J. McAughey
AEA Technology
Culham / UK

Field Measurement studies

Nanoparticle Measurement - 2nd ETH Workshop

John.McAughey@aeat.co.uk

AEA TECHNOLOGY
THE INNOVATION BUSINESS

Field Measurement Studies

Environmental Monitoring

- Particle size of vehicle emissions
- Urban Centres
  - mixed traffic
  - Diesel 'canyon'
- In-vehicle PM pollution
  - commuter trip
  - air filtration
- Mobile surveys
  - in-vehicle / environmental

Sampling regime

2 sampling campaigns

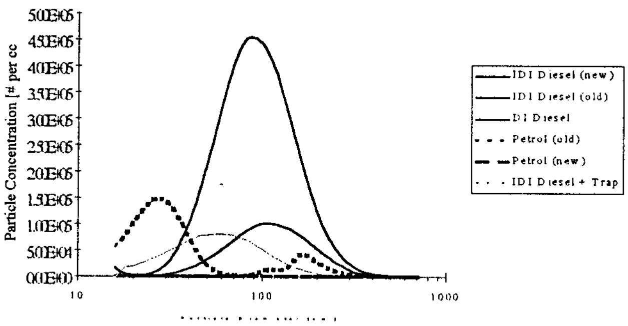
- Carfax junction, Easter 1997
- Cornmarket St, January 1998 : 'diesel canyon'

- Particle mass by TEOM
- Particle number by optical counters (> 500 nm) and condensation nucleus counter (> 5 nm)

