National Physical Laboratory

Report

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2008 Annual Report for the UK Black Smoke Network

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June 2009

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Approved on behalf of the Managing Director, NPL
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Executive Summary

The National Physical Laboratory (NPL) was awarded the contract to set up and run the UK Black Smoke Network by the Department for Environment, Food and Rural Affairs (Defra) in September 2006 under contract "RMP 2951, The Provision of Consultancy Services for the Monitoring of Black Smoke in the UK". During 2007 the number of sites in the network expanded from 14 sites to 21 sites, as samplers were installed into mainly Automatic Urban and Rural Network (AURN) sites. By March 2007 all of the 21 sites were operational.

In 2008 Defra purchased 22 Model AE22 (two channel) aethalometers from Magee Scientific to replace the original Black Smoke 8-port samplers and to provide additional monitoring at the Harwell rural background site.

Installation of the aethalometers started in October 2008 and 20 sites were installed by the end of the year. Aethalometers will be installed in the Norwich and Harwell AURN sites in 2009 when site specific issues have been addressed. When the aethalometer was installed in a Black Smoke site the Black Smoke measurements were stopped, except for 5 sites where parallel measurements were made with the aethalometer. The 5 parallel running sites were: Edinburgh St Leonard's, Halifax, Birmingham Tyburn, North Kensington and Marylebone Road. Parallel measurements will be made until at least May 2009.

This report covers the operation of the UK Black Smoke Network and the data collected by the Network in 2008. All of the aethalometer (Black Carbon) data in this report is VALIDATED ONLY as ratified data will not be available until the parallel running trial with black smoke measurements has been completed.

The data capture for Black Smoke measurements was 92.9%. Data capture for 2008 improved on the values delivered for 2007 and 2006, where data capture was 89% and 86% respectively.

Measured annual average Black Smoke Index ranged from 3.5 $\mu g.m^{-3}$ in Woolwich to 39.9 $\mu g.m^{-3}$ at Marylebone Road. In general the average Black Smoke Index measured in 2008 was lower than 2007, with network means of 8.6 $\mu g.m^{-3}$ and 9.9 $\mu g.m^{-3}$ respectively.

Black Smoke concentrations measured by the Network were compared with TEOM PM_{10}, total oxides of nitrogen (expressed as nitrogen dioxide) and particle number concentrations, for those sites where these measurements were colocated. Correlation was generally best between Black Smoke Index and NO_x concentration.

The data capture for Black Carbon measurements using the aethalometer was 91.8%.

Measured average Black Carbon concentrations ranged from 1.3 $\mu g.m^{-3}$ in Folkestone to 13.0 $\mu g.m^{-3}$ at Marylebone Road. The network mean for Black Carbon concentration was 3.1 $\mu g.m^{-3}$.

Daily averages of the measurements show that the highest concentrations of Black Smoke are found at the beginning of the week with the weekends generally having

lower values. The hourly averages of Black Carbon broadly show a commuter traffic based signature with the exception of Strabane and Dunmurry. Both these sites show elevated levels from 15:00hrs to 23:00hrs, which is probably due to local domestic heating. Also the "UV component" at these sites was significantly higher than all of the other sites. This is probably due to the fuel source used in the domestic heating.

Measured "UV component" concentrations ranged from –0.21 $\mu g.m^{-3}$ at Marylebone Road to 1.71 $\mu g.m^{-3}$ in Strabane. All sites close to the roadside showed significant negative spikes in this parameter.

Contents

1.0 Introduction

1.1 General

The National Physical Laboratory (NPL) was awarded the contract to set up and run the UK Black Smoke Network by the Department for Environment, Food and Rural Affairs (Defra) in September 2006 under contract "RMP 2951, The Provision of Consultancy Services for the Monitoring of Black Smoke in the UK". During 2007 the number of sites in the network expanded from 14 sites to 21 sites, as samplers were installed into mainly Automatic Urban and Rural Network (AURN) sites. By March 2007 all of the 21 sites were operational.

In 2008 Defra purchased 22 Model AE22 (two channel) aethalometers from Magee Scientific to replace the original Black Smoke 8-port samplers and to provide additional monitoring at the Harwell rural background site.

Installation of the aethalometers started in October 2008 and 20 sites were installed by the end of the year. Aethalometers will be installed in the Norwich and Harwell AURN sites in 2009 when site specific issues have been addressed.

When the aethalometer was installed in a Black Smoke site the Black Smoke measurements were stopped, except for 5 sites where parallel measurements were made with the aethalometer. The 5 parallel running sites were: Edinburgh St Leonard's, Halifax, Birmingham Tyburn, North Kensington and Marylebone Road. Parallel measurements will be made until at least May 2009.

The report presents both Black Smoke and Black Carbon data collected in 2008 by the 8-port sampler and the aethalometer, respectively. All of the aethalometer (Black Carbon) data in this report is VALIDATED ONLY as ratified data will not be available until the parallel running trial with black smoke measurements has been completed.

Comparisons are also made with earlier years, and with other measurements colocated with the Black Smoke samplers / aethalometers.

1.2 Measurement Methods

The following sections describe the measurement methodology for the Black Smoke and Black Carbon measurements.

1.2.1 Black Smoke

Black Smoke sampling in 2008 used the 8-port sampler that has historically been used in the UK network, based on the standard method BS 1747; ISO 9835. The principle of the 8-port sampler method involves drawing air at a constant flow rate of around 1.4 l/min through a Whatman Number 1 cellulose filter, so that about 2 m^3 of air (at ambient conditions of temperature and pressure) is sampled for each daily sample. Suspended particulate matter is collected on the filter over an area determined by a choice of clamp – in this case with a one inch diameter - forming a dark stain. The inlet (an upturned funnel) is not designed to be size selective, and has been shown in one study to collect the approximate size fraction $PM_{4.5}$.

The 8-port sampler is designed with eight pairs of filter clamps for weekly operation, providing daily sampling on a midnight-to-midnight basis. The timed eight-port valve was set to switch over at midnight to expose a fresh filter paper each day. Weekly Local Site Operator visits were made to change filter papers and to record weekly sample volumes and flow rates.

Those sample filters returned to NPL had the darkness of the stain measured with an EEL M43D reflectometer, the reflectance being determined relative to a blank filter of the same type. The procedure for this measurement has been UKAS-accredited. The instrument uses a light bulb to give a broad band source that is reflected back from the smoke stain to a photo-sensitive element and produces a reading between 0% and 100% reflectance.

The measured reflectance is used to calculate the concentration of particulate matter in the sampled air, as Black Smoke Index, with units of μg/m^3, using the relationship given in BS 1747: Part 2:

$$C = \frac{1}{V}\left(91679.22 - 3332.046R + 49.618884R^2 - 0.35329778R^3 + 0.0009863435R^4\right)$$

where:

C = concentration in μg/m^3
V = volume of sampled air in ft^3
R = reflectometer reading (%)

This relationship is only valid for values of R above 40% and for a clamp size of 1 inch. This was true for all samples in the study.

1.2.2 Black Carbon - Aethalometer

Aethalometers quantify “black carbon” on filter samples based on the transmission of light through a sample. The sample is collected onto a quartz tape, and the absorption coefficient of the sample is measured by a single pass transmission of light through the sample, measured relative to a clean piece of filter. The absorption coefficient α [m^{-1}] is calculated from the transmission, area and volume of the sample, and converted to a black carbon concentration, as a first approximation, using a mass extinction coefficient.

The aethalometers run on the Network operate at 2 wavelengths, 880nm and 370 nm. The 880nm wavelength is used to measure the Black Carbon (BC) concentration of the aerosol, while the 370nm wavelength gives a measure of the “UV component” of the aerosol. At wavelengths shorter than about 400 nm, certain classes of organic compounds (such as polycyclic aromatic hydrocarbons, and also certain compounds present in tobacco smoke and fresh diesel exhaust) start to show strong UV absorbance.

The UV component concentration is obtained by subtracting the measured BC concentration from the concentration measured by the 370nm source. The UV component is not a real physical or chemical material, but a parameter based on UV absorption due to the mix of organic compounds measured at this wavelength. This fictional material ‘UVPM’ is expressed in units of ‘BC Equivalent’.

It is well known that the response of the aethalometer is slightly non-linear with increasing attenuation as the filter spot darkens. The effect of this nonlinearity results in the aethalometer under-reading at high filter tape loadings. To correct for this nonlinearity, the model developed by A Virkkula[1] has been used to correct for increased attenuation due to spot darkening during sampling. All of the Black Carbon and UV component results in this report have been corrected by this method.

