should be followed when designing buildings. If the more stringent guidelines are applied then the designer needs to think carefully when designing for non-domestic buildings and their ventilation systems in urban areas such that these guideline values are not exceeded.

5. It has been shown in this short pilot study that there is no clear distinction between the two ventilation strategies in providing adequate indoor air quality for the occupants of the buildings with respect to externally generated air pollutants other than when combustion products were entrained into the air-conditioned building.

ACKNOWLEDGEMENTS

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REFERENCES

1. Morris, R H. *'Indoor Air Pollution'* Heating/Piping/Air Conditioning - February 1985.

2. COSHH Regulations 1994. *'Approved Codes of Practice'* ISBN 0-7176-0819-0.

3. Health and Safety Executive. *'Occupational Exposure Limits.'* EH40/95.Updated annually.

4. World Health Organisation.*'Air Quality Guidelines for Europe'* WHO Regional Publications, European Series No. 23. Copenhagen.

5. Her Majesty's Inspectorate of Pollution.*'Guidelines on Discharge Stack Heights for Polluting Emissions'*.Technical Guidance Note TGN D1 (Dispersion), 1993, ISBN 0-11-752794-7.

6. EC (1990). Directive no. 80/779/EE. *'Official Journal of the European Communities'* No L229, Vol 23.

7. Turner S. and Binnie P.*'An Indoor Air Quality Survey of Twenty-Six (26) Swiss Office Buildings.'* Environmental Technology Vol.11, pp. 303-314, 1990.

8. Phillips J et al. *'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.

9. Ekberg L E. *'Relationships between indoor and outdoor contaminants in mechanically ventilated buildings.'*Indoor Air 1996 Vol 6 pp.41-47

10. Treple I.*'Ventilation strategies in the case of polluted outdoor situations'* 9th AIVC Conference, Gwent, Belgium, 1988

11. ETSU S 1160/11. *'Gateway Two: Energy Performance Assessment.'*

12. Kukadia et al. *'Air pollution levels inside buildings in urban areas'*. To be presented at the CIBSE/ASHRAE Joint National Conference, Harrogate, September 1996.