Slide serial no 3

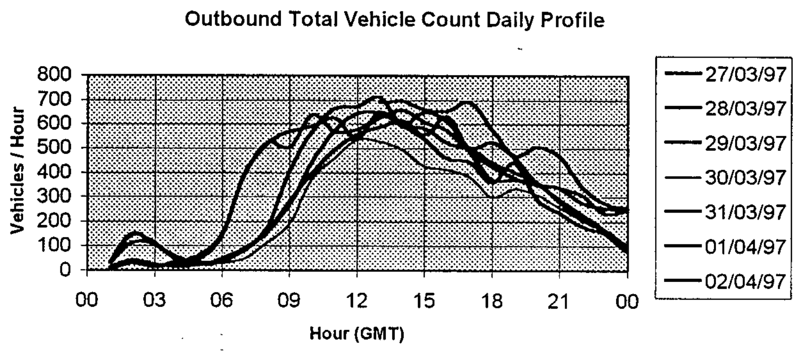
Vehicle emissions

Typical vehicle particulate emission profiles

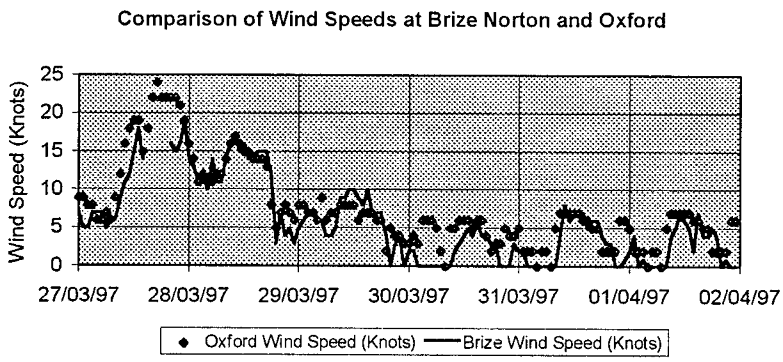


Slide serial no 4

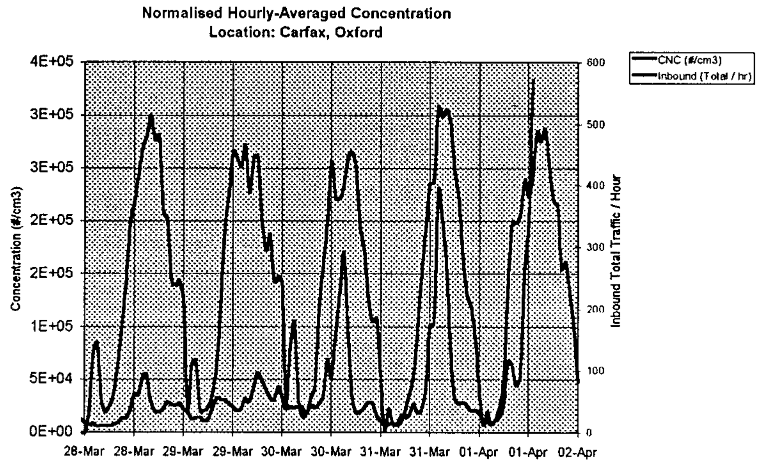
Vehicle Flow Profile



Wind speed

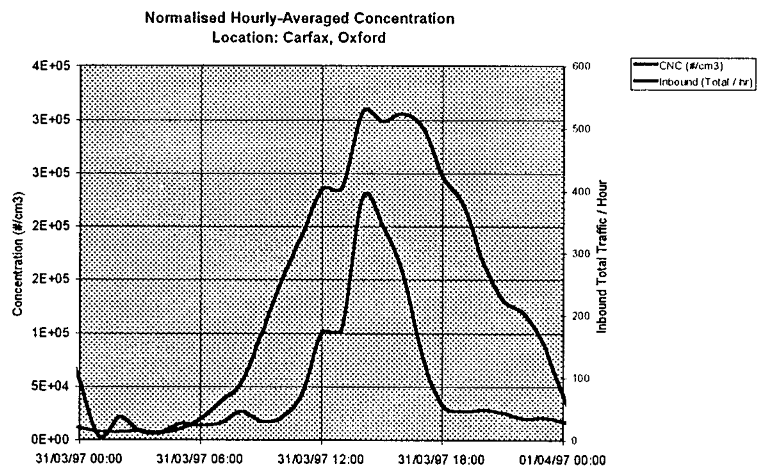


Particle number versus Traffic flow



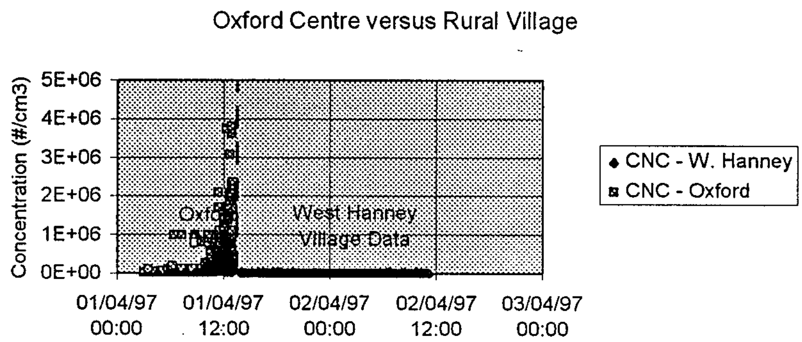
Slide serial no 7

Particle Number versus Traffic Flow

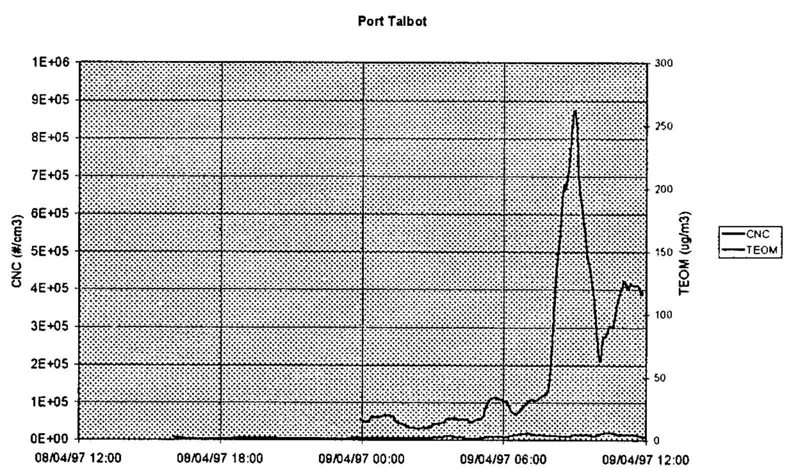


Slide serial no 8

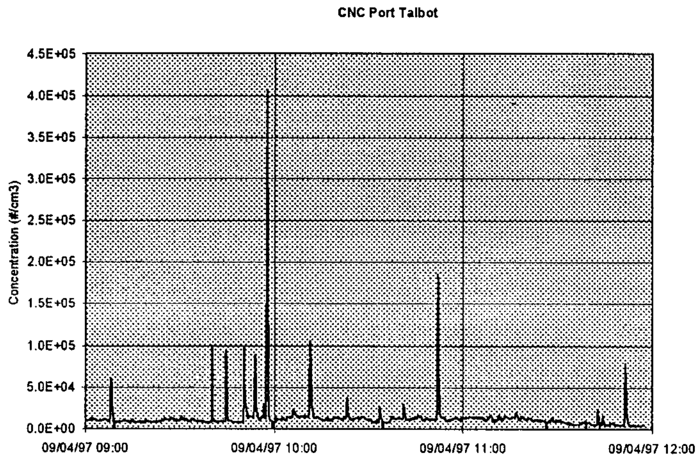
Rural Oxfordshire



Port Talbot

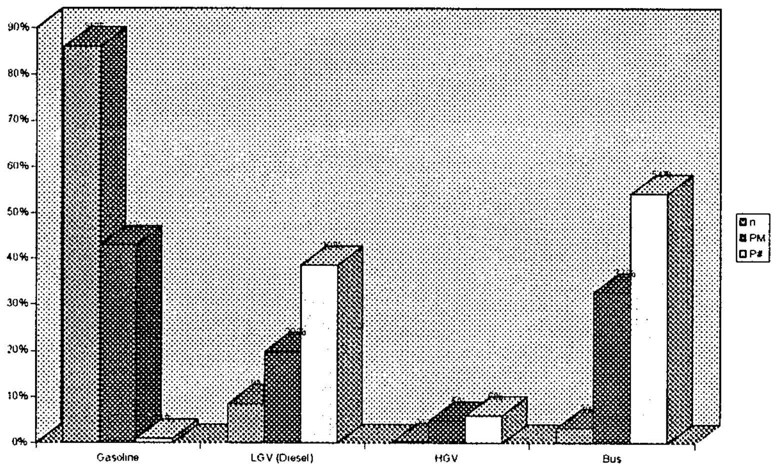


Port Talbot



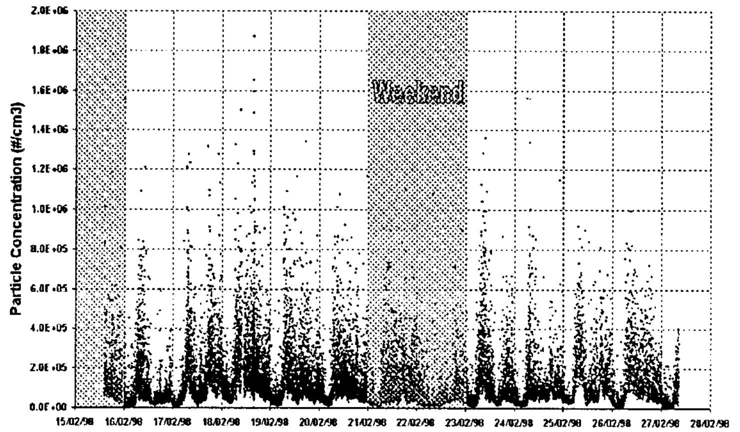
Slide serial no 11

Source attribution

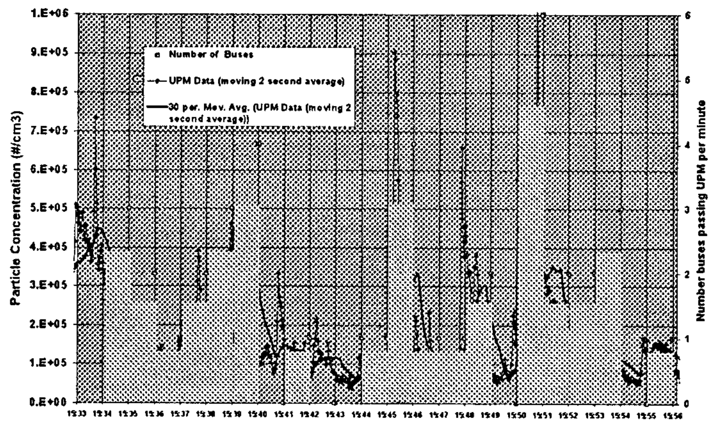


Slide serial no 12

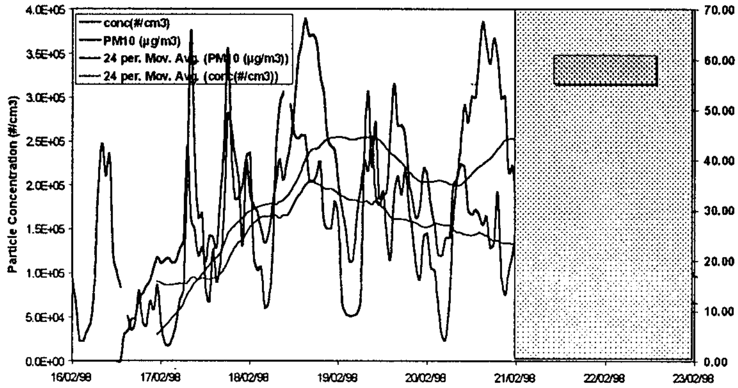
Particle number, Cornmarket St



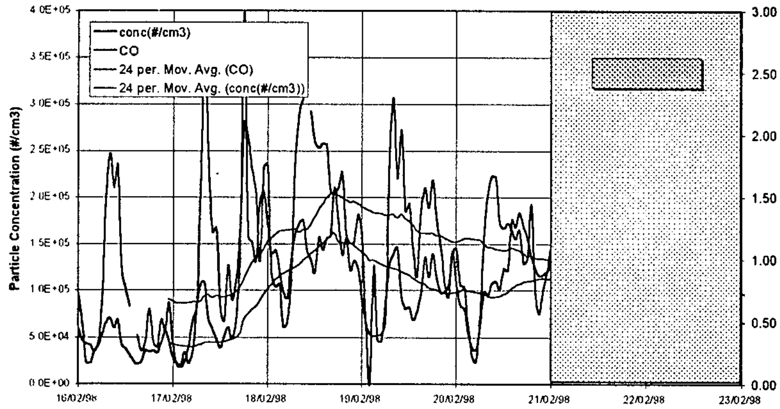
Particle # versus bus movements



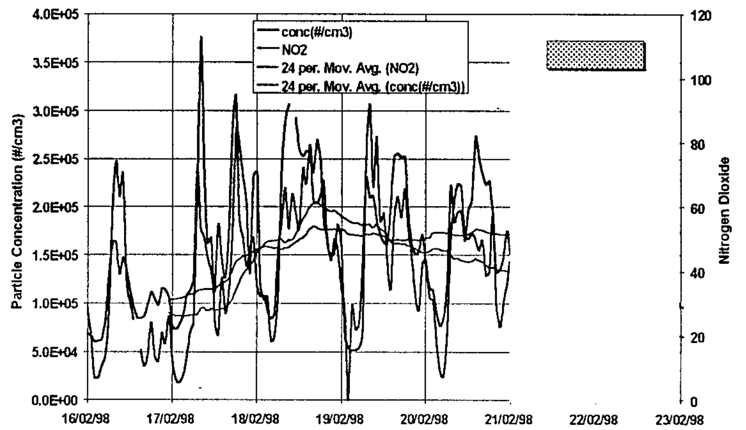
PM10 versus Particle Number



Particle number versus CO



Particle Number versus NO2



Summary

- Traffic particle emissions show high increase in particle number without necessarily showing increase in measured mass
- The particles produced are typically 100 nm or smaller
- Ultra-fine particles will disperse rapidly except in still conditions
- There is some scope for discriminating diesel and spark-ignition emissions from the profile of particle and gaseous emissions

5.4 PARTICLE NUMBER AS A TRACER FOR VEHICLE EMISSIONS

5.4.1 PARTICLE SIZE OF VEHICLE EMISSIONS