1.2.2.1 Sampling

At all sites, ambient air is drawn into the sampling system through a standard stainless steel rain cap mounted on the end of a vertical stainless steel tube. Size selection of the sampled aerosol is made by a $PM_{2.5}$ cyclone placed close to the inlet of the aethalometer. All of the tubing before the cyclone is constructed from stainless steel. Sampling has been standardised across the network by using a size selective inlet before the aethalometer, which was not possible with the Black Smoke method.

2.0 Network Infrastructure

2.1 Black Smoke

During 2008, measurements were made at 21 sites. As the aethalometers were installed Black Smoke measurements ceased at all sites, except for those where parallel measurements were made with the aethalometer. The infrastructure of all the sites was inspected during the 2008 audit round and the results are included in this report. All of the sites were found to be in a good state of repair.

On 23rd April 2008 the 8-port sampler in the Marylebone road site was replaced with a compact shelf style sampler mounted on the wall of the monitoring site. This was to enable an internal reorganisation of monitoring equipment at the station. The point at which ambient air was sampled did not change, but the length of the sampling line between the ambient atmosphere and the sampler was reduced by approximately 50% and the number of bends reduced.

A map and brief descriptions of the sites are given below.

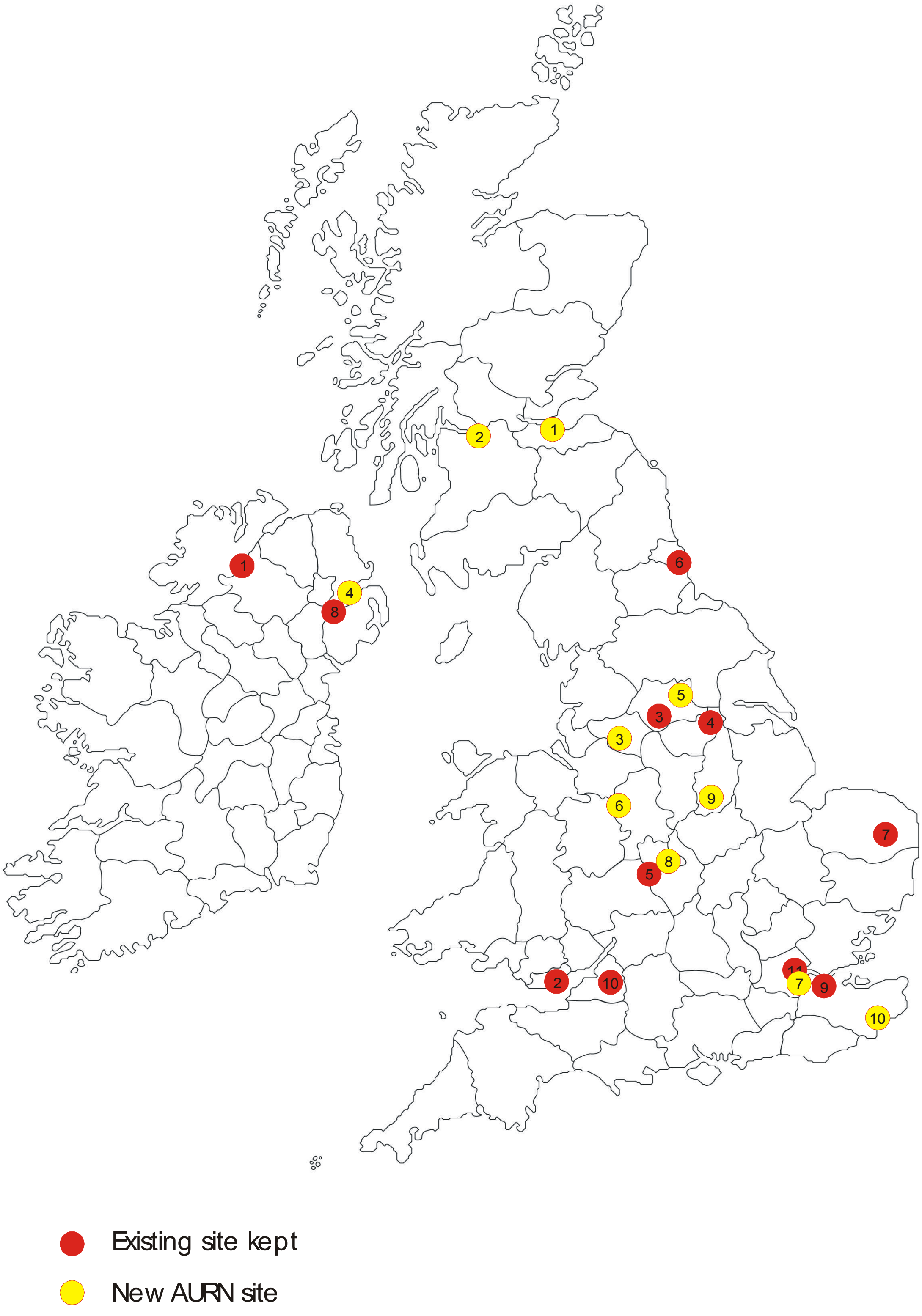


Figure 1 Location of UK Black Smoke Network Sites

Tables 1 and 2 below give the site names for the UK Black Smoke Network:

Key	Site Name	Start year
1	Strabane 2	1999
2	Cardiff 12	1961
3	Halifax 17	2003
4	South Kirkby 1	1970
5	Halesowen 8	2004
6	Sunderland 8	1961
7	Norwich 7	1961
8	Dunmurry 3	1993
9	Woolwich 9	1955
10	Bath 6	1981
11	Marylebone Road	1997

Table 1 Long-Running Black Smoke Sites

Key	Site Name	Site Type	Other Analysers
1	Edinburgh St Leonard's	Urban Background	FDMS TEOM PM_{10}
2	Glasgow Centre	Urban Centre	FDMS TEOM PM_{10}
3	Manchester Piccadilly	Urban Centre	FDMS TEOM PM_{10}
4	Belfast Centre	Urban Centre	FDMS TEOM PM_{10}
5	Bradford Town Hall	Urban Centre	N/A
6	Stoke Centre	Urban Centre	FDMS TEOM PM_{10}
7	North Kensington	Urban Background	FDMS TEOM PM_{10} + carbon + nitrate + manual $PM_{2.5}$
8	Birmingham Tyburn	Urban Background	FDMS TEOM PM_{10}
9	Nottingham Centre	Urban Centre	FDMS TEOM PM_{10}
10	Folkestone, Kent Network	Rural	TEOM PM_{10} + $PM_{2.5}$

Table 2 Sites With Black Smoke Recently Installed

Two other sites, described in Section 5.1.6, produce data on an affiliate basis.

Table 3 below gives the date of the last Black Smoke measurement made at each site, when the sampler was replaced by the aethalometer.

Site	End Of Measurements
Bath 6	01/11/2008
Belfast Centre	27/10/2008
Bradford Town Hall	27/11/2008
Cardiff 12	30/09/2008
Dunmurry 3	21/10/2008
Folkestone	20/10/2008
Glasgow Centre	30/11/2008
Halesowen 8	28/10/2008
Manchester Picc	27/10/2008
Nottingham Centre	06/11/2008
South Kirkby 1	30/11/2008
Stoke Centre	27/10/2008
Strabane 2	28/10/2008
Sunderland 8	06/11/2008
Woolwich 9	21/10/2008

Table 3 Date of Last Black Smoke Measurement Performed At Sites

Parallel measurements with the aethalometer were made at the following sites: Edinburgh St Leonard's, Halifax, Birmingham Tyburn, North Kensington and Marylebone Road and will continue until at least May 2009.

2.2 Black Carbon

2.2.1 Network Design

Originally it was planned to make a straight swap in instrumentation when installing the aethalometers, but due to siting restraints and local development pressures, two of the original Black Smoke Network sites had to be relocated.

The building housing the Halesowen 8-port sampler was due for demolition and development into new shops, so the replacement aethalometer was installed in the Dudley Central air monitoring site. The Dudley site is 4 miles from the original site and is the same site classification.

The building housing the Norwich 7 sampler was in a bad state of repair, which the Council had no control over, and there were also problems installing a phone line to the site to allow remote data download. Therefore, it was decided to install the replacement aethalometer into the Norwich AURN site. The AURN site is 2.5 miles from the original site and is the same site classification. The site is currently waiting commissioning.

