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The significance of urban pollution in relation to ventilation air supply

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The present 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 examine the frequency of excess pollution events between 1992 - 1995. The results identify the most appropriate periods for natural ventilation of offices in urban areas. Preliminary in-situ experiments also demonstrate that both PM_{10} and NO_2 concentrations decrease with increasing height from a busy road.

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. Natural ventilation of offices in urban locations is feasible so long as indoor air quality is not adversely affected. Filtration of air supply is an option but may unacceptably restrict air the flow of air into buildings. One possible solution is to vary ventilation occasions to avoid 'polluted' periods.

A general perception exists that pollution at roof level is likely to be less than by a road side, but there appears to be little quantitative evidence for this. Since offices can vary 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 the second section 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 report examined the urban pollution problem across Europe, using seven countries 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. In each city a model was used to predict the reduction in emissions of pollutants required to meet standards. The percent reduction in pollution estimated for each of the seven cities is presented in Table 1.

Table 1. Emission reduction requirements necessary to achieve air quality standards.

City	percentage reduction required to meet standards			
	NO_x (hourly means)		CO (hourly means)	
	< 200 $\mu gm^{-3}_{(a)}$	< 93 $\mu gm^{-3}_{(b)}$	< 10 $mgm^{-3}_{(a)}$	< 5 $mgm^{-3}_{(b)}$
London*	0	31.5	0	0
The Hague*	0	0.0	0	0
Cologne*	0	20.5	0	0
Lyon**	0	22.5	0	0
Milan**	0	45.0	0	0
Athens**	0	50.0	0	0
Madrid**	0	39.0	0	0

KEY
- * North European Cities
- ** South European Cities
- (a) set by the European Commission
- (b) set by the World Health Organisation

The scope of the NatVent project refers to cold and moderate climate regions of Europe, hence the northern region. Of the cities in Table 1 only London, The Hague and Cologne fall within the climatic zone specified. Of these three locations London requires the greatest reduction in pollution emissions. On this basis London can be used to represent relatively poor air quality in urban environments across northern Europe.

Figure 1 (a) - (b) summarise the number of occasions when air quality has been termed 'poor' between 1992 - 1995, at UK sampling sites (2).

