SITING CONSIDERATIONS FOR URBAN POLLUTION MONITORS

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Abstract—This paper addresses the problem of comparability between urban pollution data measured at the kerbside. The cost of monitoring and the inadequacy of methodological approaches to analysis have made the existing kerbside data of questionable value. In this paper we briefly review the existing pollution monitoring methodologies and describe those used in this research. The use of a novel, small, affordable, self-contained carbon monoxide (CO) monitor, developed at UCL, has allowed the collection of kerbside data which is highly detailed, both spatially and temporally. This has led in turn to new analysis methods which use location-specific concentration profiles to compare pollution exposure at different sites throughout the full range of readings. We propose that this profile can be used to smooth out the large fluctuations found in time series kerbside pollution data and can also be used to characterise and compare different locations. This method can also be used to compare pollution concentrations for the same location before and after the implementation of different traffic management measures. These detailed data have produced findings of up to a threefold difference in pollutant concentrations (6 min averages of CO measured at head height) between different sides of the same road under cross-wind conditions, with the leeward side of the street experiencing higher levels than the windward. Finally, we summarise a suggested methodology for data acquisition and analysis in future kerbside atmospheric pollution studies.

Key word index: Air pollution, wind direction, monitoring methodology, kerbside, street canyon.

1. INTRODUCTION

This paper presents findings which suggest radical differences in kerbside pollutant levels between two sensing positions on opposite sides of the same road depending on the direction of the prevailing wind. These findings are taken from pollution surveys carried out during the course of the EPSRC project “The effect of street grid configuration on urban pollution: civilising urban traffic”, GR/J50613. During this project a novel monitoring instrument, the StreetBox, was developed. This instrument allowed simultaneous pollution concentration data to be gathered from a number of sites within a small urban area at 6 min intervals.

The data gathered during this project was combined with traffic flow measurements, locally measured meteorological data and information about the three-dimensional form of the built-up area to provide an insight into factors affecting pollution concentrations at the street segment scale. The main findings of the project, detailed in the final report to the EPSRC (Croxford and Penn, 1996), were that the street grid configuration can be used to determine up to 76% of the variation in pollutant concentrations in the 12 streets that were monitored.

We concentrate on showing the effect of local prevailing wind direction and the form of the local urban area on pollutant concentrations. As shown clearly in Oke (1987), and backed up more recently with measurements in Berkowicz et al. (1996), and also Buckland (1996), the direction of the prevailing wind with respect to the orientation of the direction of the street can set up vortices within that street. Simple vortices occur when the wind direction is perpendicular to the street and the height to width ratio of the cross-section of the street is approximately equal to one. Within the vortex relatively clean rooftop air is drawn down the windward face of the street canyon, across the road at street level, in reverse direction to the wind direction at roof level, bringing pollutants in the road across to the leeward side and then up the leeward face of the canyon. The effect is to make one side of the street experience higher pollutant levels than the other.

The fact that vortices form in street canyons when the prevailing wind blows perpendicular to the street...
has been known for many years, but the implications of this for monitoring survey protocols does not appear to have been taken into account in urban kerbside pollution surveys to date. The large-scale multi-site surveys that have been carried out have mostly used diffusion tubes and the assumption has been that over the sampling period the effects of wind in bringing clean or dirty air across a monitoring point will even out. The national, continuous pollution monitoring networks do not, as a matter of course, measure wind direction or indeed any climatic information close to the monitoring sites, and little mention is made of climatic effects in reports. This makes it hard to evaluate the likely effects of wind direction and local site characteristics on the results of monitoring at a particular site.