In addition to replacing all of the existing 8-port samplers with aethalometers, an aethalometer is to be installed in the Harwell AURN site in 2009.

Figure 2 shows the locations of the aethalometers.

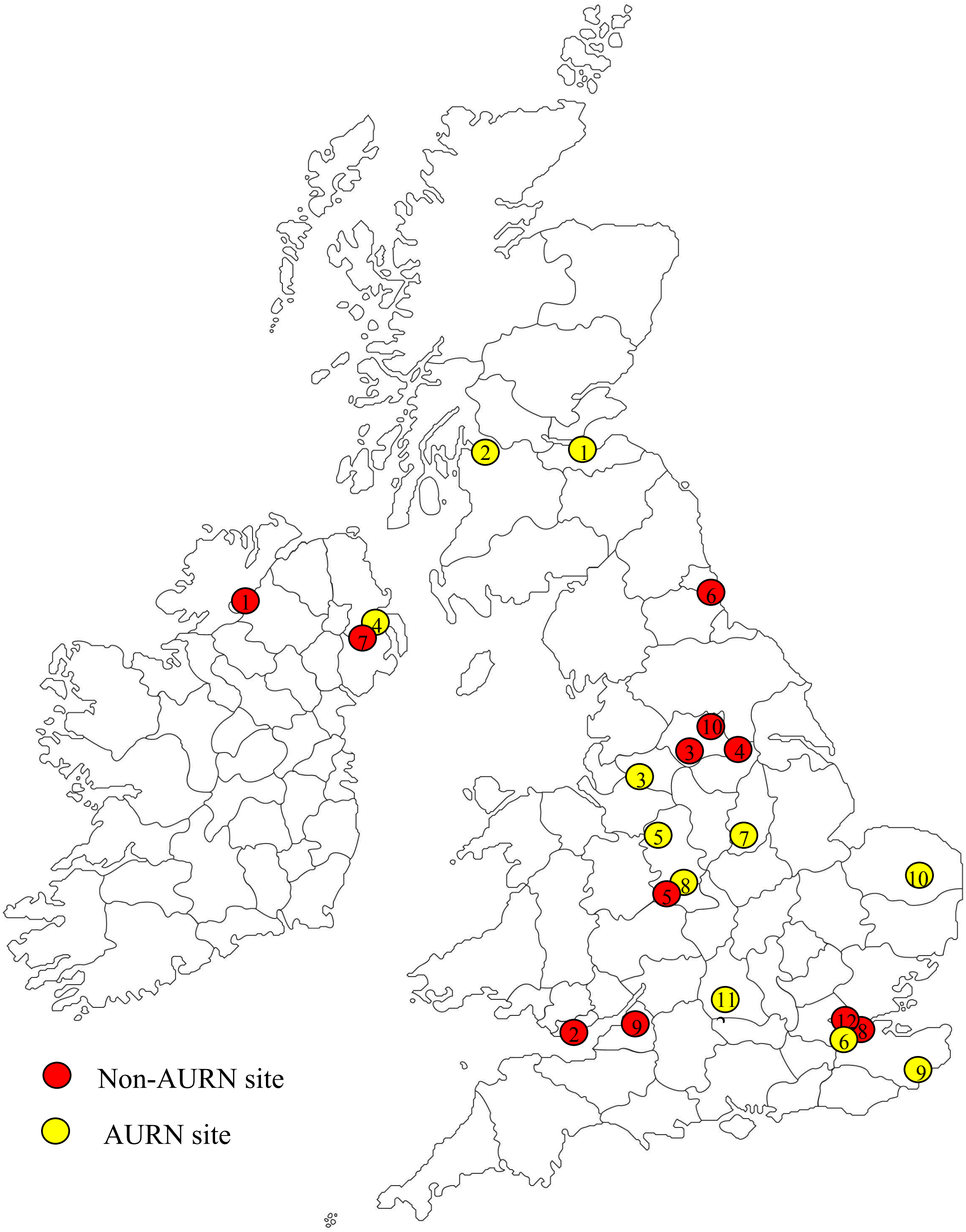


Figure 2 Location of Aethalometers making up the UK Black Smoke Network

Tables 4 and 5 below give the site names and classifications for the UK Black Smoke Network:

Key	Site Name
1	Strabane 2
2	Cardiff 12
3	Halifax 17
4	South Kirkby 1
5	Dudley Central
6	Sunderland 8
7	Dunmurry 3
8	Woolwich 9
9	Bath 6
10	Bradford Town Hall

Table 4 Non-AURN

Key	Site Name	Site Type	Other Analysers
1	Edinburgh St Leonard's	Urban Background	FDMS TEOM PM_{10}
2	Glasgow Centre	Urban Centre	FDMS TEOM PM_{10}
3	Manchester Piccadilly	Urban Centre	FDMS TEOM PM_{10}
4	Belfast Centre	Urban Centre	FDMS TEOM PM_{10}
5	Stoke Centre	Urban Centre	FDMS TEOM PM_{10}
6	North Kensington	Urban Background	FDMS TEOM PM_{10} + nitrate + number counting + manual $PM_{2.5}$
7	Nottingham Centre	Urban Centre	FDMS TEOM PM_{10}
8	Birmingham Tyburn	Urban Background	FDMS TEOM PM_{10}
9	Folkestone, Kent Network	Rural	TEOM PM_{10} + $PM_{2.5}$
10	Norwich	Urban Background	FDMS TEOM PM_{10}
11	Harwell	Rural	FDMS TEOM PM_{10} + FDMS TEOM $PM_{2.5}$ + nitrate + number counting + manual $PM_{2.5}$
12	Marylebone Road	Roadside	FDMS TEOM PM_{10} + $PM_{2.5}$ + nitrate + number counting + manual $PM_{2.5}$

Table 5 AURN sites

2.2.2 Network Operation

The operation of the Network was set up to mirror that of the AURN, to include a Central Management and Control Unit (CMCU) and a Quality Assurance and Quality Control Unit (QA/QC). The CMCU activities are carried out by the Environmental Research Group at King's College London (KCL). These activities include the routine collection of data from site, initial data validation and instrument fault finding, routine liaison with the Local Site Operators (LSO) and the Equipment Support Unit (ESU). The QA/QC activities are performed by NPL and include: site audits, inter-laboratory performance schemes and data ratification.

As the aethalometer produces real-time continuous data it was decided to perform remote data collection and diagnostics at each site via a modem to maximise data capture and minimise LSO costs. A summary of this activity is outlined below:

Measurements are collected from the 21 sites on the network between 6 am and 7 am every morning and again between 6 pm and 7pm in the evening. Measurements of black carbon, UV carbon, flow and the raw attenuation signals since the last data collection are requested from the aethalometer and written to a text file on the server at KCL. These files are placed in a queue and processed into the central Microsoft SQL database. This database is mirrored to a second, on site server every hour and backed up to tape on a daily basis; these tapes are stored off site for added database security. When the files are processed, the 5 minute mean measurements are averaged to 15 minute means so that the averaging period is the same as measurements made using gaseous and particulate monitors on the AURN. A valid 15 minute measurement is only calculated where two valid 5 minute measurements exist in that 15 minute period. A range of sensibility checks are undertaken at this point to ensure measurements are above zero and below a maximum limit (100 µg m^{-3}); the flow data is also checked to ensure it is 4 l/min (±10 %).

The data from each site is assessed using a range of algorithms/criteria, which determine whether the site requires a manual check; this is 'risk-based' data checking and provides a method for improving the efficiency of the data checking procedure. The list of algorithms/criteria examine whether:

- Data warning flags have been attached to the data, either from the instrument or from the sensibility checks during processing.
- Data checking resulted in any notes or actions on the previous day.
- There are any services, local site operator visits or audits being undertaken that day.
- The data is stable for more than 6 consecutive 15 minute periods.
- The data capture over the previous 24 hours is less than 90 %.
- The site was not manually checked the previous day.

If any of these tests produce a positive result, the site is included in a list of sites to be examined manually. Where necessary, this manual validation is undertaken using MONNET every working day; a screen shot of the 5 day data checking graph is shown in Figure 3. This shows the black carbon and UV carbon measurements and the flow measured by the instrument. Where NO_X measurements are available from the site (such as North Kensington and Marylebone Road) these are included as a method of assessing the impact of local traffic emissions. Further manual checks are made comparing the measurements between sites across the network to identify any outliers.