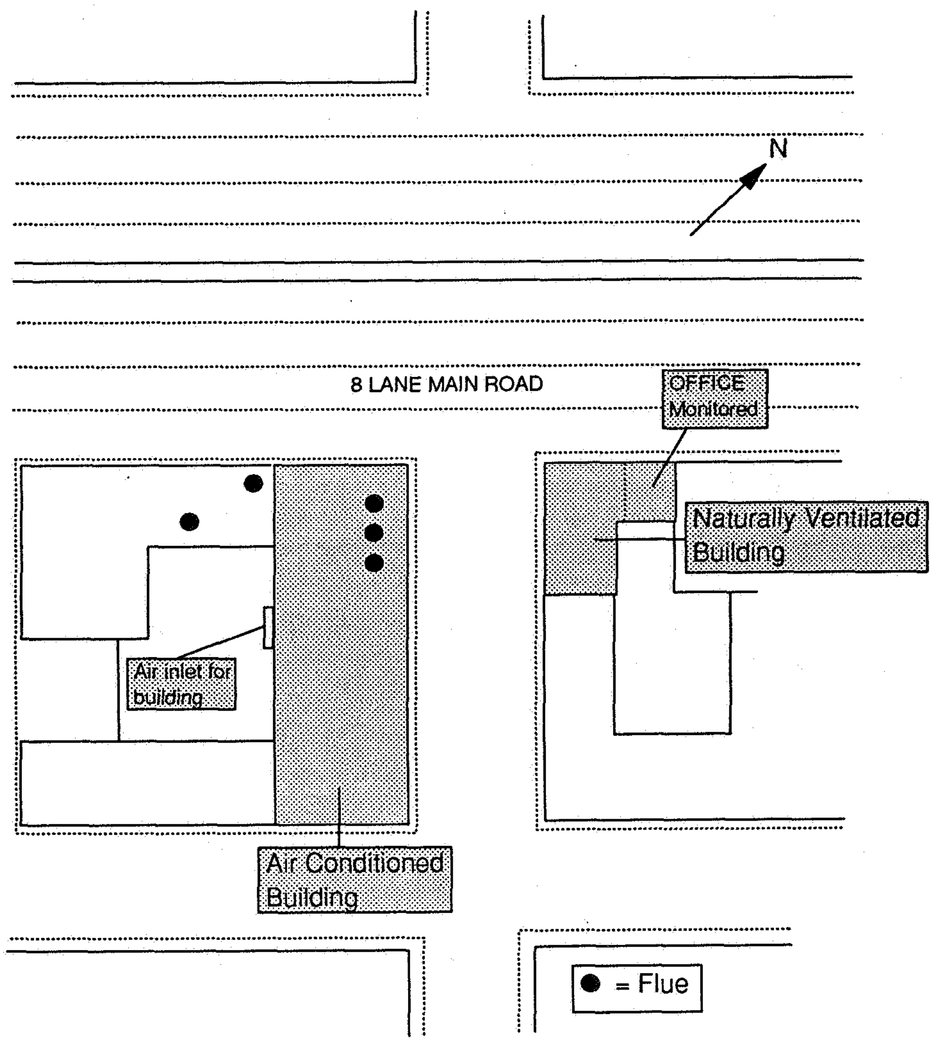

Figure 1. Site plan of monitored buildings