A recent paper by Chan and Hwang (1996) attempts to solve this problem and describes a method for calculating a representativeness statistic for a given monitoring station. They compare data from 22 sites up to 750 m from their monitoring station and show that for the pollutants \( \text{SO}_2 \), \( \text{O}_3 \), \( \text{NO}_2 \) and \( \text{PM}_{10} \), the monitoring station is more representative of the surrounding area than for the pollutants \( \text{CO} \), total hydrocarbons (THC), non-methane hydrocarbons (NMHC), and NO. The second set of pollutants are generally due directly to traffic and concentrations will drop rapidly with distance form source, the first set of pollutants can be subject to long distance transport mechanisms and are not necessarily directly related to traffic sources. They suggest that this representativeness statistic should be calculated and published along with monitored background data to allow for more accurate comparison of pollutant levels in different cities. One of the possible criticisms of this work might be that the sites chosen to provide data for comparison are themselves not representative.

Section 2 reviews some of these previous pollution monitoring surveys and their methodologies. An example of each of several different types of survey is given along with an assessment of the aims and objectives of each survey. Section 3 presents results from using up to 24 StreetBox instruments, simultaneously monitoring a small area of central London (approximately 1 km²). The StreetBox instrument was set up to measure carbon monoxide concentrations, temperature, wind speed, light and humidity and to store average readings every 6 min. A method of analysis is described, developed specifically to utilise the data from these instruments which is of higher resolution, both spatially and temporally, than previous survey methods have allowed. We suggest that the methods of analysis allow location specific regularities in pollution concentration profiles to be isolated from the large data sets of rapidly fluctuating time-series data.

Section 4 considers the results of the StreetBox survey together with aspects of previous researchers’ work, and suggests a possible monitoring methodology for kerbside urban pollution surveys. In particular, we focus on the factors to be considered when siting urban kerbside monitoring stations in order to provide relatively robust and comparable measures of ambient pollution between locations. Finally, we suggest a method of analysing the data to provide clear evidence of the regular pollution characteristics of a particular monitoring location for use in surveys to evaluate the effects of local traffic management implementations.

2. PREVIOUS POLLUTION SURVEY TECHNIQUES

Most previous pollution surveys are constrained by several factors, in the case of continuous pollution monitors, by the cost and bulk of the monitoring equipment and by power supply requirements, or in the cases of both diffusion tube and bag surveys, by the lack of temporal resolution of the measurements. All of these methods have been used to survey various pollutants at different temporal and spatial scales. Amongst the largest recent surveys were the national U.K. surveys using passive sampler tubes to monitor nitrogen dioxide. We summarise these and other types of survey technique below, briefly reviewing scale, methodology and equipment used.

2.1. Continuous-monitoring surveys

Government sponsored air quality monitoring networks exist in most European countries. The majority of sites are located to measure the urban background concentration of pollutants. Each site requires a secure air-conditioned room with a power supply and telephone line to contain the instruments, these constraints and the associated costs reduce the number of possible sites. The results from these sites are used to monitor long-term trends in pollutant concentrations and they are also used to compare pollution concentrations in different cities and countries. Exceedances of the World Health Organisation (WHO) limits for a particular pollutant are compiled using these data.

One of the largest of these networks is in the North Rhine/Westphalia region of Germany, where 76 stationary continuous monitors and 8 mobile monitoring stations are used to measure \( \text{SO}_2 \), \( \text{NO} \), \( \text{NO}_2 \), \( \text{CO} \), \( \text{TSP} \), ozone and seven meteorological variables, Pfeffer (1994). In the U.K. the enhanced urban monitoring network (EUN) now complements the automated urban network (AUN) and provides 84 automatic monitoring stations across the U.K.; no meteorological data is measured at any of these sites.

Other smaller-scale surveys carried out by researchers have used a few continuous-monitoring instruments in several sites to investigate pollutant distributions; however because of the cost, bulk and siting requirements of these continuous monitors, the studies have been unable to be used to make observations about street-to-street scale variations in pollutant distribution. One of these studies by Bell has been using Siemens-designed monitors in a study of
Leicester. These monitors are restricted by power supply and communication requirements to monitoring locations at, or very near to, traffic lights. An attempt was made to correlate SCOOT\* automatic traffic flow data with continuous CO concentrations; however, significantly, the results were disappointing in that they showed only poor correlations between instantaneous traffic flows and kerbside CO concentrations (Bell, 1996). These results are possibly due to the location of the pollution sensors, the fluctuations of kerbside pollution measurements in locations subject to turbulence from moving traffic and also the problematic flow dynamics of local wind at street intersections where effects of building geometry were not well understood.

