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The Significance of Urban Pollution and its dilution associated with height

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SYNOPSIS

This paper identifies the significance of pollution at five sites amongst the worst on the British mainland, hence indicative of other polluted areas within Europe. Three sites are located in London and one each in Birmingham and Cardiff. The pollutants examined are NO_2, SO_2, O_3 and PM_{10}. Newly proposed DOE figures defining poor air quality have been used to re-examine the frequency of excess pollution episodes between 1992 - 1995. The results identify the most appropriate periods for natural ventilation of offices in urban areas in terms of the hour in a day and time of year. Preliminary in-situ experiments also demonstrate that both PM_{10} and NO_2 concentrations decrease with increasing height from a busy road, and that this could be a useful strategy for reducing the impact of contaminants derived from vehicle emissions.

1. INTRODUCTION

The aim of this paper is to suggest ways in which barriers to natural ventilation may be overcome. The study forms part of the Pan-European project titled NatVent involving seven countries; the UK Building Research Establishment (BRE) are the co-ordinators. A widely perceived barrier to effective natural ventilation in urban areas is the ingress of external pollutants. Filtration of air supply is an option but may unacceptably restrict the flow of air into buildings. A possible solution is to vary ventilation periods to avoid 'polluted' occasions.

A general perception exists that pollution at roof level is likely to be less than by the road side, but there appears to be little quantitative evidence for this. Since the siting of offices varies substantially in height it is useful to examine how height influences the concentration of mainly traffic generated pollutants. If a dilution effect is evident it may be possible to recommend a suitable height for positioning air inlets in buildings to avoid or reduce the need for filtration. In section 3 of this paper the concentrations of PM_{10}, and NO_2 are examined at varying heights from a busy road.

2. THE EXTENT OF URBAN POLLUTION IN CITIES

2.1 Selection Of sample sites

A recent European report examined the urban pollution problem across Europe, using seven cities sited as representative "of their air quality, geographical location and characteristics of their vehicle fleet", (1). The locations chosen were, London, The Hague, Cologne, Lyon, Milan, Athens and Madrid. Of these cities London, The Hague and Cologne are located within an area of Europe covered by the NatVent project, namely cold - temperate climatic regions. In each city a model was used to predict the reduction in pollution emissions necessary to achieve required standards. London, by inference, was the most polluted city and thus is a typical worst case North European area.

A study of urban pollution in the UK has been conducted for some time. Periods of poor air quality have been identified and published (2). An examination of poor air quality episodes reveals that PM_{10} and NO_2 have been major problems at a number of locations. SO_2 and O_3 concentrations have also presented problems, but to a lesser extent. The worst areas for PM_{10} excess pollution levels during 1992 - 1995 were, London Bloomsbury, Birmingham City Centre and Cardiff City Centre. During the same period NO_2 excess levels were a major problem in Cromwell Road and Bridge Place, both situated in London. Hence an assessment of air quality at these locations is a useful guide to the situation in similar regions of northern Europe. Additional information on each of the sites is provided below.

London, Bridge Place:

- Urban background site.
- Based on 2nd floor in a street near a busy area in Victoria.

London, Cromwell Road:

- Kerbside site.
- Based in central London at busy arterial road.
- High traffic density of approximately 60,000 vehicles per day.

London, Bloomsbury:

- Urban Centre site.
- Based at Russel Square 35m from Kerbside.

Birmingham City Centre:

- Kerbside site.
- Based on the busy Stratford road where gradient is 1:20.
- Traffic density is approximately 20,000 vehicles per day.

Cardiff City Centre:

- Kerbside site.
- Based on the busy Queen Street.
- Traffic density is approximately 30,000 vehicles per day.

2.2 Evaluation method

The pollutants reviewed at each location are highlighted in Table 1.