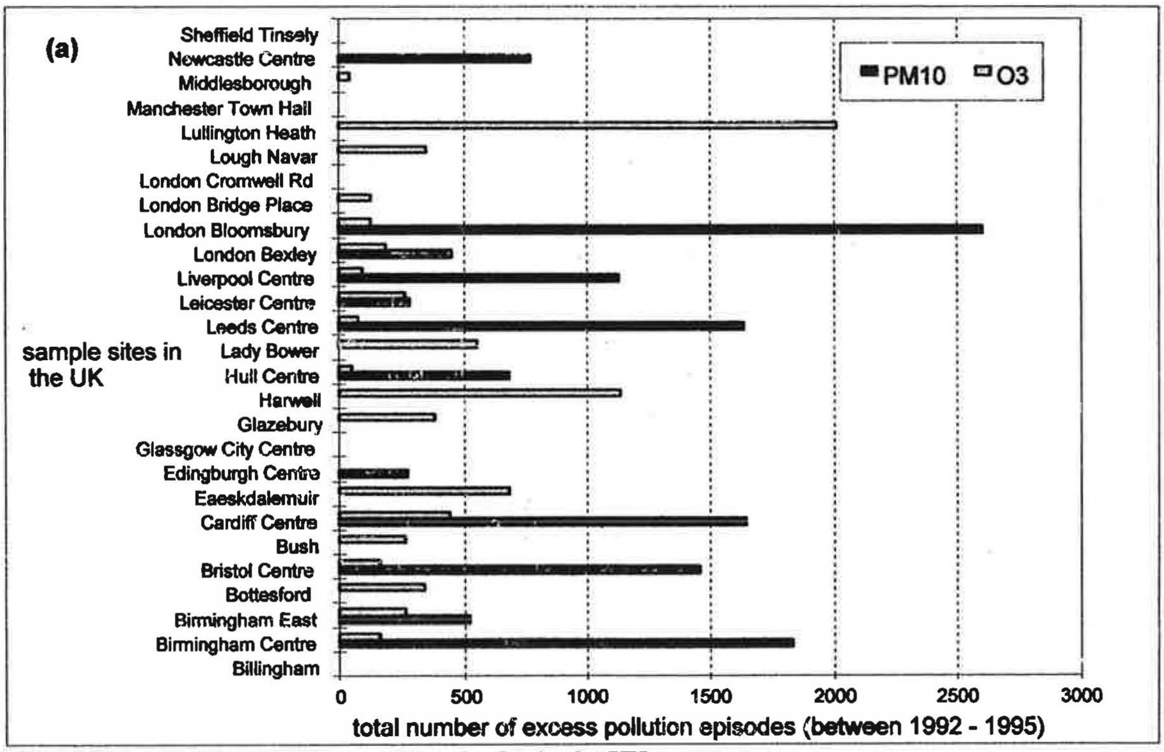

Figure 1(a). Excess PM_{10} and O_3 episodes in the UK.

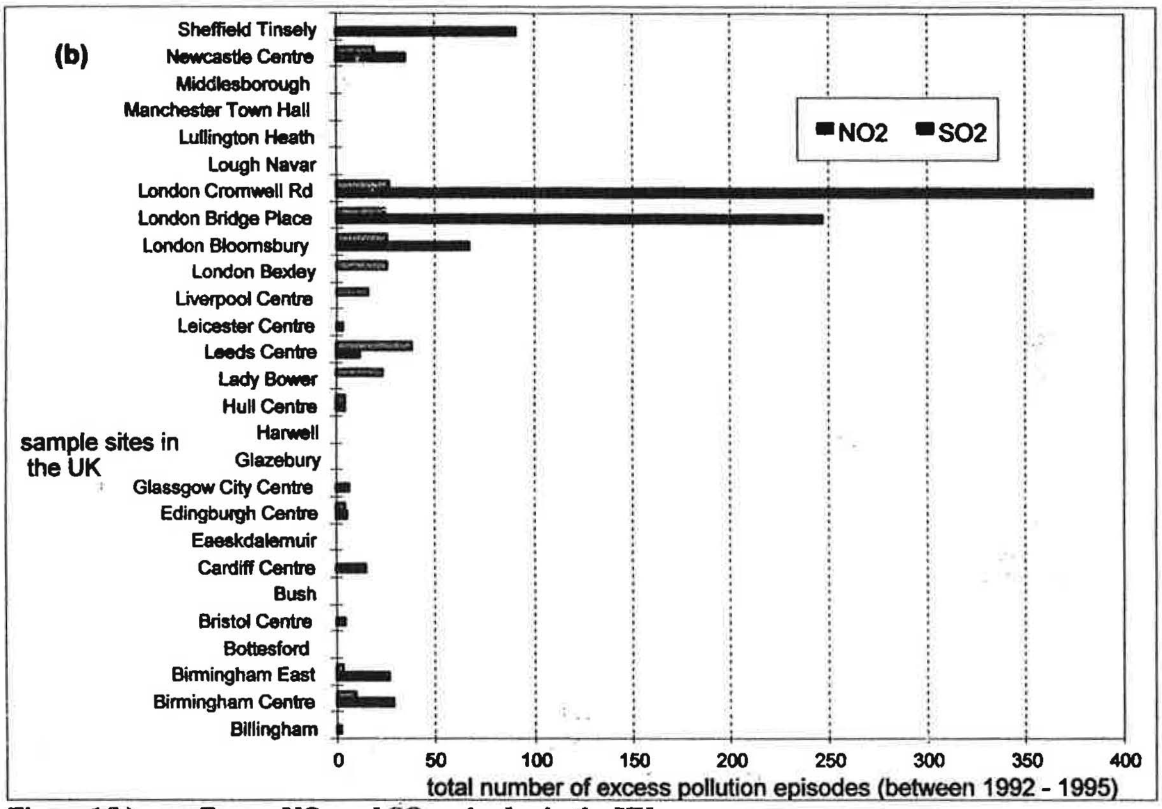

Figure 1(b). Excess NO_2 and SO_2 episodes in the UK.