2.2. NO\textsubscript{2} tube surveys

Small diffusion tubes have been used to produce area surveys of NO\textsubscript{2} concentrations. These tubes are inexpensive to produce and to analyse and are used to give a one or two week average figure for the ambient NO\textsubscript{2} concentration during the exposure period. A typical accuracy for each tube would be approximately 10%. National surveys using NO\textsubscript{2} tubes have produced maps of the U.K. in terms of NO\textsubscript{2} concentrations in 1986, 1991 and 1994 (Campbell \textit{et al.}, 1992), and the National U.K. NO\textsubscript{2} Survey 1994 (AEA, 1994). These surveys revealed an average increase of 35% in NO\textsubscript{2} over the five year period from 1986 to 1991, consistent with a 38% increase in estimated emissions due to increased vehicle traffic.

There have been comprehensive studies of NO\textsubscript{2} in London (Greater London Council, 1986), including surveys using over a hundred diffusion tubes producing weekly averages over an area of 1600 km\textsuperscript{2}. The yearly average values varied from 80 \(\mu\text{g} \cdot \text{m}^{-3}\) in the centre to less than 50 \(\mu\text{g} \cdot \text{m}^{-3}\) in the suburbs. Other cities have also been surveyed in similar detail, including Cambridge with 60 tubes, averages ranging from 29 to 73 \(\mu\text{g} \cdot \text{m}^{-3}\) (15–38 ppb) (Cambridge City Council, 1993).

Laxen and Noordally (1987) used NO\textsubscript{2} diffusion tubes to show the variation of NO\textsubscript{2} weekly averages along a street and a set of junctions. Their main findings are, first, that the highest levels are found on the centreline of a road, with a rapid decline over the first 10–15 m; second, that NO\textsubscript{2} concentrations are 10–15% higher at traffic lights than 60 m upstream; and third, that concentrations decline to background levels with an increase of height to 20 m above the road. Laxen and Noordally do not report on the effect of vortices forming due to wind direction, but the data they present show higher NO\textsubscript{2} levels on the leeward side of a street and lower on the windward side of the street. This is in agreement with the findings on vortex formation given in Berkowicz \textit{et al.} (1995) and explored in more detail in Section 3 of this paper.

2.3. Bag surveys

Tedlar sampling bags were used in a study in Hong Kong reported by Chan and Wu (1993), to look at bus-commuter and pedestrian exposure to traffic air pollution. The bags allow a snapshot of pollution to be taken at a number of sites at distinct points in time, by capturing a sample of air from each site in a different bag. The bags are then analysed in the laboratory. In this survey the pollutants analysed were NO, NO\textsubscript{2}, CO, SO\textsubscript{2}. The main findings were that 10% of in-bus measurements and 1.7% of road-side measurements of NO\textsubscript{2} exceeded the Hong Kong Air Quality Objective, other pollutants were below the Objectives. In-bus levels of all pollutants were much higher than ambient or roadside measurements. Correlations showed that in-bus concentrations of NO, NO\textsubscript{2}, and SO\textsubscript{2} could be predicted from roadside data. No meteorological data were considered.

3. RESULTS FROM THE STREETBOX SURVEY

The existing studies of pollution in city streets have not been able to look at both temporal and spatial variations at high resolution due mainly to the cost of available equipment. A new self-contained monitoring instrument, the StreetBox, was therefore developed under the EPSRC funded project GRJ/50613 to allow affordable multi-location simultaneous surveys to be made over an urban area, (Croxford \textit{et al.}, 1996; Croxford and Penn, 1995). This instrument measures carbon monoxide (CO), temperature, relative humidity, light, and wind speed and logs them in a miniature databooking computer at user-specified intervals. The unit has an independent power supply that allows comparative freedom in choice of site. Results from monitoring several streets in London using this instrument are presented below to illustrate various problems encountered when monitoring urban ambient kerbside pollution at head height as experienced by pedestrians. The magnitudes of various effects on pollutant concentrations are investigated using measurements of carbon monoxide taken on both sides of 12 street segments in a small area of central London.