Table 1. Pollutants reviewed between 1992 - 1995, at five UK sites

Site	NO_2	PM_{10}	SO_2	O_3
Bridge Place, London	√	-	√	√
Cromwell Rd, London	√	-	√	-
Bloomsbury, London	√	√	√	√
Birmingham City Centre	√	√	√	√
Cardiff City Centre	√	√	√	√

The Department of the Environment (DoE) has published a 'consultation draft' outlining desirable maximum levels in ambient concentrations of pollutants to be achieved by 2005 (3). Table 2 identifies some of the pollutants of concern and the concentrations that must not be exceeded (unless figures are otherwise revised) by 2005. It also indicates some of the health problems attributed to each pollutant.

Table 2. Proposed standards and specific objectives

	Pollutant			
	NO_2	PM_{10}	SO_2	O_3
standard limits sample mean times	104.6 ppb 1 hour	50 μgm^{-3} 24 hours*	100 ppb 15 minutes	50 ppb 8 hours*
health problems	-respiratory	-respiratory &, cardiovascular	-respiratory & chest pains	-respiratory

The concentration values expressed in Table 2 are used to re-examine the magnitude of the problem between 1992 - 1995, at each site. The specific aim is to identify the time of day and period in the year when pollution levels would be termed excessive on the basis of the projected objectives for 2005. This highlights the degree of the problem as it currently stands.

A different criterion from that highlighted in Table 2 is used in evaluating SO_2 levels at the five UK sampling sites; 60 minute averaging times are used in place of 15 minute periods. This is largely due to the format of the data acquired. Although variation in concentrations are 'smoothed' out by this alternative approach the overall effect will not have a great impact on final conclusions.

From hourly means of NO_2 and SO_2 the percentage of time attributed to excess pollution levels is determined for the months between 1992 - 1995; each month consisting of a collection of four monthly sets of data. The same approach is adopted when examining PM_{10} and O_3. Although these pollutants are measured as running means (refer to Table 2) with overlapping periods between months the degree to which this occurs is constant for each pollutant and therefore has a minimal impact on overall results. When this approach is completed the month associated with poorest levels of each pollutant can be identified. During these periods diurnal variations are investigated.

2.3 Results

Figure 1 illustrates the percentage of time attributed to poor air quality due to individual pollutants. This applies to months between 1992 - 1995, so each month represents a total of four periods (eg Jan., 1992, 1993, 1994 and 1995).

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[*] These are running means.