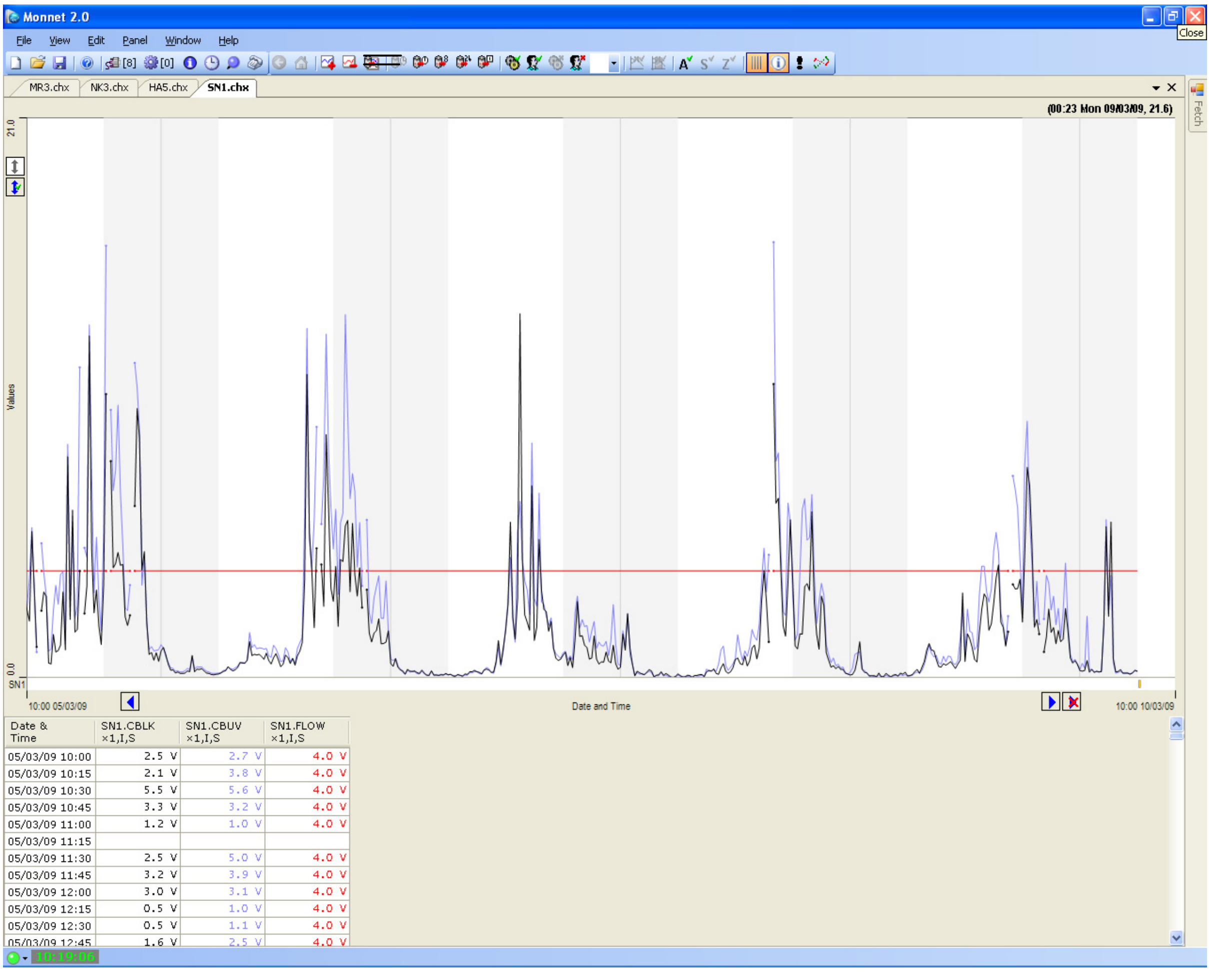


Figure 3 MONNET data checking graph

Issues raised during the manual data checking are noted in the database, this information is retained and passed to NPL to inform the ratification process. Occasionally, issues raised during data checking require an intervention from either the local site operator (LSO) or the equipment support unit. If this is the case a visit request is sent to either the LSO or Air Monitors. The reports generated from these visits are processed at KCL and stored according to the site that they pertain to. The directory is mirrored to the web server and accessible via a password protected web portal for access during ratification.

2.2.3 Aethalometer Installations

Air Monitors who are acting as the Equipment Support Unit (ESU) for the aethalometers installed all of the instrumentation and sampling systems.

Figures 3a and 3b shows a typical site installation of an aethalometer and the sampling system including the $PM_{2.5}$ cyclone and rain cap.

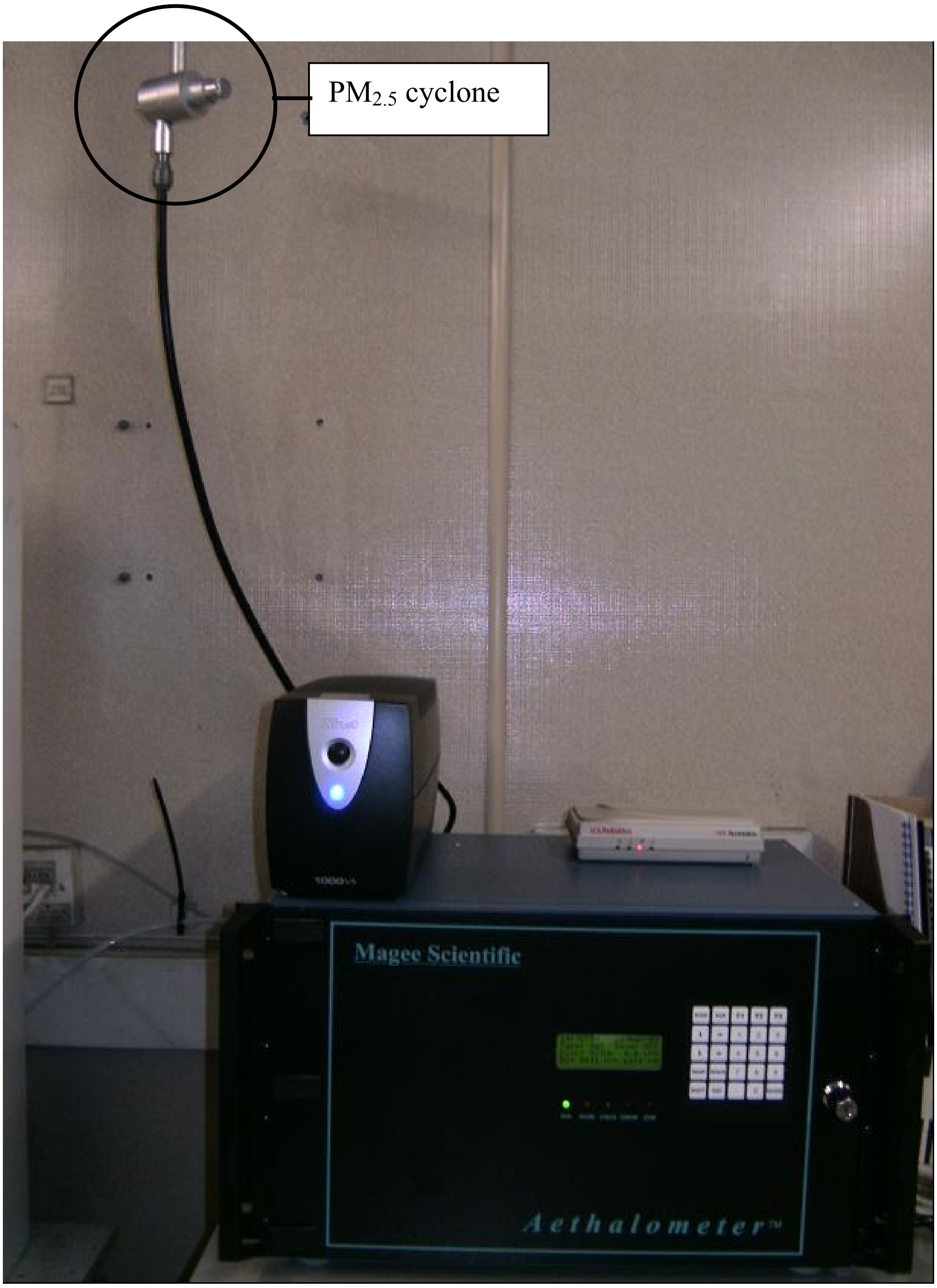


Figure 3a Installation Of Aethalometer And $PM_{2.5}$ Cyclone At A Network Site

Figure 3b Stainless Steel Rain Cap And Inlet Pipe Work For The Aethalometer At The Marylebone Road Site

Table 6 gives the date of the first measurements of Black Carbon from each Network site.