The area is largely homogeneous in terms of building height, with most streets having a canyon-type profile with a height to width ratio of between 0.7 and 1.7. All the measurement points were at the same height (2 m) and as far from any street junction as possible. The monitoring instruments were mounted on lamp posts, or similar street furniture, all at similar distances from the kerb (about 1 m). The aim of this method of siting was to ensure the best possible chance of achieving a representative monitoring position for the street segment. A rooftop monitoring site was set up on one of the tallest buildings within the

\*Split cycle and offset optimization technique, software for improving traffic light timing, based on data from induction loops buried in the road.
area, and equipped with meteorological equipment to measure local rooftop wind speed and direction. A StreetBox was also set up near the sampling point of one of Westminster Council’s continuous monitoring points to allow for comparison of the StreetBox’s readings against conventional NDIR equipment.

When measuring kerbside pollution every gust of wind or passing truck can blow clean or dirty air across a kerbside monitor. The graph in Fig. 1 gives an example of the raw data for a 24 h period with data logged every 6 min for three different streets. The data are very “spiky” and difficult to analyse. Although it seems clear that the three streets display very different underlying concentration trends, these are well masked by the rapid fluctuations of the data.

In order to compare locations we have used the shape of the frequency distribution of the pollution. All individual measurements are ordered from lowest CO concentration to highest, and plotted on a scale that shows the percentage of readings below any given concentration. This allows a full picture not only of mean concentrations at a particular monitoring site, but also of the extreme values. Each monitoring site displays different frequency distribution characteristics for CO concentrations. The percentile plots of pollution measurements from five streets are given in Fig. 2. Euston Road has the highest curve indicating that at each percentile point the measurements on Euston Road are higher than those for each of the other roads. For example, 80% of the CO measurements made on Euston Road in November were less than 5.5 ppm, whereas the 80th percentile figure for Gower Street was 4 ppm. More detailed comparisons can be made by comparing the profiles of different streets. For example, Tottenham Court Road shows a higher concentration than Gordon Street until the 85th percentile, however for the upper extreme values the Gordon Street plot crosses over showing that at the upper extreme it becomes the more polluted street. This method of analysis also allows clear comparisons to be made between the characteristic frequency distribution for a particular monitoring site under different conditions such as prevailing wind direction or time of day, or potentially, before and after changes to the road network or traffic management implementations.

Figure 3 shows an example of how percentile comparisons for day time vs nighttime measurements can be made for several streets on the same graph. Each point plots the daytime against nighttime concentrations for a particular percentile value, for instance, the top point is the 99th percentile and this is 15 ppm CO for Gordon Square during the daytime and 4.5 ppm CO for nighttime measurements. As might be expected all the daytime readings are higher than those at night.

Figures 4 and 5 show how the CO concentrations on Euston Road (Fig. 4) are influenced much more dramatically by the rooftop wind direction than those on Torrington Place (Fig. 5). Both graphs are plotted on the same scale. In the case of the Euston Road the three lowest percentile plots are for NW, NE, and N winds, the highest two are for S and SE. As the roads are parallel and the measuring points are both on the southerly side of the road, the differences in concentrations are likely to be mainly due to traffic flow differences where the Euston Road carries the higher flows. However, the differences in the shapes of the profiles (Euston Road, height to width ratio of 0.7 compared to Torrington Place at 1.7), are likely to be due to the difference in the geometry of the street canyons and their effect on local street level wind,
altering the average and extreme measures under the same prevailing wind conditions (roof level). See Table 1 for information on each site.