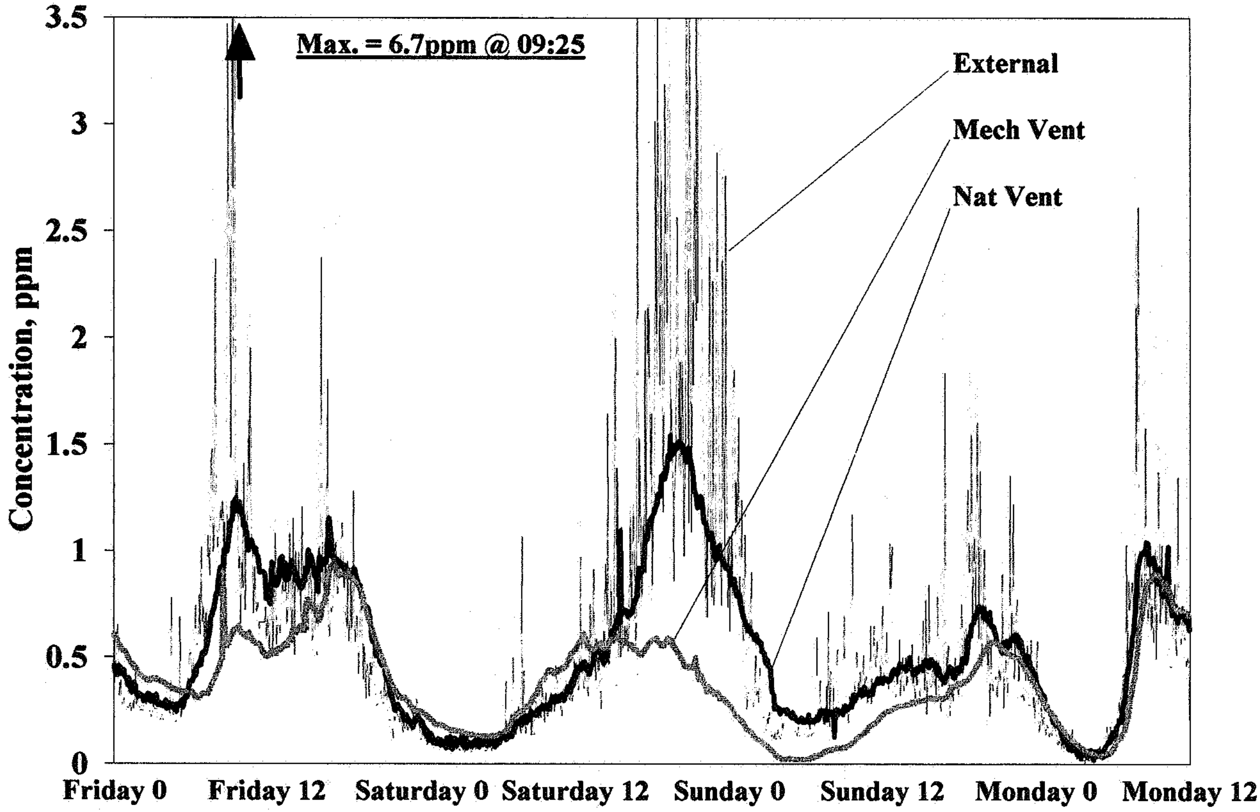

Figure 2. Carbon Monoxide

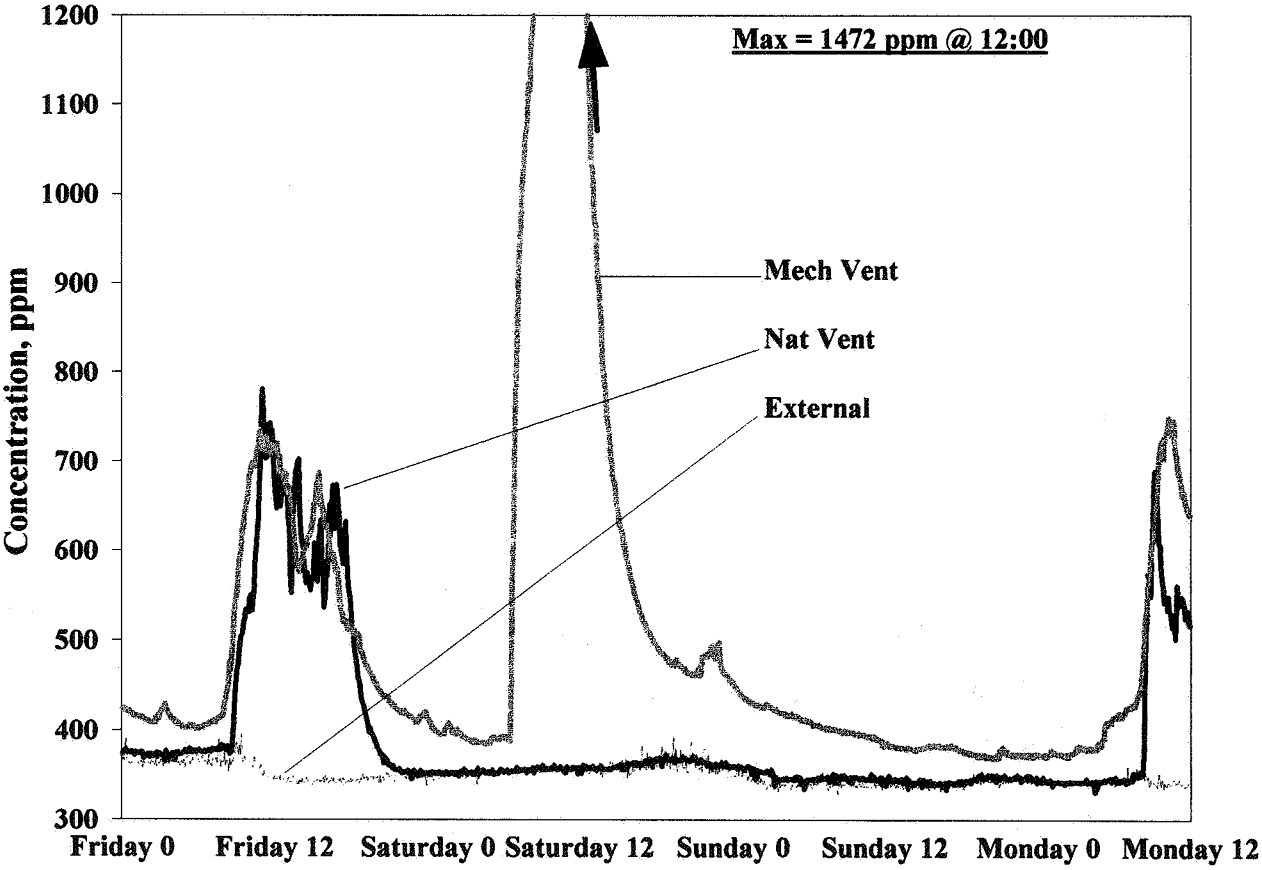