Excess pollution levels are specified because of the impact pollutants have on public health. The pollutants referred to in figure 1 (a) and (b) have specific impacts on the health of individuals. These effects are summarised briefly in Table 2.

Table 2. Health problems attributed to excess pollution episodes.

Health problems:	PM_{10} (3)	O_3 (4)	NO_2 (4)	SO_2 (4)
- respiratory	√	√	√	√
- cardiovascular	√			
- chest pains				√
- mortality	√			

The concentration of particles in the atmosphere is an increasingly important issue thus air supplied to buildings needs to be drawn from areas where PM_{10} levels are low. Figure 1 (a) indicates that particle concentrations have been a particular problem at London Bloomsbury, Birmingham City Centre and Cardiff City Centre. Ozone concentrations at these locations have been much less of a problem, but there is evidence that the pollutant may become an increasing problem, for reasons that will be explained later. Figure 1 (b) indicates that ambient concentrations of NO_2 are unacceptably high most frequently at Bridge Place and Cromwell Road, in London. SO_2 concentrations have exceeded set limits within urban areas, however not to the same extent as NO_2. In assessing the impact of urban air quality on ventilation strategies for non domestic buildings, the five above mentioned sites are a useful sample of environments where the problem is most severe on the British mainland. Additional details about each location 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 3.

Table 3. **Pollutants analysed 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 reductions in ambient concentrations of pollutants to be achieved by 2005. Table 4 identifies some of the pollutants of concern and the concentrations that must not be exceeded (unless figures are otherwise revised) by 2005.

Table 4. **Proposed standards and specific objectives.**

Pollutant	Standard		Specific objective
	concentration	measured as;	
NO_2	104.6 ppb	1 hour mean	to be achieved by 2005#
PM_{10}	50 μgm^{-3}	running 24 hour mean	to be achieved by 2005
SO_2	100 ppb	15 minute mean	to be achieved by 2005
O_3	50 ppb	running 8 hour mean	to be achieved by 2005

reference, (3)

The concentration values expressed in Table 4 are used to evaluate 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 examines the degree of the problem as it currently stands.

A different criterion from that highlighted in Table 4 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 should not have a great impact on final conclusions.

these are provisional objectives that may be altered after a review in 1999, or sooner if compelling evidence dictates this is necessary.

From hour means of NO_2 and SO_2 the percentage of time attributed to excess pollution levels is determined for the months between 1992 - 1995; over the four year period each month will be 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 4) 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 for each pollutant can be identified. During these periods diurnal variations are investigated.

2.3 Results

Figure 2 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 four periods (eg Jan., 1992, 1993, 1994 and 1995).