Existing emission factors and particle measurements of all particles are based on mass metrics. However, the most recent data available suggest that the majority of particles emitted from vehicle exhausts are significantly less than 1 μm diameter, with very high number concentrations (Moon & Donald, 1997), and that this is true for diesel and petrol-based engines (Greenwood *et al*, 1996, Rickeard *et al*, 1996). Examples of the size distribution of exhaust emissions are shown in Figure 5.12 from a range of diesel and gasoline engines at 90kph (steady state) (from Moon & Donald, 1997). Despite the wide range of engines, vehicles and fuels tested, the particle size distributions measured are very similar. For number based distributions, most consist of a single peak between 60nm and 120nm with a wide log normal distribution. With some engine/fuel combinations, or at certain conditions, a second peak is seen at a much smaller size, from 10nm to 30nm. This has been seen by most of the instrument types used, so it is not a characteristic of any measuring technique. Mass based measurements confirm what is seen by the number based instruments, showing a peak from 150nm to 300nm. However, for some engines and fuels significant mass based emissions have been seen at higher sizes, up to 10μm.

Thus monitoring of these distinctive size ranges in urban centres by real-time measurement of particle size distribution, or more simply, by particle counting offers scope to discriminate particles sourced from vehicles.

5.4.2 PARTICLE NUMBER VERSUS PM_{10} DATA FOR HIGH VEHICLE DENSITIES

The usefulness of particle counting is borne out by existing data reported by Jones & Harrison (1995) and Booker & Earnshaw (1998) for monitoring in Birmingham (A38 roadside) and Oxford (City centre) respectively. In each case, where particle number is monitored at roadside, counts may vary rapidly in the range 10^9 - 10^{13} particles /m^3, and are typically more sensitive than equivalent co-located mass measurements. Hourly averaged measurements are of the order of 5 x 10^{11} particles /m^3. By comparing hourly averaged mass and number data, it is notable that :