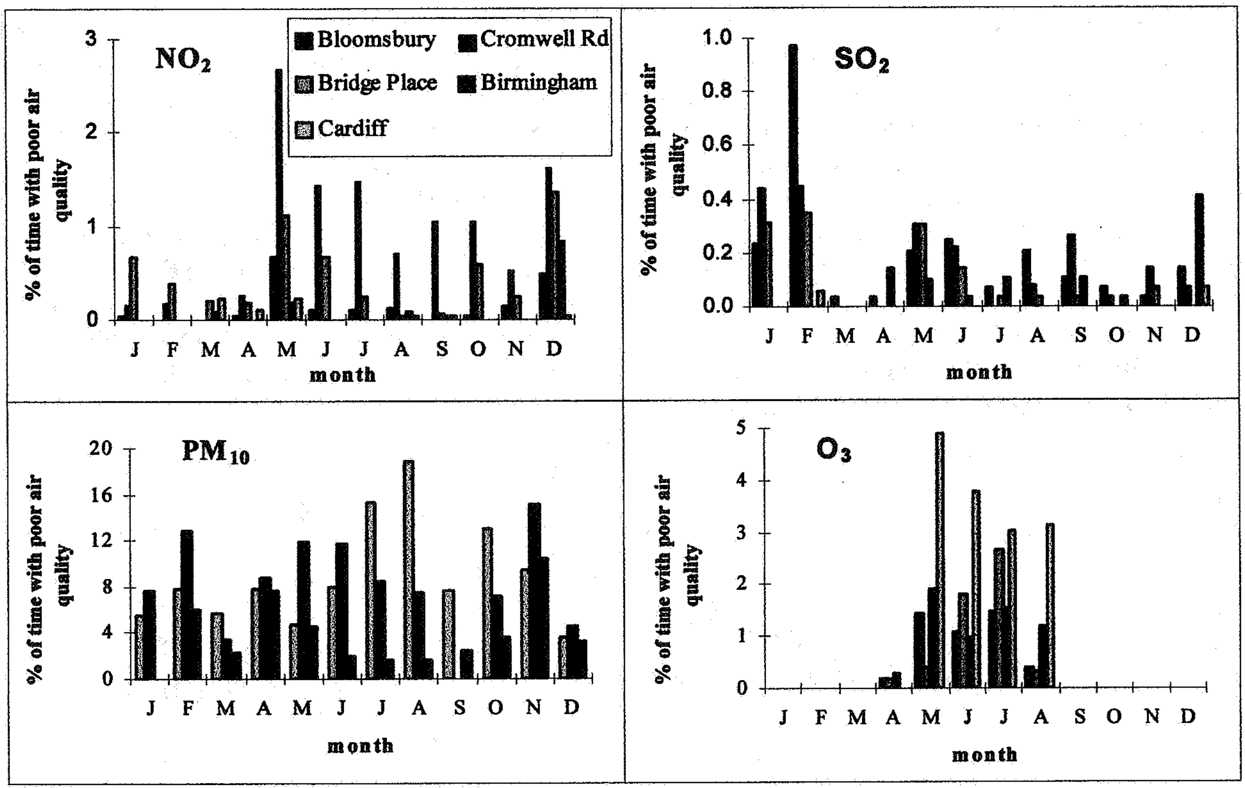

Figure 1 **Amount of time associated with poor air quality during months between the years 1992 - 1995. The bench mark concentrations are those outlined in Table 2.**

For each pollutant in Figure 1 the maximum period of time attributed to poor air quality can be identified during each month. The values are provided in table 3, and the figure typed in bold if it exceeds 5%.

Table 3. **Maximum percentage of time of poor air quality for each pollutant**

grouped months (during 1992-1995)	maximum percent of time attributed to excess pollution levels			
	NO_2	SO_2	PM_{10}*	O_3
January	0.7	0.4	**7.7**	0.0
February	0.4	1.0	**12.9**	0.0
March	0.2	0.0	**3.4**	0.0
April	0.3	0.1	**8.9**	0.3
May	2.7	0.3	**11.9**	4.9
June	1.4	0.3	**11.7**	3.8
July	1.5	0.1	**8.5**	3.0
August	0.7	0.2	**7.5**	3.1
September	1.1	0.3	2.4	0.0
October	1.0	0.1	**7.2**	0.0
November	0.5	0.1	**15.1**	0.0
December	1.6	0.4	4.5	0.0

Key

* These values do not include the Cardiff results because during 1994 the site was found to be 'contaminated' by building works. This had affected the normal distribution of particles at the site.

PM_{10} is the only pollutant that exceeds guideline values quoted in Table 2 for more than 5% of sampling periods. The worst period for PM_{10} excesses is during November months between 1992 - 1995; 15.1% of this period is associated with excess concentrations of PM_{10}. February months are the worst for SO_2, and May months the poorest for NO_2 and O_3. These months are used to examine diurnal variations for the relevant pollutant. The data analysed is the set associated with the highest excess pollution episodes; for example it can be established that in May O_3 exceeded the bench mark most often. Reference to Figure 1 reveals that Cardiff is the location where excess O_3 concentrations occur for 4.9% of May months between 1992 - 1995. Hence diurnal variations during May months at Cardiff are studied. A similar approach is adopted for the other pollutants. Figure 2 illustrates diurnal variations for the pollutants in the way described above. NO_2 and SO_2 variations are expressed as percent excess episodes. This is not possible for PM_{10} and O_3 as excess concentrations are analysed on a running mean basis, instead diurnal variation of concentration values are highlighted.