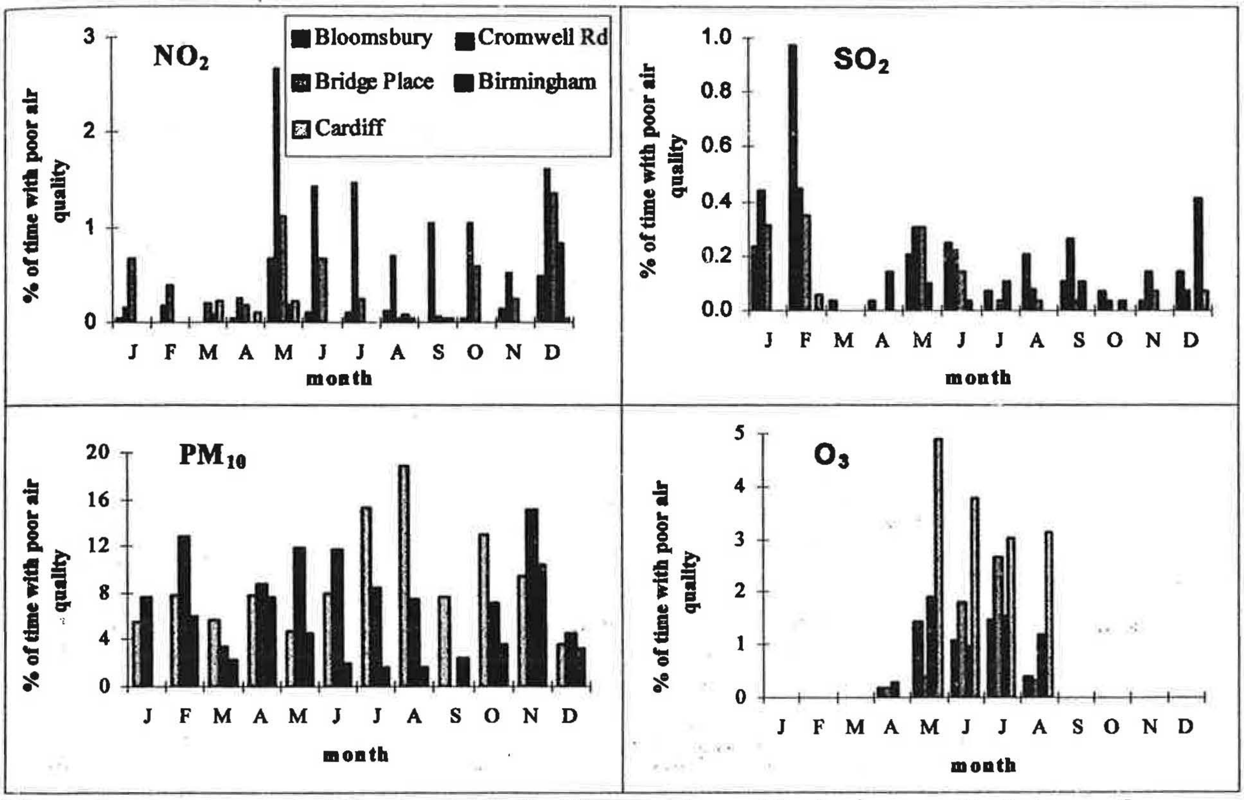

Figure 2. Amount of time associated with poor air quality during months between the years 1992 - 1995. The bench mark concentrations are those outlined in Table 2.

From Figure 2 the maximum percentage of time attributed to poor air quality can be identified during each month for each pollutant, when all relevant sites are considered. For example the value for NO_2 during months of May is approximately 2.5%. Table 5 adopts this approach for each pollutant. Where poor air quality occurs for in excess of 5% of the sample month values are typed in bold.

Table 4. 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 5 for more than 5% of sample 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 May was established as the month when O_3 exceeded the bench mark most often. Reference to Figure 2 reveals that Cardiff is the location where excess O_3 concentrations arise 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 3 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.