- the particles contributing to this number peak are sub-micron, and have little mass associated with them. The data of Booker *et al* in Oxford shows increased particle counts as measured by a Condensation Particle Counter (CPC: 0.005 - 10μm) but not by optical or time-of-flight instruments (0.5 - 10μm) where the lowest size observed is 0.5 μm. No elevation of particle mass by the TEOM was observed.
- no significant increase in particle mass was observed in the Oxford study when comparing PM_{10} at the City Centre with a suburban location with lower traffic densities.

- Figure 5.13 indicates that particle number concentration is heavily influenced by meteorological conditions; on windy days, any traffic plume, as measured by particle counting is rapidly dispersed. However, on still days a clear temporal relationship between traffic flow and particle count is observed.
- on still days, the particle number peak exhibits a strong correlation with traffic density. The use of traffic census data derived from chassis length and height combined with emissions factors different vehicle types indicate that in Oxford, diesel buses are a significant contributor to particle emissions (as shown in Figure 5.14) whilst petrol vehicles make little contribution to particle number.

5.4.3 PARTICLE NUMBER MONITORING OF DIESEL EMISSIONS

In a follow-up study in Oxford City Centre, the samplers were moved from a crossroads split between a through road dominated by petrol-engined vehicles, to an area confined to (principally diesel) bus and taxi traffic moving through the centre, essentially, a 'diesel canyon' , less prone to interference from through petrol-engined traffic. This is a common pattern in a number of UK cities.