Site	Start Of Measurements
Bath 6	06/11/2008
Belfast Centre	29/10/2008
Birmingham Tyburn	16/10/2008
Bradford Town Hall	02/12/2008
Cardiff 12	10/10/2008
Dunmurry 3	29/10/2008
Edinburgh St Leonard’s	29/10/2008
Folkestone	28/10/2008
Glasgow Centre	10/11/2008
Dudley Central	29/10/2008
Halifax 17	13/11/2008
Manchester Piccadilly	31/10/2008
Marylebone Road	04/11/2008
North Ken	05/11/2008
Nottingham Centre	07/11/2008
South Kirkby 1	11/11/2008
Stoke Centre	15/11/2008
Strabane 2	29/10/2008
Sunderland 8	11/11/2008
Woolwich 9	25/10/2008

Table 6 Black Carbon Measurement Start Dates For Each Site

3.0 Quality Assurance and Quality Control (QA/QC)

Quality Assurance and Quality Control activities cover two main areas: site audits and instrument calibration. The first addresses sampling issues and the second ensures the consistency and accuracy of the instruments measuring reflectance for Black Smoke measurements and absorption for Black Carbon.

3.1 Site Audits

In most cases audits were carried out at the same time for both the 8-port samplers and the aethalometers. Table 7 gives the site audit dates.

Site	Audit Date
Bath	28/11/2008
Belfast Centre	08/07/2008
Belfast Centre	18/11/2008
Birmingham Tyburn	29/10/2008
Bradford	09/12/2008
Cardiff 12	02/10/2008
Dudley Central	29/10/2008
Dunmurry 3	18/11/2008
Edinburgh	08/10/2008
Folkestone	04/11/2008
Glasgow	10/12/2008
Halifax	13/11/2008
Manchester	17/11/2008
Marylebone Road	23/04/2008
Marylebone Road	05/11/2008
N. Kensington	05/11/2008
Nottingham	08/12/2008
South Kirkby	13/11/2008
Stoke on Trent	17/11/2008
Strabane	18/11/2008
Sunderland	09/12/2008
Woolwich 9	04/11/2008

Table 7 Site Audit Date

The 8-port sampler at Sunderland had been removed from site by the LSO before it could be audited. The aethalometer was audited at the above visit.

3.1.1 Black Smoke

With the exception of the parallel running sites, all of the 8-port samplers were audited after routine sampling had ceased.

3.1.1.1 Sampler Leak Rates

The leak rate of each port on an 8-port sampler is calculated by comparing the flow at the dry gas meter to the inlet manifold flow while sampling through each port. Some of the 8-port samplers failed the initial leak rate test at the annual audit; this will affect the overall measurement uncertainty for these sites. Black smoke measurements have not been corrected for leak rate. The effect of these leaks on the measurement uncertainty is discussed in Section 4.1. Table 8 gives the results of the sample leak rates.

	Percentage Leak Rate Port							
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Bath 6	5.7	5.4	5.5	5.6	5.2	5.7	5.6	5.8
Belfast Centre	8.3	8.2	9.1	8.7	8.7	8.4	8.6	8.6
Belfast Centre	5.5	5.5	5.7	5.8	6.3	6.0	6.0	5.2
Birmingham Tyburn	6.6	7.0	7.1	5.6	4.7	6.6	6.1	5.8
Bradford Town Hall	5.3	5.5	4.7	5.9	5.3	5.3	5.5	5.3
Cardiff 12	6.6	6.1	5.6	5.8	5.3	5.7	6.0	6.4
Dunmurry 3	7.9	7.7	8.5	7.9	8.3	8.6	9.3	8.1
Edinburgh St Leonard's	6.1	5.8	5.6	6.0	5.4	5.4	5.4	5.8
Folkestone	6.2	5.5	5.0	4.8	4.9	4.3	5.2	5.2
Glasgow Centre	6.9	5.7	5.4	5.2	5.3	5.4	6.1	7.0
Halesowen 8	7.3	8.2	7.6	7.3	8.3	8.8	8.8	8.4
Halifax 17	10.4	10.1	10.4	10.4	9.8	9.9	9.8	10.5
Manchester Piccadilly	4.1	3.9	4.2	4.5	4.5	4.5	4.4	5.3
Marylebone Road[1]	8.1	10.4	10.2	11.8	11.5	11.6	11.3	8.4
Marylebone Road[2]	4.8	5.0	5.1	4.6	5.1	4.8	5.0	4.8
Marylebone Road[3]	5.3	7.1	9.6	6.8	8.0	6.9	9.0	8.9
North Kensington	7.6	7.1	8.1	8.1	8.5	8.3	8.0	7.9
Norwich 7	5.2	5.5	5.2	5.5	5.0	5.1	5.4	5.5
South Kirkby 1	10.7	8.9	8.8	8.7	10.1	19.7	8.0	10.4
Stoke on Trent	4.4	4.3	4.4	4.6	4.4	4.4	4.6	4.6
Strabane 2	5.4	5.4	5.4	5.8	5.5	5.5	6.4	6.2
Woolwich 9	5.9	6.9	6.2	6.5	6.4	7.3	7.1	6.5

1 Sampler being replaced
2 Replacement sampler
3 November audit

Table 8 Sampler Leak Rates

The 8-port sampler at Nottingham had been disassembled by the LSO when the aethalometer had been installed to save space in the cabin. Therefore, it was not possible to perform a leak test, however, a flow calibration was performed.

The regular greasing of the ground glass joints by the LSOs, as described in the Black Smoke LSO Manual[2], has reduced the leak rates from previous years. The average leak rate for 2008 was 6.6%, while the average for 2007 was 8%.

3.1.1.2 Measurement Of Sample Flow And Calibration Of Rotameter

During the 2008 audit round, only the Belfast rotameter was found to be contaminated with water. It is assumed that this water was due to condensation out of the flow stream within the sampler, after the bubbler. The flow meter was dried and the LSO instructed on how to perform this procedure. Due to this water contamination the readings from the inline flow meter were considered to be invalid at the data ratification stage. This reduction in number of sites affected by water from three sites in 2007, to one in 2008, is probably due to the implementation of the improved LSO procedures as laid down in the Black Smoke LSO Manual.

The sample flow entering the dry gas meter was measured using a BIOS Dry-Cal2 flow meter, which was calibrated at NPL against National Standards. When taking into account the repeatability of the measurements in the field, the flow at the dry gas meter was measured with an uncertainty of ±2.5%, expressed with a level of confidence of 95%. Table 9 shows the results of the measurements of sample flow and the derived rotameter factor. The nominal flow is 1.4 l per min.

Site	Sample flow, litres per minute	Sample flow after repair, litres per minute	Rotameter factor	Remedial action
Bath 6	1.43		0.98	
Belfast Centre	1.36		0.88	
Belfast Centre	1.36		0.96	
Birmingham Tyburn	1.11	1.43	1.02	1
Bradford Town Hall	1.39		1.01	
Cardiff 12	1.42		0.99	
Dunmurry 3	1.43		0.91	
Edinburgh St Leonard's	1.44		0.99	
Folkestone	1.41		0.96	
Glasgow Centre	1.38		1.02	
Halesowen 8	1.40		0.90	
Halifax 17	1.38		0.95	
Manchester Piccadilly	1.49		1.02	
Marylebone Road[1]	1.39		1.02	
Marylebone Road[2]	1.33		1.04	
Marylebone Road[3]	1.31	1.37	1.02	1
North Kensington	1.40		0.91	
Norwich 7	1.42		1.09	
Nottingham Centre	1.32		0.99	
South Kirkby 1	1.40		1.00	
Stoke on Trent	1.50		1.04	
Strabane 2	1.45		1.11	
Woolwich 9	1.36		0.98	

1 Sampler being replaced
2 Replacement sampler
3 November audit

Remedial Action Codes

1 Partially blocked orifice, replaced

Table 9 Measured Sample Flow For Each Site

All of the flows reported in Table 9 are measured and reported at ambient temperature and pressure and are therefore volumetric flows.