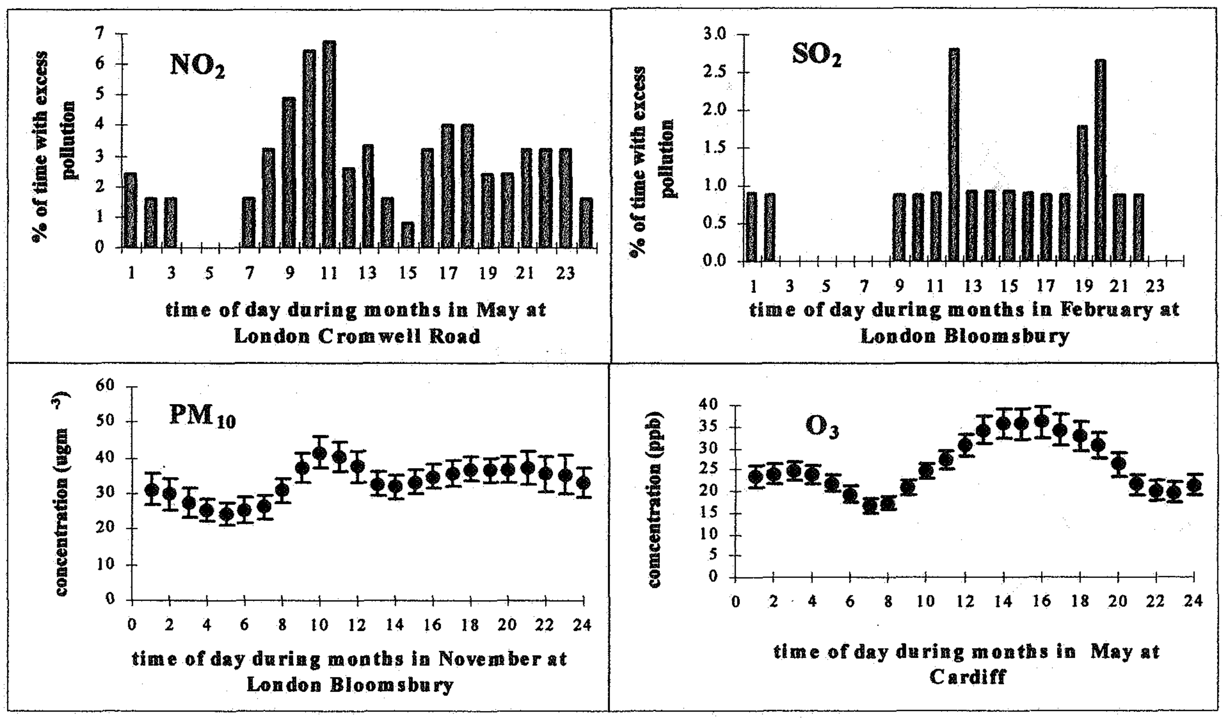

Figure 2 Diurnal variations in pollution levels between 1992 - 1995.

Figure 2 shows that excess episodes of SO_2 do not rise above 5% for any hour during February at London Bloomsbury, even though this month and site is the most onerous of all the areas studied. Excess episodes of NO_2 exceed 5% of sampling hours during May at London Cromwell Road on only two occasions (at 10.00 and 11.00 hours). Figure 2 provides means and associated standard error for diurnal variations of PM_{10} and O_3. Between 09.00 - 11.00 hours PM_{10} concentrations reach a significant peak. For O_3 this peak occurs between 14.00 - 16.00 hours. In the months when PM_{10} and O_3 excess episodes are relatively high these peak periods are likely to be a real problem.