Figure 3. Carbon Dioxide

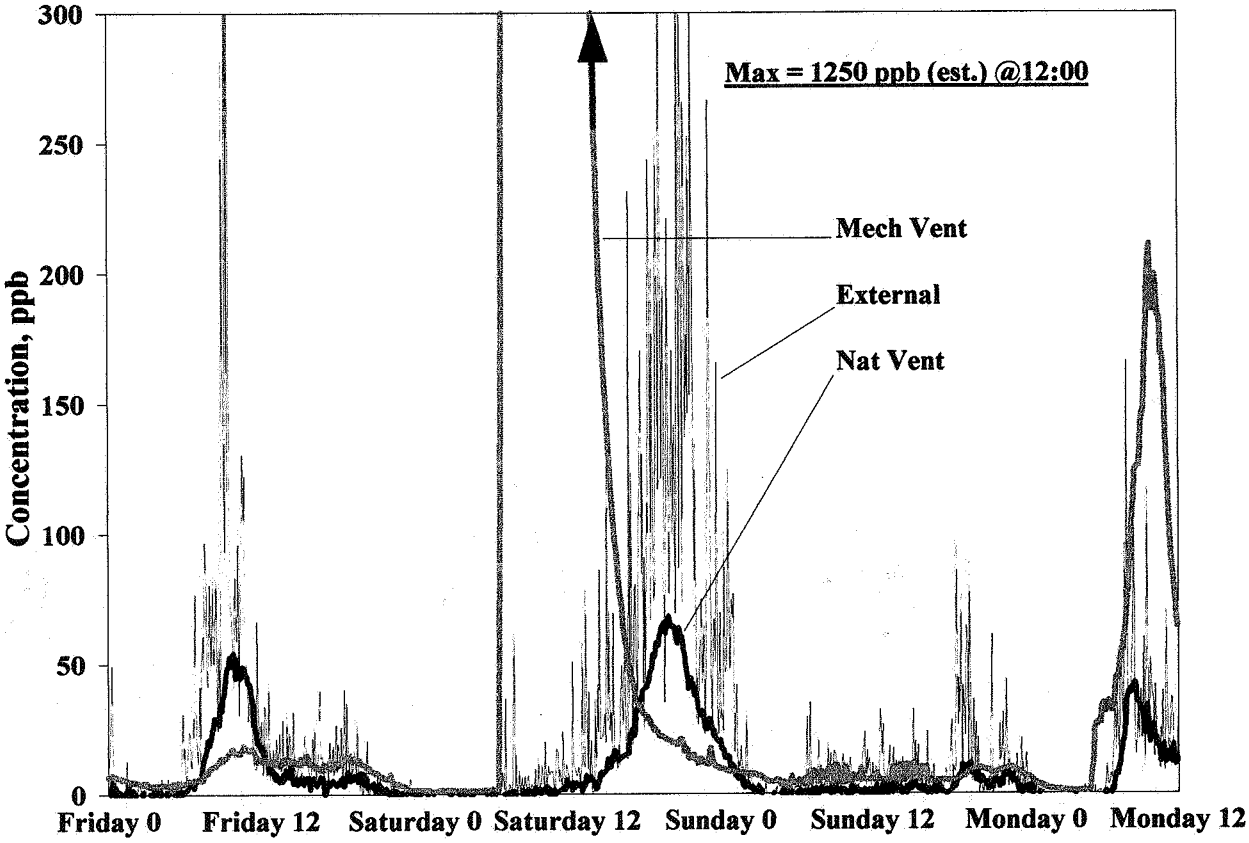

Figure 4. Nitric Oxide