Thus, there was scope for monitoring to further discriminate between petrol and diesel sources. PM_{10}, particle number NO_2 and CO were measured in real-time and preliminary data suggest:

- Figure 5.15 shows a plot of particle number data versus time over an extended period with averaged 30 seconds values shown. A strong relationship is again observed between traffic density and particle number; and in this case rush hour peaks are more clearly discriminated, consistent with peak densities for bus traffic. It is also notable that levels are significantly lower over a weekend, where bus traffic is reduced.
- Figure 5.16 indicates that PM_{10} data and Particle Number data show similar patterns. This is consistent with monitoring a dominant single source in the region of the sampler. However, it can be noted that Particle number shows a more consistent double rush hour pattern, and falls to very low background levels overnight. In contrast, residual PM_{10} values are observed overnight consistent with imported secondary aerosol
- by reducing the time period of measurement to 2 second and 1 minute moving averages, real-time particle number data can be related to individual bus movements, as shown in Figure 5.17. These data suggest there is scope to identify individual 'dirty' vehicles.
- a series of correlations were observed between the gaseous and particle measurements - these offer scope in discriminating diesel (NO_2) and petrol (CO) engined emissions, which may in turn improve the validation of the receptor modelling approach. In Figure 5.18, a very strong correlation is observed between Particle Number and NO_2, both on an hourly and daily average basis, consistent with the sampling location being dominated by diesel sources. In Figure 5.19, a plot of CO versus Particle Number shows a reasonable correlation (although not as strong as for NO_2. This is consistent with a contribution from petrol-engined vehicles nearby in the City Centre area, which will contribute a similar rush hour pattern as the diesel buses.

In conclusion, these recent data indicate that there is scope for Particle Number to be used as a real-time metric of local vehicle emissions. Comparison with existing PM_{10} data and CO and NO_2 gaseous concentrations may offer a route to further discriminate between diesel and petrol emissions, as may more accurate particle size distribution data. However, there remains a lack of information on the long-term temporal and spatial distribution of these emissions under varying weather conditions, which requires further investigation.

5.4.4 PARTICLE NUMBER MONITORING AT THREE LOCATIONS

In addition to the $PM_{2.5}$ and PM_{10} measurements at the four additional sites mentioned in Section 3.5, the Department of the Environment, Transport and the Regions is also funding measurements of particle number size distributions at three of the sites: a) the kerbside site on Marylebone Road, London; b) the central urban background site at London Bloomsbury; and c) the rural background site at Harwell. Number particle size distributions in the particle size range 10 to 450 nm have been measured since the beginning of May 1998 using Scanning Mobility Particle Sizers (SMPS). Problems of inlet blockage by particles of aerodynamic diameter larger than about 1 µm are still being experienced at the Bloomsbury site (possibly associated with pollen from the surrounding trees), and so we can only present here some preliminary data from the other two sites. A comparison of the diurnal trends of hourly average total particle numbers from Marylebone Road and Harwell for the months of April and May 1998 are given in Figure 5.20. The wide difference in total particle is clearly shown with levels averaging between 30,000 to 70,000 particles/cm^3 at Marylebone Road, and 3,000 to 18,000 particles/cm^3 at Harwell. In addition, there is a clear difference in diurnal patterns with a rapid rise in number concentration due to the early morning traffic being clearly seen at Marylebone Road, but not at Harwell. The diurnal variation in particle number is similar to that of NOx and differs from CO, consistent with a predominantly diesel source at Marylebone Road.