The next four graphs (Figs 6–9), together, show clearly how the prevailing wind direction above roof level affects pollution concentrations measured at particular kerbside sites at street level. Each graph represents a wind direction, the measurements that appear on each graph are only those made by sensors that are on that side of the road. All of the monitored streets are in a street grid which points approximately 45° from north. So each monitoring site is considered as being on either the NE, SE, SW or NW side of the road. The measurements plotted are split by the current prevailing roof level wind direction into those readings that place a particular monitoring site on the windward side of the street and those that are not. All of the CO measurements for each street are plotted as a comparison of percentile distributions between “windward” and “other” measurements. These graphs

Fig. 2. Percentile plots or frequency distributions of carbon monoxide measurements taken in November, for five sensor positions.

Fig. 3. Percentile plot comparisons for five sensor positions comparing CO measurements between two states of nighttime or daytime. (Here daytime is arbitrarily taken as 06:30 to 19:00, with nighttime as everything else). The figures are carbon monoxide in ppm.
Table 1. Site information, for each of the monitoring positions. The direction at the end of the road name refers to the side of the road that the monitor was sited on (e is an estimated value)

<table>
<thead>
<tr>
<th>Road name</th>
<th>Building height (m)</th>
<th>Road width (m)</th>
<th>Height to width ratio</th>
<th>Cars(h⁻¹)</th>
<th>75th percentile CO (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euston Road SE</td>
<td>25.0</td>
<td>36.3</td>
<td>0.7</td>
<td>2300</td>
<td>5.0</td>
</tr>
<tr>
<td>Gordon Square NE</td>
<td>20.0</td>
<td>25.0</td>
<td>0.8</td>
<td>77</td>
<td>1.8</td>
</tr>
<tr>
<td>Gordon Street NE</td>
<td>19.0</td>
<td>20.0</td>
<td>1.0</td>
<td>412</td>
<td>2.0</td>
</tr>
<tr>
<td>Gordon Street SW</td>
<td>19.0</td>
<td>20.0</td>
<td>1.0</td>
<td>412</td>
<td>2.0</td>
</tr>
<tr>
<td>Gower Place NW</td>
<td>22.5</td>
<td>15.0</td>
<td>1.5</td>
<td>101</td>
<td>1.6</td>
</tr>
<tr>
<td>Gower Place SE</td>
<td>22.5</td>
<td>15.0</td>
<td>1.5</td>
<td>101</td>
<td>1.0</td>
</tr>
<tr>
<td>Gower Street NE #1</td>
<td>20.0</td>
<td>20.0</td>
<td>1.0</td>
<td>842</td>
<td>3.9</td>
</tr>
<tr>
<td>Gower Street SW #2</td>
<td>20.0</td>
<td>20.0</td>
<td>1.0</td>
<td>842</td>
<td>3.7</td>
</tr>
<tr>
<td>Grafton Way NW</td>
<td>20.0</td>
<td>20.0</td>
<td>1.0</td>
<td>252</td>
<td>2.9</td>
</tr>
<tr>
<td>Torrington Place SE</td>
<td>25.0</td>
<td>15.0</td>
<td>1.7</td>
<td>650</td>
<td>3.0</td>
</tr>
<tr>
<td>Tottenham Court Road NE</td>
<td>20.0</td>
<td>28.1</td>
<td>0.7</td>
<td>1014</td>
<td>2.7</td>
</tr>
<tr>
<td>University Street NW</td>
<td>22.0</td>
<td>16.3</td>
<td>1.3</td>
<td>289</td>
<td>2.7</td>
</tr>
<tr>
<td>Upper Woburn Place SW</td>
<td>20.0</td>
<td>23.8</td>
<td>0.8</td>
<td>1360(e)</td>
<td>2.1</td>
</tr>
</tbody>
</table>