The rotameter factor is derived by measuring the flow at the inlet of the rotameter and comparing it with the reported flow and is calculated using the following equation:

$$Rotameter\ factor = \frac{reported\ flow\ from\ rotameter}{measured\ flow\ at\ rotameter}$$

3.1.1.3 Local Site Operator (LSO) Assessment And Training

All LSOs were found to be performing their duties with good attention to detail and in a conscientious manner. The only fault with LSO performance was that at more than one site, the water had completely evaporated from one or more of the bubblers. The Drechsel bottles should be topped up to a level that is sufficient to last one weeks sampling, as specified in the LSO Procedure Manual. The level required will vary between summer and winter periods.

3.1.2 Black Carbon

All of the aethalometers were audited shortly after installation to make sure that they were installed correctly and to assess their performance.

3.1.2.1 Sampler Leak Rate and Calibration of Sample Flow

The leak rate for aethalometers is measured in a similar fashion to that on the 8-port sampler. The flow rate at the input to the analyser is compared to that measured at the exhaust of the analyser. The major difference with the aethalometer is that these measurements are performed simultaneously and therefore two calibrated flow meters are required. According to the manufacturer, the maximum acceptable leak rate is 20%. As with Black Smoke, the Black Carbon concentrations are not corrected for leak rate, but the leak rate is included in the uncertainty budget.

The absolute value of the inlet flow measured during the leak test is used to calibrate the sample flow of the instrument.

Both flow meters used were calibrated at NPL against National Standards. When taking into account the repeatability of the measurements in the field, the flow inlet and exhaust flows were measured with an uncertainty of ±2.5%, expressed with a level of confidence of 95%.

Table 10 gives the measured leak rates and sample flows for each site.

Site	Leak Rate, %	Stated Sample Flow, litres per minute	Measured Sample Flow, litres per minute
Cardiff 12	16.7	4.0	3.85
Edinburgh	9.5	4.0	4.02
Birmingham Tyburn	9.8	4.0	3.91
Dudley Central	6.4	3.9	4.22
Folkestone	4.5	4.0	4.10
Woolwich 9	7.9	4.0	4.22
Marylebone Road	13.4	4.0	4.08
N. Kensington	11.5	4.0	3.88
Halifax	20.1	4.0	3.64
Halifax[1]	15.3	4.0	3.88
South Kirkby	8.2	4.0	4.20
Manchester	10.0	4.0	3.84
Stoke on Trent	10.7	4.0	3.91
Belfast Centre	6.3	4.0	4.16
Dunmurry 3	7.3	4.0	4.01
Strabane	8.4	4.0	3.83
Bath	7.9	4.0	4.16
Nottingham	11.4	4.0	4.49
Bradford	4.7	4.0	3.76
Sunderland	6.8	4.0	4.07
Glasgow	7.8	4.0	4.16

1 Post repair

Table 10 Aethalometer Leak Rates and Sample Flows

When the Halifax aethalometer was first tested it was found to have a large build up of filter tape on the sealing nozzle between the measurement cell and the tape. When this was removed the leak rate improved from 20.1% to 15.3%.

3.2 Optical Calibration

The following two sections set out the calibration methodologies for the optical parts of the Black Smoke and Black Carbon measurements.

3.2.1 Reflectometer Calibration – Black Smoke

The smoke stains on all of the filters from the individual sites are centrally measured by NPL on one reflectometer. A multi-point calibration curve for this reflectometer is generated using calibration tiles that have been calibrated under UKAS procedures at NPL. The uncertainty of each calibration tile value is ±0.71%, expressed with a level of confidence of 95%. By using a multi-point calibration curve (absolute reflectivity), the calibration uncertainty is reduced. The uncertainty associated with the multi-point calibration is ±0.74%, expressed with a level of confidence of 95%. As well as performing regular multi-point calibrations, check tiles are also measured on each measurement day. Figure 4 shows the calibration history of the NPL reflectometer when using these three check tiles.

Figure 4 Reflectometer Calibration History

These regular calibrations of the reflectometer show that its accuracy and drift are within the allowable uncertainty and no correction of the measured reflectances has had to be made.

3.2.2 Aethalometer Calibration

The aethalometer measurement does not depend on any absolute calibration of the detectors' response signals, but instead relies upon their ability to determine very small changes in optical transmission. However, there is an inbuilt routine in the aethalometer to measure the Optical Test Ratio (OTR), so that drift in the instrument can be monitored.

To enable an inter instrument comparison to be made, NPL manufactured a test strip that could be used to challenge each aethalometer to obtain its OTR at a wavelength of 880nm only. The absorbance of the test strip was determined by the Optical Standards Team at NPL, at this wavelength, and is traceable to National Standards. The uncertainty of the absorbance of the test strip is 0.6%, expressed with level of confidence of 95%. The expected value of the OTR should lie in the range 0.7 to 1.0.

When a single aethalometer was challenged with the NPL test strip 6 times the standard deviation of the OTR was 7.6%.

The single instrument was also challenged with the manufacturer's supplied test strip 10 times and the standard deviation of the OTR was 7.2%. The absolute adsorption value of the manufacturers supplied test strip was not determined.

Table 11 shows the audit results for each aethalometer challenged with the NPL test strip.

Site	Sensing Beam Value	Reference Beam Value	Optical Test Ratio
Cardiff 12	48.25	50.17	0.96
Edinburgh	46.24	50.55	0.92
Birmingham Tyburn	50.89	59.06	0.86
Dudley Central	50.11	61.05	0.82
Folkestone	51.15	58.63	0.87
Woolwich 9	48.25	56.18	0.85
Marylebone Road	38.48	52.64	0.73
N. Kensington	33.05	54.89	0.60
Halifax	69.54	56.46	1.23
South Kirkby	49.02	55.08	0.89
Manchester	39.87	58.80	0.67
Stoke on Trent	41.29	56.36	0.73
Belfast Centre	41.80	52.68	0.79
Dunmurry 3	46.08	53.53	0.86
Strabane	45.69	56.25	0.81
Bath	47.31	57.49	0.82
Nottingham	48.22	55.83	0.86
Bradford	49.01	63.96	0.76
Sunderland	45.69	55.29	0.82
Glasgow	47.37	60.44	0.78
		Mean	0.83
		Standard Deviation	0.13
		Excluding Halifax	
		Mean	0.813
		Standard Deviation	0.09

Table 11 Results Of The Optical Test Ratio Intercomparison

From looking at the test results from Halifax there was a problem with the sensing beam value measurement. Therefore, this measurement of OTR is invalid. No valid reason was found for excluding the result from North Kensington.

The results give an indication of comparability of the absorption data in the aethalometers across the network. These results are better represented as a chart in Figure 5.

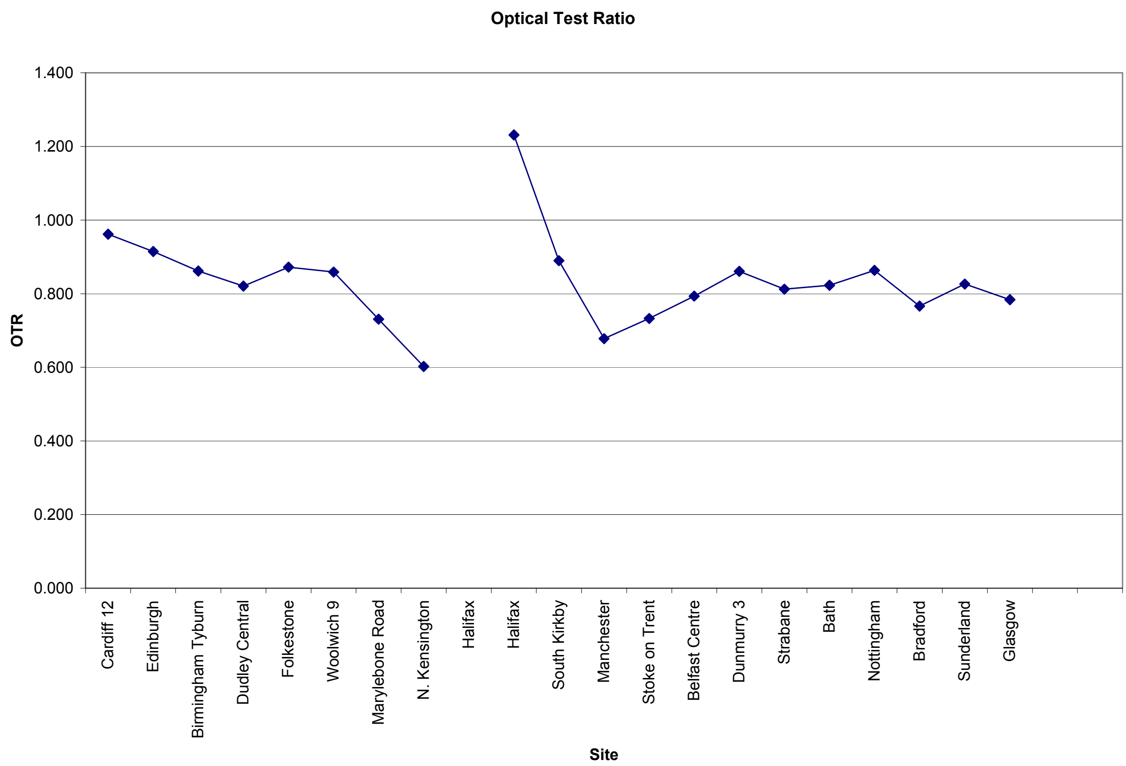


Figure 5 Results Of The Optical Test Ratio Intercomparison

The results of the OTR tests were not used to scale the ratified data, but are just used for intercomparison purposes and to estimate the measurement uncertainty. The tests will be refined in future years as more experience with the instrument is gained.