Figure 5.12 : Typical vehicle particulate emission profiles

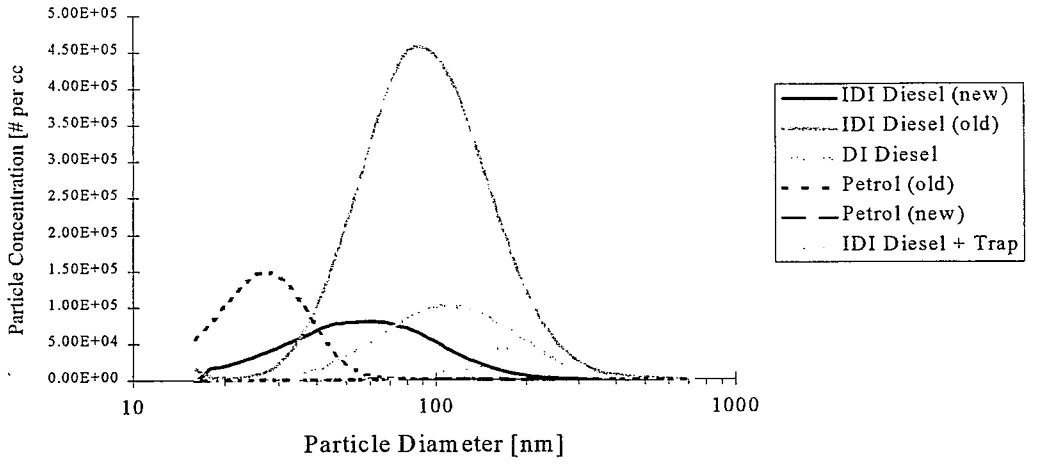


Figure 5.13: Particle Number versus Inbound Traffic Flow

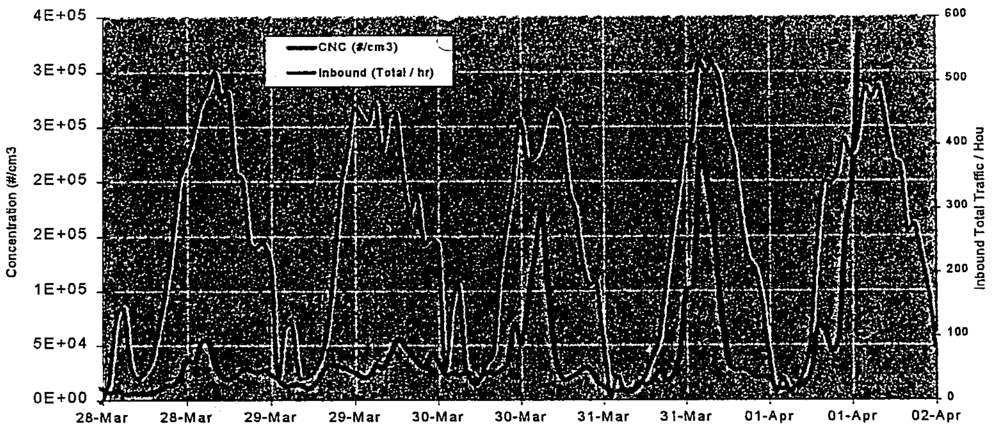
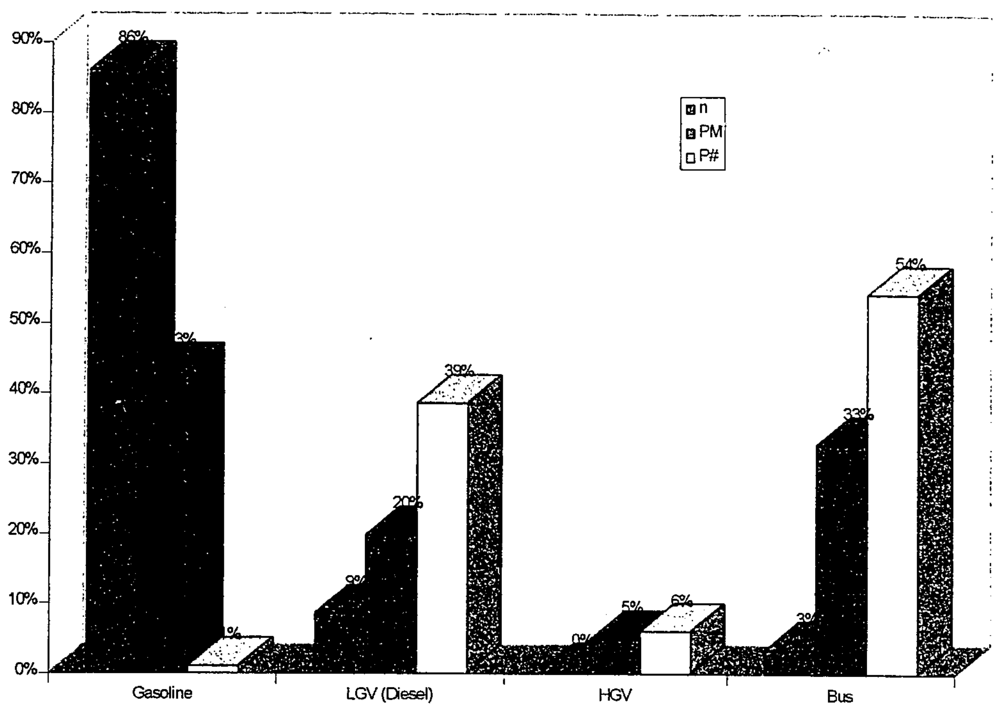


Figure 5.14 : Particle Mass and Particle Number by Vehicle Class (Oxford Carfax) (n=number of vehicles (%); PM = contribution to PM_{10} mass (%); P# = contribution to particle number (%)).