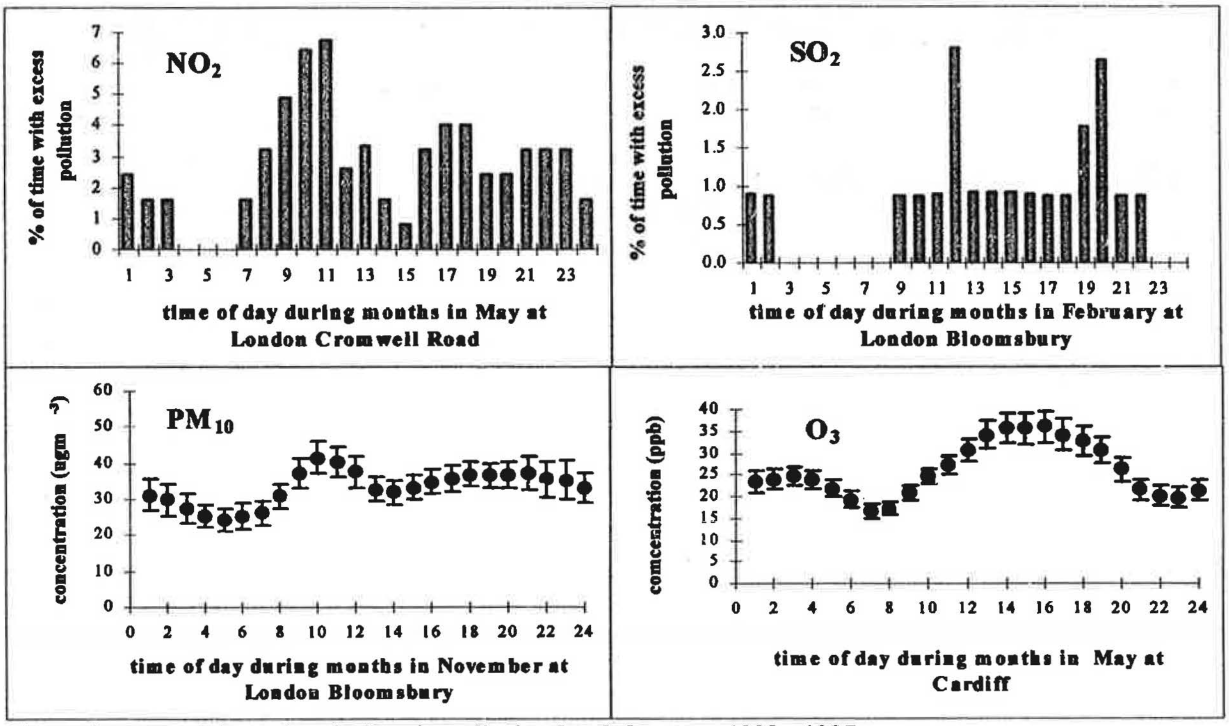

Figure 3. Diurnal variations in pollution levels between 1992 - 1995.

From Figure 3 excess concentrations 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 3 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 in terms of PM_{10} and O_3 concentrations.

The data analysed above chiefly relates to pollutants monitored near road level. Natural ventilation systems with a central operating mechanism can 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 2 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. A photograph of the building and its surroundings is seen in figure 4.

Figure 4. Norfolk House, situated alongside a busy road in Croydon, London.

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 6 summarises the differences in height between monitoring positions, on different days..

Table 6. 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 5 illustrates this relationship for each pollutant.

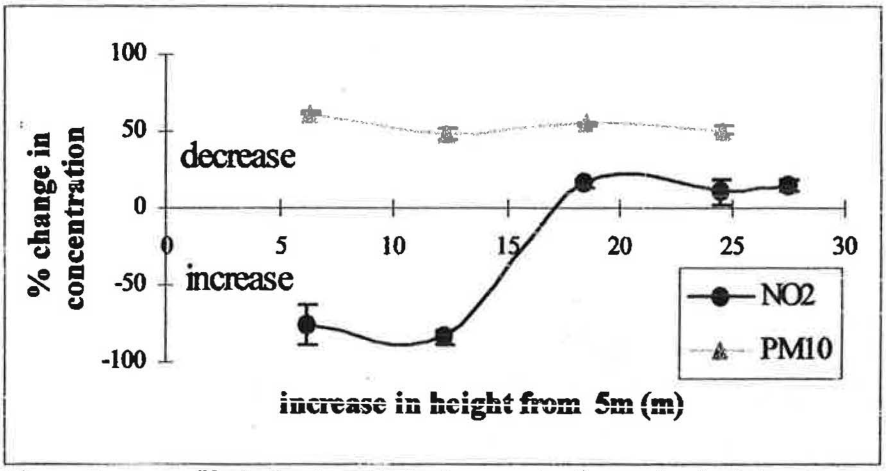

Figure 5. **Variation in pollutant concentration and noise intensity as a function of alterations in height from road level.**

PM_{10} concentrations are diluted with height in all circumstances according to Figure 5; 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%, 18.4 - 27.4 m above 5 m

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 as to 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 by Table 7 for the pollutants reviewed in section 1 of this paper. The assumption made in Table 7 is that excess pollution for up to 5% of sampling times is an acceptable frequency of episodes.

Table 7. Suitable and unsuitable periods for natural ventilation due to pollutants in urban environments (letters in boxes denote the type of pollution problem).

hour	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 7 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 that additional dilution of pollutants may occur 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 7 demonstrates likely occasions when PM_{10} and O_3 concentrations are likely to 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.

Using the criteria set out in Table 7 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 7 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, which will assist in keeping NO_2 concentrations below critical values. Section 2 also clearly demonstrated that height from roadsides is an important issue and can result in substantial reductions in pollutant concentrations.

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 7. Table 7 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. Table 1 demonstrates that 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 2 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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7. References

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