The data analysed above chiefly relates to pollutants monitored near road level. Natural ventilation systems with a central operating mechanism may draw air in at roof level. The advantage of this is that ambient concentrations of pollutants may be reduced as a function of height. In section 3 a quantitative investigation of this issue is made.

3. THE DILUTION OF TRAFFIC RELATED POLLUTANTS WITH HEIGHT

3.1 Evaluation method

Norfolk House, a ten storey building situated alongside a busy major road in Croydon London, was selected for the analysis. The windows on the road side of the office block were openable and allowed monitoring probes to be held outside. The pollutants monitored were PM_{10} and NO_2, previously identified as the main contributors to poor air quality in British cities. Particle measurements were made using a light scattering particle counter with mean sampling times of 24 hours. NO_2 was analysed using a gas chemiluminescence techniques with sampling periods of an hour.

Air quality measurements were taken between 08.00 to 18.00 hours during five working days. On each day outdoor air quality was assessed at two heights; the lower position was fixed so that over the week dilution of each pollutant with increasing height could be examined. Table 4 summarises the differences in height between monitoring positions, on different days..

Table 4. Analytical protocol of altitude monitoring exercise

Day	Control height (m)	Variable height (m)	difference in height (m)
1	5.00	11.10	6.10
2	5.00	17.20	12.20
3	5:00	23.30	18.30
4	5.00	29.40	24.40
5	5.00	32.45	27.45

3.2 Results

Differences in the concentration of pollutants between two heights were calculated as a percentage of the value at the lower fixed height of 5m. On each day an overall mean value was determined with standard error at the 95% confidence level. The daily means were contrasted to develop a profile of height against concentration. Although the distance between measuring points varied from one day to the next by calculating percent change in concentrations between points an overall picture of height effects is possible. Figure 3 illustrates this relationship for each pollutant.

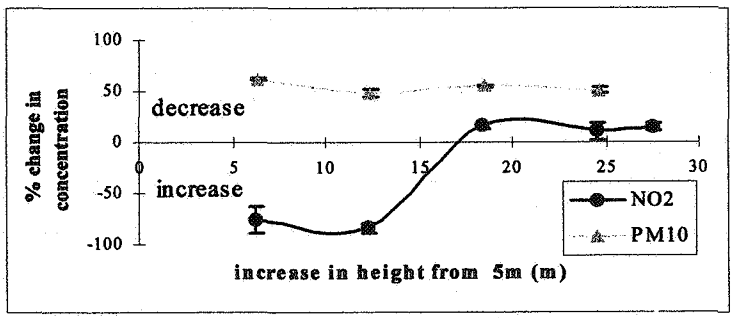

Figure 3 Variation in pollutant concentrations as a function of alterations in height from road level.

PM_{10} concentrations are diluted with height in all circumstances according to Figure 3; particle concentrations diminish by between 48 - 61%, between 6.1 - 24.4 m above 5 m. The relationship between PM_{10} concentrations and height is not linear. NO_2 behaves differently in that between 6.1 - 12.2 m above 5 m its concentration increases. Beyond 18.4 m above 5 m NO_2 levels fall by between 10 - 16.

The significance of variations in meteorological conditions in a vertical plane has not been assessed in this exercise which imposes a limitation on the results obtained from this approach.. However this preliminary exercise is of use as it indicates potential improvements in the quality of air provided to buildings when supply is at a sufficient height from busy roads.

4. DISCUSSION

A potential strategy for natural ventilation of non domestic buildings in cities is to avoid periods when pollution loads from traffic may be high. The exercise in section 1 allows a decision to be made about the frequency of 'acceptable' excess pollution episodes in the outdoor environment. This is a possible design strategy for natural ventilation of non domestic buildings. An example of this approach is shown in Table 5 for the pollutants reviewed in section 1 of this paper. The assumption made in Table 5 is that excess outdoor pollution for up to 5% of sampling times is an acceptable frequency of episodes.