Simplifying Assumptions

Gasoline = All cars + Motorbikes
Diesel = All LGV + HGV + Buses

Particle mass emissions from Chapter 3, Table 3.2 for Pre-Stage I Urban Cycles
Particle Number emissions from Moon & Donald (1997) for light-duty ECE and heavy-duty FIGE cycles

Figure 5.15 : Particle Number Monitoring (30s average) in Cornmarket Street, Oxford

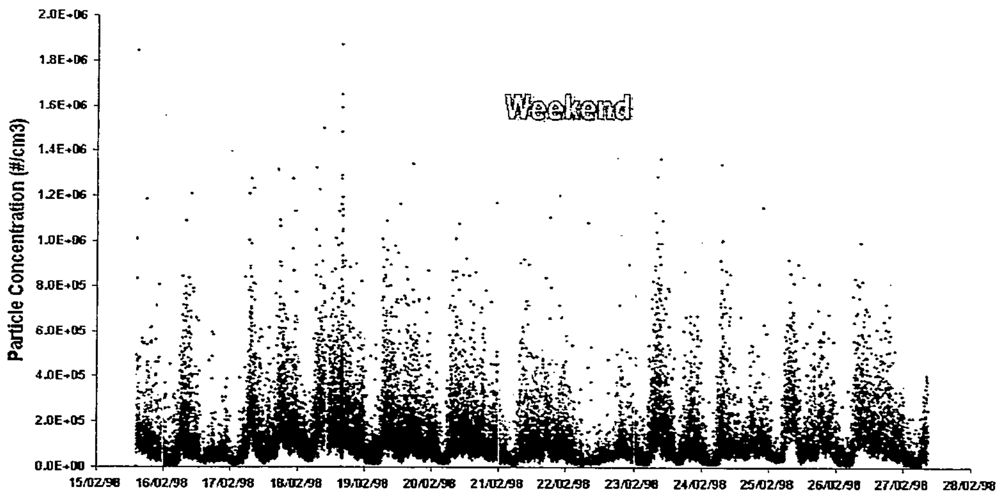


Figure 5.16: Particle Number versus PM10 (hourly and daily average)

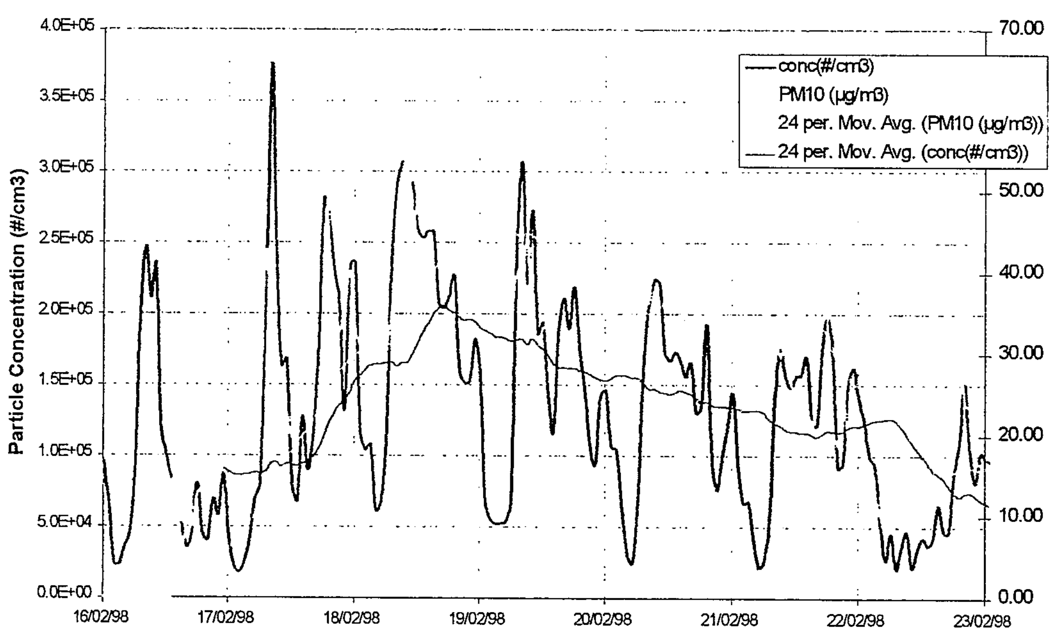


Figure 5.17 Particle Number Concentration versus Bus Movements

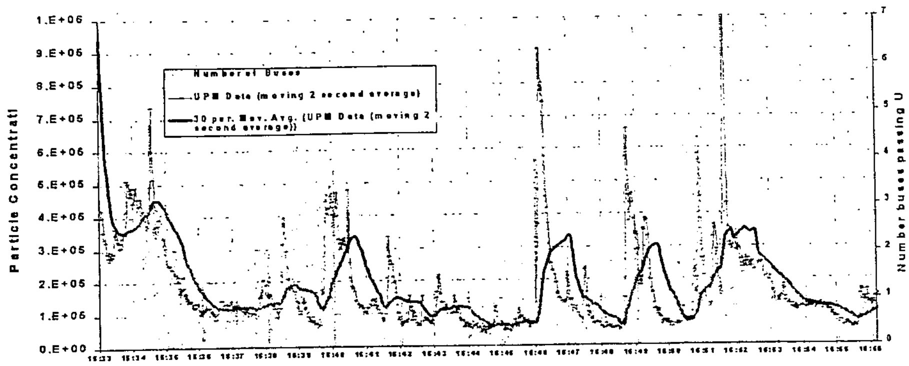


Figure 5.18 Particle Number Concentration versus NO_2 (hourly and daily average)