In Fig. 6 the sensing positions in Grafton Way N, University Street N and Gower Place N, are all in the quadrant centred on the NW point of the compass. The top circle, for example, shows the 99th %ile value for University Street (North West side). When the wind is blowing from the NW (i.e. the sensor is on the windward side), the value is 10 ppm of CO, but with all other wind directions the value is only 5.7 ppm. For most of the monitoring sites this pattern is repeated with CO values significantly higher when the roof top wind is blowing from the same side of the street as the sensor position. The implication is that when a rooftop wind stream passes perpendicular to a street canyon a vortex forms where wind descends the far wall of the street and flows in the reverse direction across the canyon at street level. The effect is to bring relatively “clean” roof top air down onto sensors located on the windward side of the street and to carry emissions from vehicles on the street directly onto sensors located on the leeward kerb. These effects have been noted before (Oke, 1987) and can be reproduced by CFD modelling (see Ni Riain et al., 1996).

The few exceptions to the “clean windward, dirty leeward” rule are interesting. In Fig. 7, the Gordon Square NE site is situated on the northeast side of a London square, which makes the site behave as a canyon with a very wide H : W ratio (<0.3) changing the flow regime from “skimming” to “isolated roughness”, to use Oke's terminology (Oke, 1987), so, the wind from the West side blows ‘dirty’ air directly off the street onto the sensor rather than the vortex effect seen with canyon type streets.

Torrington Place SE (Fig. 9) shows very little difference in CO concentrations with different wind directions, this may be due to the high H : W ratio (1.7), possibly a double vortex forms which mixes the air and removes the previously seen wind effects. However, Gordon Street NE (Fig. 7) also shows little effect of wind direction on CO concentrations, and this is a “normal” canyon, (H : W of 1.0). The main similarity...
between these two monitoring points is that both the Gordon Street NE site and the Torrington Place SE site tend to have stationary traffic queues for long periods of the day. This leads to the possibility that the presence of the static queues, affects the formation of vortices. However, the present study suggests that the effects of roof level wind direction and building geometry cannot be ignored in setting up kerbside monitoring studies if comparable measurements from different sites are to be obtained.

4. A METHODOLOGY FOR URBAN KERBSIDE POLLUTION MONITORING

The study described in Section 3 attempted to generate a representative value for pollution for each of several streets. It developed monitors that allowed measures of CO concentration to be obtained at high temporal resolutions at a large number of monitoring sites within a small urban area for the same time periods. The three main findings of the study were, first, that there were radical variations between monitors located at sites within metres of one another, second, large differences in pollutant concentrations can be found across a street depending on the prevailing wind direction, and thirdly that a single representative value could not fully describe the differences between two monitoring sites. This last finding required the more detailed information contained in a full frequency distribution plot of the occurrence of different pollution concentrations over time. The results and the literature review have revealed several observations that can be made regarding the siting of monitors intended to measure urban kerbside pollution.

4.1. General observations for protocol definition

1. Measurements of pollutants at or near junctions are more complicated due to turbulent wind effects, which can form small eddies and the importance of traffic light timings, which can mean that two co-located monitors read very differently (Bell, 1996). If the junction has traffic lights often the measured readings will reflect the traffic light switching times. The pollutant concentrations measured can be unrelated to traffic flow, just looking at pollutant measurements one “dirty” vehicle may emit as much pollutant and thus appear the same as many “clean” ones. The midpoint between junctions should provide a representative measurement for the street as a whole, traffic flow will be affected least by traffic lights and turbulence will be at its minimum. It can be
hoped also that the vehicles will be neither accelerating or decelerating.

Between the midpoint and the junction pollutant levels might be expected to rise; this will be affected however by the building configurations near the junction. After the junction, traffic will often be accelerating and hence pollutant levels may be higher than at the junction itself.

2. Trees tend to reduce the wind speed and hence increase local pollutant levels, in the CAR model a tree lined street with the treetops touching is considered as having 50% higher pollutant levels compared to the same street without trees (Boeft et al., 1995).