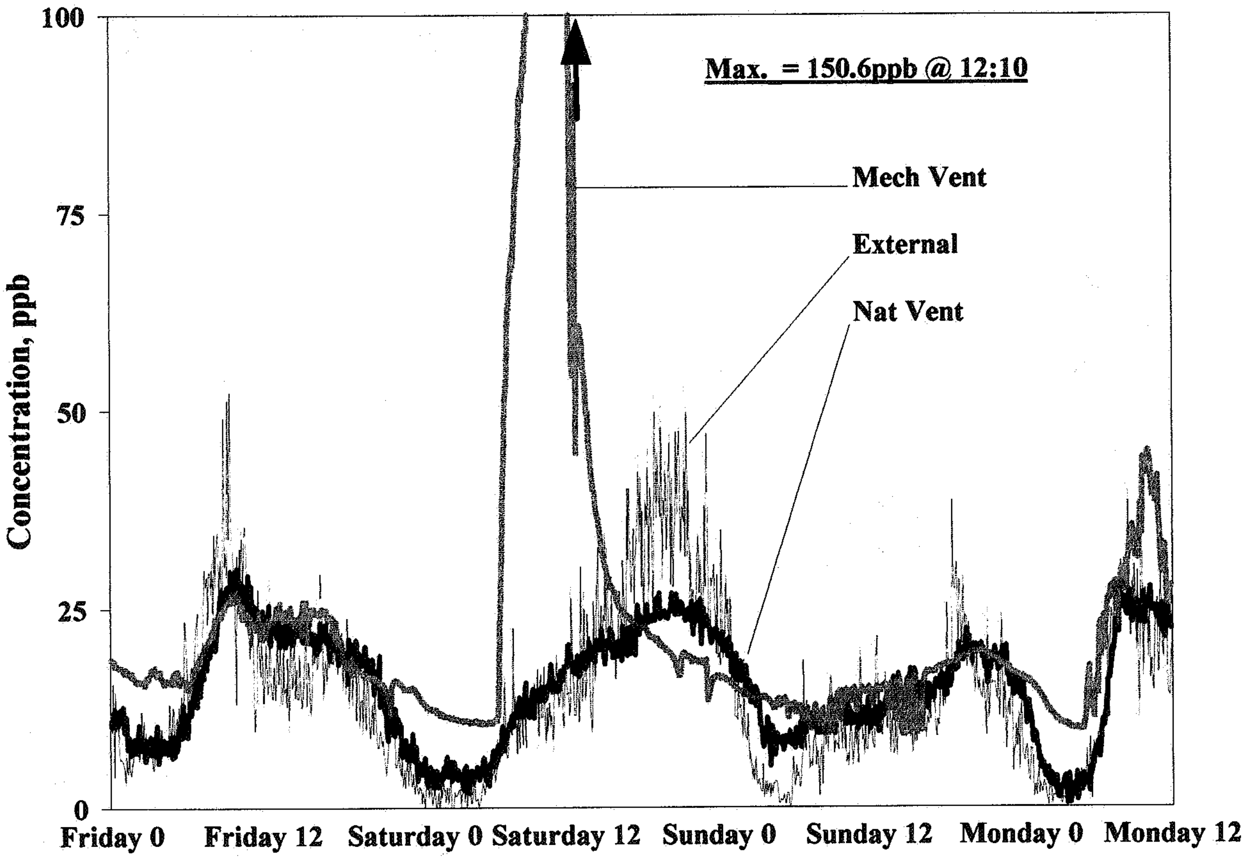

Figure 5. Nitrogen Dioxide

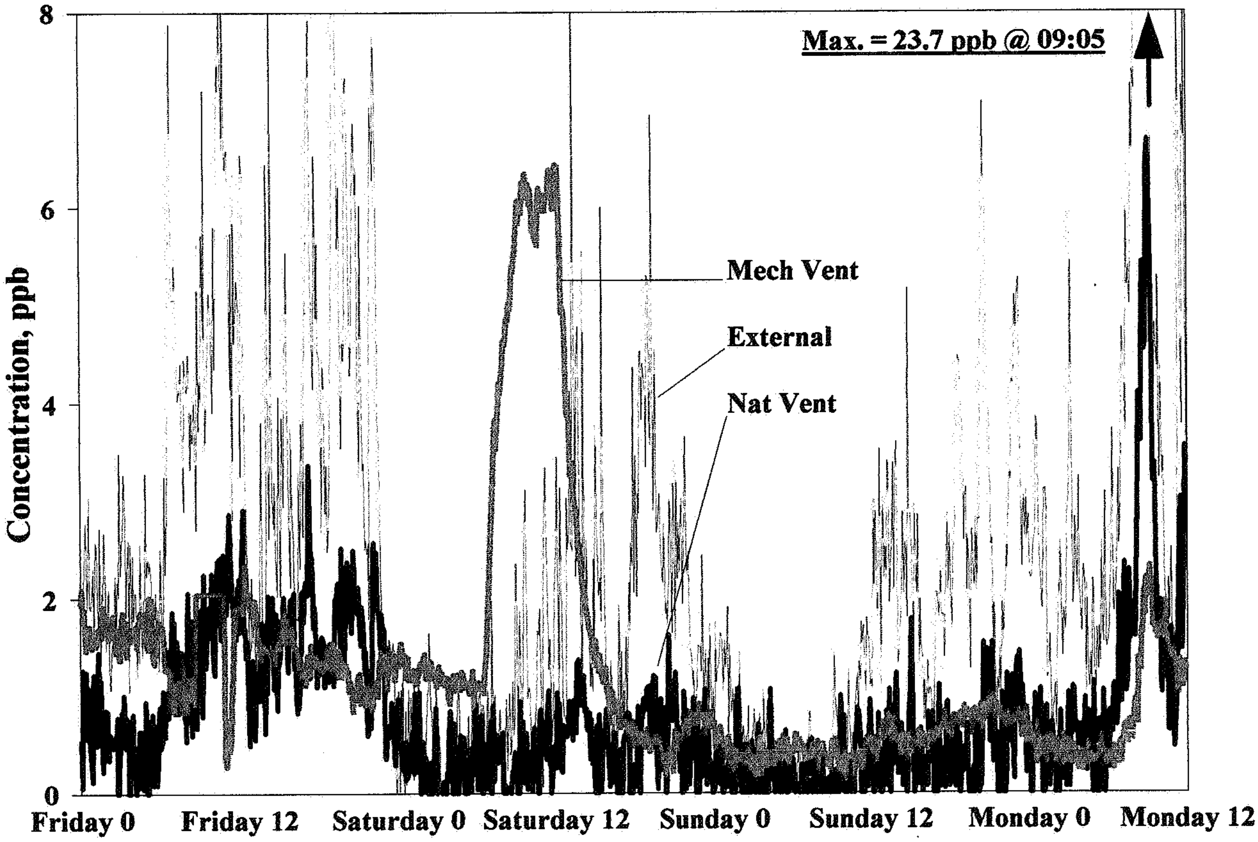