4.0 Measurement Uncertainty

4.1 Black Smoke

The measurement uncertainty for Black Smoke Index is dominated at high values by the sampling leak rate, and at low values by the repeatability of the reflectance measurement on real filter samples.

A more detailed uncertainty budget for the Black Smoke method was given in the 2006 Annual Report[3]. This uncertainty budget assumed a maximum sampling leak rate of 6%. At the 2008 audits some of the samplers failed this leak rate criteria, so the overall measurement uncertainty will increase. The largest annual mean leak rate was measured at Marylebone Road with a value of 10.4%. The effect of this leak rate on the overall measurement uncertainty can be seen in Table 12:

	Uncertainty (95%) in BSI as % mid range					
	BSI (µg.m-^{3})	157 - 97	97 - 58	58 - 31	31 - 12	12 – 0
	Leak rate, %					
Typical site	6.0	9.5	10.2	11.9	17.2	41
Marylebone Road	10.4	15.4	15.8	17.0	21.0	43

Table 12 Measurement uncertainty

At the low average concentrations at the majority of sites the provisional uncertainty is around 30%, dominated by the repeatability of the reflectance measurement on real filter samples. The provisional uncertainty at Marylebone Road is around 14%.

4.1.1 Limit Of Quantification

Prior to NPL taking over the running of the Black Smoke Network in 2006, the measurement of the individual filter reflectances was reported with a precision of 1.0%. NPL report reflectances with a precision of 0.1%

While this does not affect the accuracy of measurements in general, because the repeatability of the reflectance measurements is more than 1%, there will be a small effect arising from the changed limit of quantification. Previously, the maximum reflectance measurement of 99% led to a minimum reported Black Smoke concentration of 0.9 µg.m^{-3}. The new quantification limit is close to 0.1 µg.m^{-3}. In 2008, some measurements from Glasgow Centre and Edinburgh St Leonard's were at or below the limit of quantification.

4.2 Black Carbon

A breakdown of the uncertainty budget for the aethalometer is given below.

There are two main elements to this: sample volume and measurement of absorption.

4.2.1 Sample Volume

From measurements at the site audit the sample volume can be determined with an uncertainty of ±11%, expressed with a level of confidence of 95%. Included in this uncertainty are contributions from flow rate accuracy, repeatability, drift and leaks.

The leak rate is not used to correct the results, but is included as an uncertainty if the sampler passes the leak test at audit. The manufacturer's tolerance for leak rate is 20%. In the case of this uncertainty calculation the average value of leak rate determined in the 2008 audits was used. As leak rate is considered to be a rectangular distribution, its contribution to the standard uncertainty in sample volume is 5.3%.

4.2.2 Measurement of Absorption

The aethalometer measurement does not depend on any absolute calibration of the detectors' response signals, but instead relies upon their ability to determine very small changes in optical transmission. The aethalometer's ability to do this is determined by the Optical Test Ratio (OTR) test performed at the site audits. As the results at ratification were not scaled by the individual OTR results the standard deviation of all the OTR results has been included in the uncertainty calculation. For the 2008 audits the standard deviation of the OTR results was 10.4%.

When a single aethalometer was challenged with one test strip 6 times the standard deviation of the OTR was 7.6%. This uncertainty was not included in the overall uncertainty of the adsorption measurement as it is included in the inter-instrument comparison.

4.2.3 Correction for Spot Darkening

The Virkkula model[1] was used to correct the measured concentrations due to the fact that the aethalometer becomes slightly non-linear at high attenuation values when the filter tape is heavily loaded. This effect and its attempted correction introduce an uncertainty into the measurements. At most sites the correction can be seen to work well on the 15-minute data, in that there is minimal discontinuity when the spot location changes, and the associated uncertainty is considered to be negligible. At sites where the concentration is changing quickly, such as Marylebone Road, this uncertainty in the 15-minute data becomes significant. When hourly averages have been produced from this 15-minute data the effect is less significant. The uncertainty due to this effect is being investigated and has not been included in the overall measurement uncertainty.

4.2.4 Preliminary Overall Measurement Uncertainty

As QA/QC procedures are being developed, the overall measurement uncertainty is a preliminary value. Further work is being done to develop these procedures and will be reported on at a later date.

When the contributions from sample volume and measurement of adsorption are combined, the overall measurement uncertainty for Black Carbon concentrations is 23.5%, expressed with a level of confidence of 95%. This is an indicative measurement uncertainty for the aethalometer method and is calculated from the results of the 2008 audit data. The site specific overall measurement uncertainty may differ from this value.

QA/QC tests and estimates of uncertainty will be refined in future years as more experience of the aethalometers is gained.

5.0 Results

The concentration data for 2008 are presented in the following sections as time series graphs, summary graphs and tables of the annual mean concentration and data capture.

All of the Black Carbon and UV Component data has been corrected for spot darkening using the Virkkula method.

5.1 Black Smoke

5.1.1 Time Series

The following charts show the Black Smoke concentrations measured by the UK Black Smoke Network for 2008. Data has been split into regions of the UK for presentation purposes.

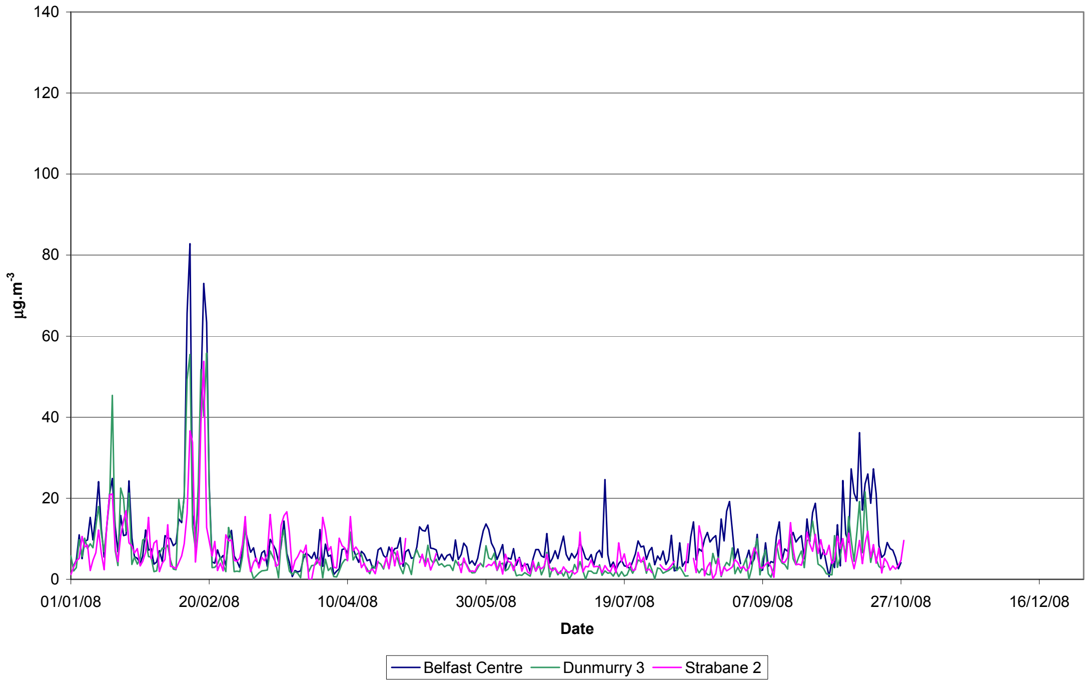
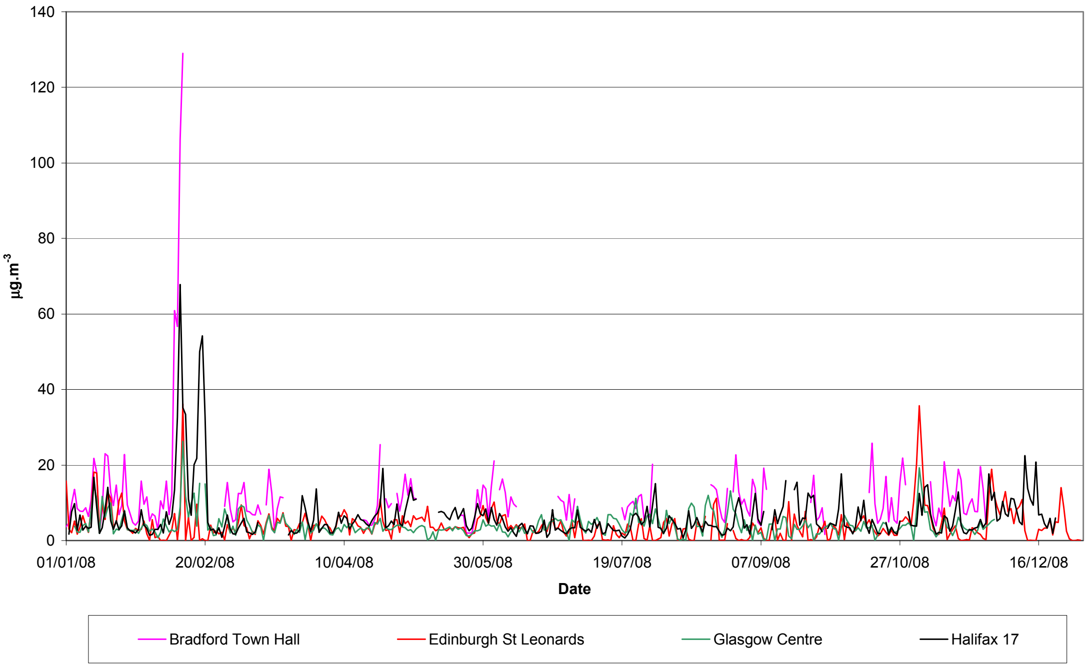