3. The wind direction at roof height will determine vortex formation and also local wind speed. If the wind direction is within 30° of being perpendicular to the street axis and the wind speed is greater than 1 m s⁻¹, vortices are likely to form (Berkowicz et al., 1995).

4. Ideal pollutant concentrations vary with height in an exponential manner with distance from the source. In practice, conditions are not ideal and this relationship will be affected by the factors mentioned above. As stated earlier, in Laxen and Noordally (1987), pollutant levels are close to background within 15–20 m of the centreline of the road, either horizontally or vertically.

Using these observations and experience gained during the project we propose a new protocol for measuring urban pollution. The first question that should be answered is, what are you trying to investigate, and why?, once this is clear then the protocol can be followed.

- Monitoring height at 2 ± 0.2 m. For practical purposes, measuring slightly above head height will reduce the chance of vandalism and still allow easy access for maintenance, and most importantly provides a good indication of head height pollutant levels experienced by pedestrians.
- Monitoring positions should be as far from junctions as possible, and be at a position where the street profile is representative of the street segment as a whole, and also where two monitors can be sited opposite each other (i.e. if the street is “canyon-like” for more than 50% of its length then choose a site that represents this, also attention should be paid to the average building height along the street).
- Measurements with averages at 6 min intervals provide ten points an hour; this gives good detail of peaks and troughs, and allows significant analyses to be made with wind direction information. The measurements should be made synchronously.
- Percentiles can be calculated for each site, and for each side of the road, under different wind conditions. We found that splitting the wind direction into octants provides a clear indication, of effects with different wind directions. Using a statistical package (StatView 4.0, for the Macintosh, Cherwell Scientific) which allows percentile comparisons, such as those used in medical studies to split male and female effects, percentile comparison graphs can be made. The above graphs have split the data into two parts so that the sensor position is on the windward side of the street in one part and not on the windward side of the street for the other part. This shows up clear effects as seen above.

- We propose that the shapes of the percentile curves can be used to investigate the effects of road network changes. A generally low percentile curve having a steep rise at the upper percentiles suggests a road with generally low levels of traffic, but occasional severe congestion; see Gordon St curve in Fig. 2. By splitting the percentile data into two and comparing percentiles from before and after a road network change, the slope of the regression line would show clearly if the network change produced an improvement or not and would also show at which percentiles the effect was greatest.
- It is crucial that wind direction data is available at the same monitoring interval as the pollutant data and that this wind direction data is measured above roof top height as near as possible to the monitoring area. A database can then be constructed including both the local pollution measurements and the roof top meteorological data. This can then be analysed using the methods put forward in this paper.

5. CONCLUSIONS

This paper has presented results from the analysis of a large data set of fine-scale temporal and spatial measurements of carbon monoxide. The instruments used to collect these data were developed specifically for this purpose and enabled highly detailed findings to be made.

The paper has revealed the scale of differences in pollutant concentrations (up to threefold) that can be found between different sides of the same street under certain wind conditions. This finding is important because most urban airborne pollution studies that have been carried out to date, have neglected to include full consideration of various meteorological factors. This lack of meteorological data has missed the effect of prevailing wind direction on pollutant concentrations.

A possible methodology for monitoring urban airborne pollution at the fine scale is proposed. This method could be used in a variety of further studies to help identify the scale of air pollution effects to be found in an urban environment caused by various factors such as making a change to a road network and to provide a basis for comparing pollution experienced in different streets.

Studies attempting to link asthmatic and respiratory problems and proximity to traffic have not taken
into account, which side of the road the patient lived on. For example, increased incidence of congestive heart disease has been linked to increased ambient levels of carbon monoxide (Morris et al., 1995); this effect has been observed between 7 U.S. cities. However, no account was taken of the side of the road with respect to wind direction. The research presented in this paper suggests that this could be an important factor and is certainly a subject for future research.

Future research is also needed into the possible economic effects that may be related to street orientation and, the direction of the prevailing wind, for example, differential facade erosion of buildings on different sides of the same street.

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