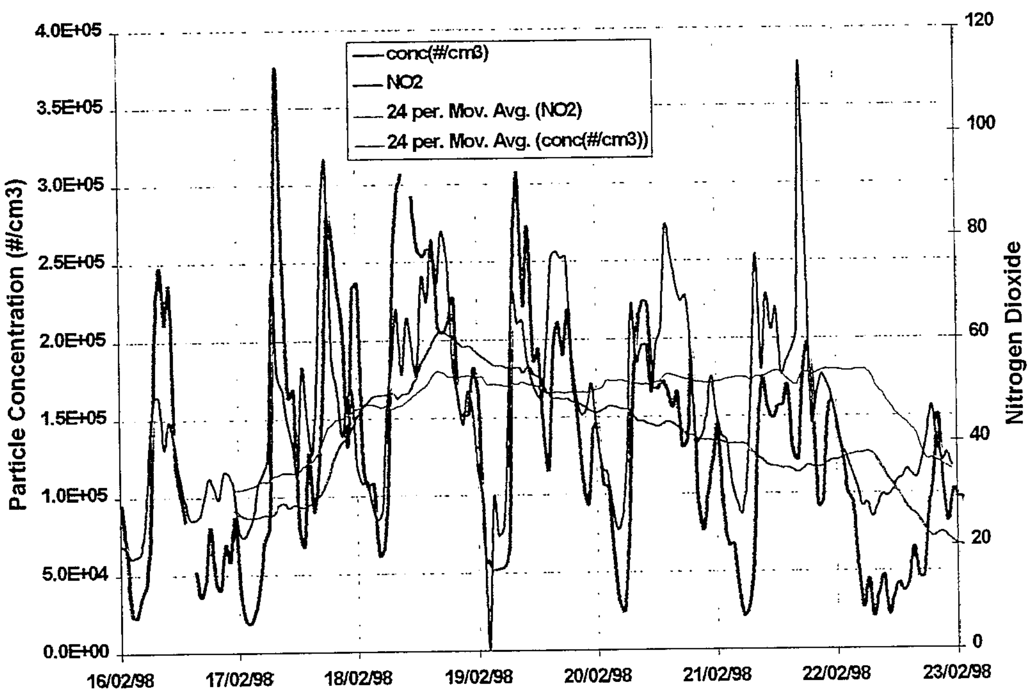


Figure 5.19: Particle Number versus CO (hourly and daily average)

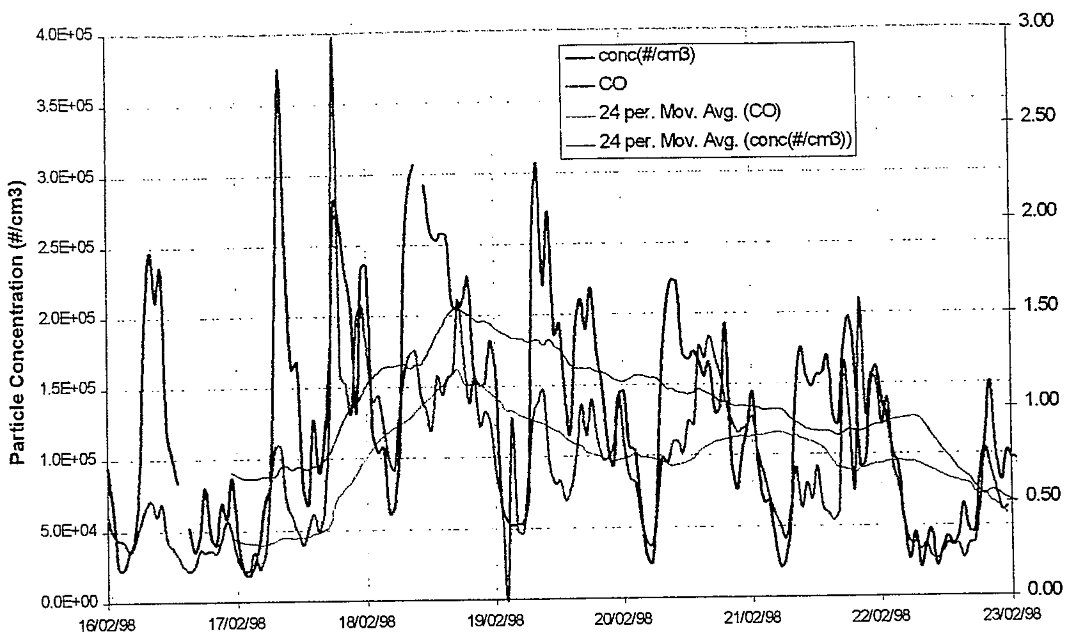


Figure 5.20 A comparison of the diurnal trends of average total particle numbers from Marylebone Road and Harwell for the months of April and May 1998.