Table 5 Suitable and unsuitable periods for natural ventilation due to pollutants in urban environments (letters in cells denote type of pollution problem)

hour of day	month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1												
2												
3												
4												
5												
6												
7												
8												
9	p	p		p	p	p	p	p		p	p	
10	p	p		p	p & n	p	p	p		p	p	
11	p	p		p	p & n	p	p	p		p	p	
12												
13												
14					o							
15					o							
16					o							
17												
18												
19												
20												
21												
22												
23												
24												

KEY

p = PM_{10} n = NO_2 o = O_3

The assumption behind Table 5 that 5% is a suitable upper bench mark for an acceptable frequency of excess pollution episodes is an important one as a different value may produce a dissimilar distribution of appropriate periods for natural ventilation. However 5% is a reasonable value given the additional dilution effect of pollutants with increased height from road traffic emissions. There is also evidence of much lower indoor concentrations of pollutants compared to outdoor levels, (4); up to 60% lower indoor concentrations in a naturally ventilated building compared to outdoor values at street level.

Table 5 demonstrates likely occasions when PM_{10} and O_3 ambient concentrations may be too high. Since this is based on calculations of percent excess episodes on monthly time scales it is possible that there are other periods in the day when the problem may also be consistent. Over the long term O_3 may become more significant in urban areas where other pollutants diminish; NO reacts with O_3 producing NO_2. If traffic emissions of NO decrease O_3 concentrations will rise. This is most likely to occur during peak hours of traffic intensity. However there is evidence that building materials such as masonry, are effective at breaking up O_3 molecules, hence overall the pollutant is not a severe problem (5).

Using the criteria set out in Table 5 SO_2 does not appear to be a significant urban pollutant. There were no periods when excess SO_2 concentrations prevailed for up to 5% of sampling periods. Although the sites examined were not the worst in Britain for this pollutant, they still represented areas where the problem was comparatively significant. Table 5 indicates that NO_2 concentrations can be persistently high, however these are very infrequent and the locations studied were the poorest for NO_2 levels in the UK. Further more tougher legislation to control vehicle emissions are likely to be enforced given ongoing concerns about air quality. This will assist in maintaining NO_2 concentrations below critical values. Section 3 also clearly demonstrated that height from roadsides is an important issue and can result in substantial reductions in pollutant concentrations, although further work is required to quantify the effects of meteorological considerations.

5. CONCLUSION

Table 2 indicates the adverse health effects associated with high concentrations of urban pollutants. It emphasises the need for unpolluted air when supplying non domestic buildings adequate ventilation. When natural ventilation is the favoured option the quality of the supply air is even more critical, given that low driving forces attributed to natural ventilation prohibits the inclusion of extensive air filtration mechanisms. Whilst air conditioning generates larger pressures that will cope with air cleaning processes it is not an ideal solution for strategies geared to reducing energy consumption. Thus an alternative approach is necessary.

A potential low energy solution is to supply air to buildings for ventilation purposes in a way that avoids the most onerous pollution periods. Either air inlets can be shut off during these occasions, or fan assisted ventilation utilised, with polluted air drawn in through a system of cleaning filters. Deciding when to switch to a fan assisted scheme is possible from the approach made in Table 5. Table 5 indicates the periods during a year when natural ventilation is a possible low energy option, and also indicates the occasions when a fan assisted scheme would need to be operated to allow for air cleaning via filters.

The analysis of pollution data from the British mainland examined areas where the problem appeared most evident. London is a good representative of high polluting areas of northern Europe, where the climate is cold to moderate. Thus measures identified in this paper geared to reducing the demand for energy due to ventilation can be adopted in similar regions of Europe. Whilst it is not possible to account for all circumstances that may occur the approach described in this paper is a useful step towards the promotion of natural ventilation. It is also note worthy that section 3 of this paper suggests that intelligent location of air inlets may greatly reduce the need for costly air filtration systems.

6. ACKNOWLEDGEMENTS

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