Figure 6. **Sulphur Dioxide**

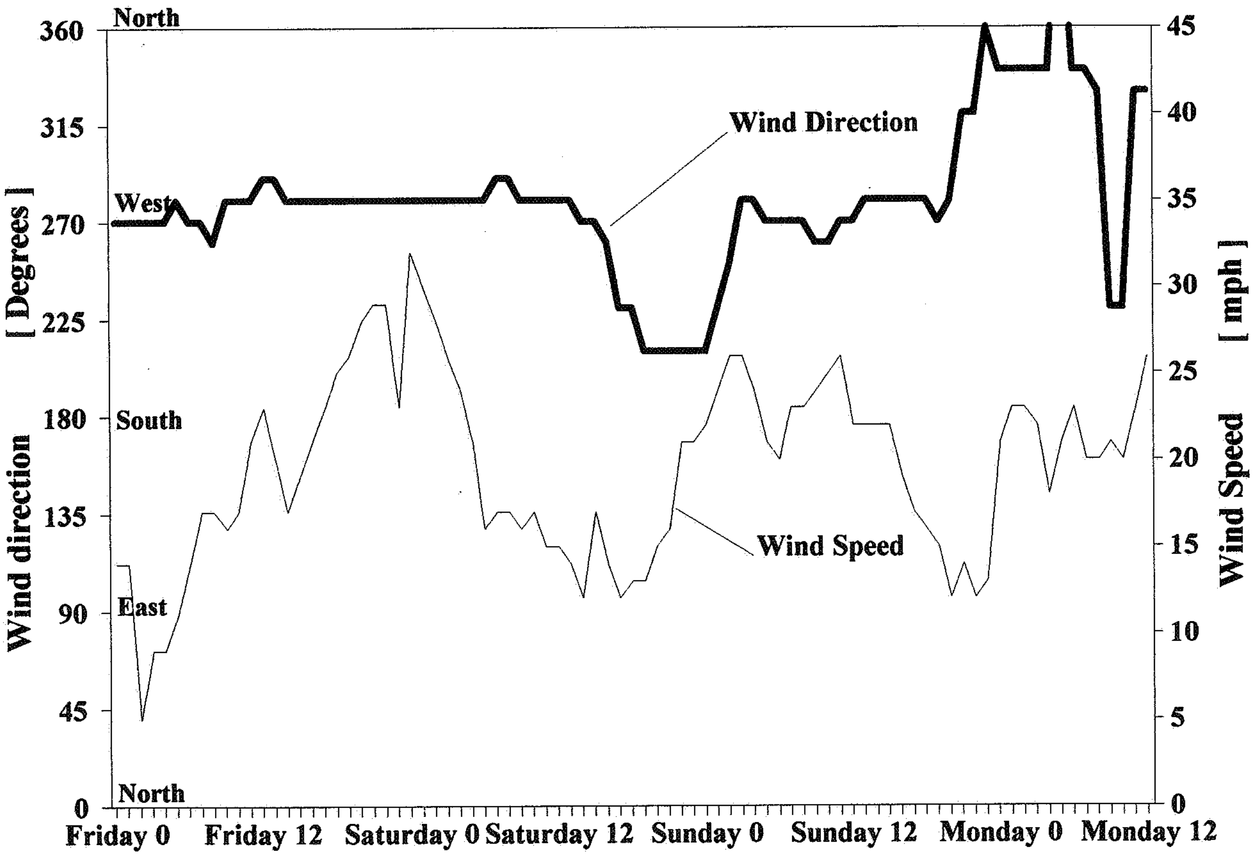

Figure 7. **Wind Speed and Direction**