Figure 6 Black Smoke concentrations during 2008 in Northern Ireland



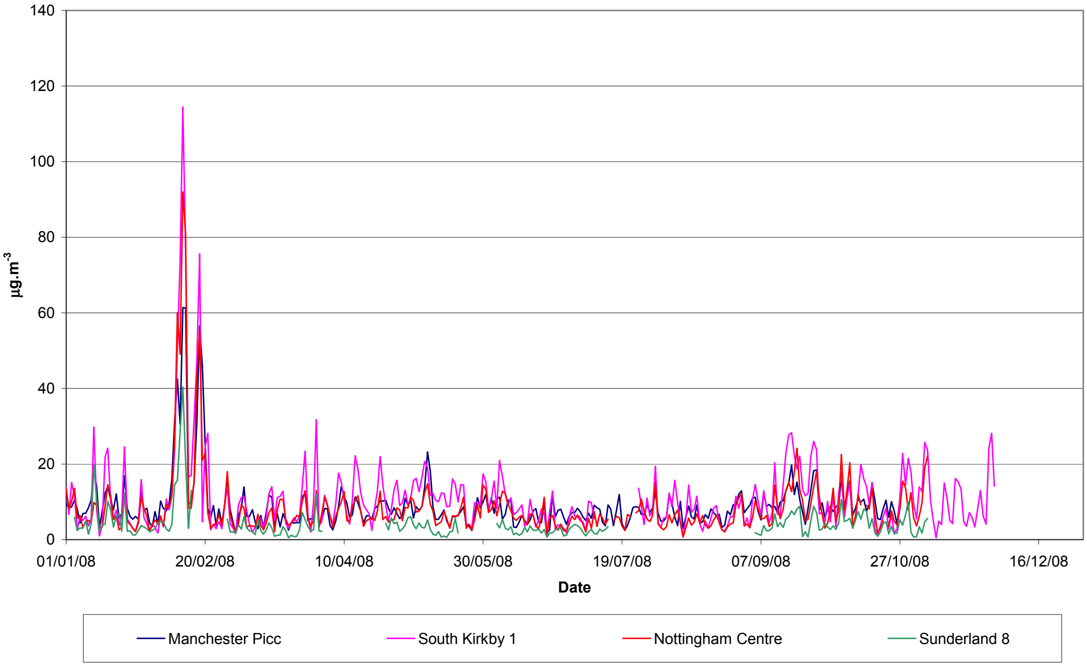


Figure 7 + 8 Black Smoke concentrations during 2008 in Scotland and Northern England

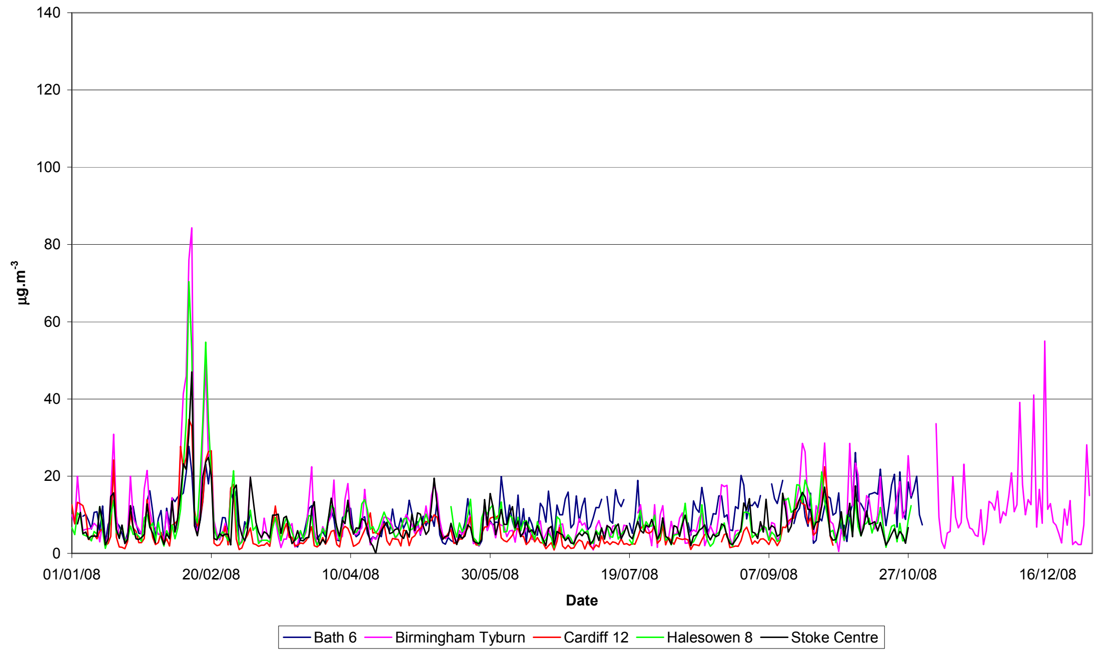


Figure 9 + 10 Black Smoke concentrations during 2008 in Southern England and Wales

5.1.2 Averages and Data Capture

Table 13 gives the annual averages and data capture for each site for 2008.

Site	Black Smoke Concentration, µg.m^{-3}	Data Capture %
Bath 6	9.9	85.9
Belfast Centre	9.1	99.3
Birmingham Tyburn	9.6	94.3
Bradford Town Hall	12.0	55.1
Cardiff 12	5.7	98.2
Dunmurry 3	5.8	99.3
Edinburgh St Leonard's	4.0	99.5
Folkestone	3.9	86.7
Glasgow Centre	4.2	98.8
Halesowen 8	7.9	97.0
Halifax 17	6.3	90.4
Manchester Piccadilly	9.0	100.0
Marylebone Road	39.9	99.2
North Kensington	7.2	98.9
Norwich 7	5.4	97.8
Nottingham Centre	8.3	98.7
South Kirkby 1	10.9	95.5
Stoke Centre	7.3	99.0
Strabane 2	6.0	94.4
Sunderland 8	4.1	67.2
Woolwich 9	3.5	94.6

Averages and data capture are calculated over the period that Black Smoke measurements were made at each site, which is not necessarily a complete calendar year.

Table 13 Annual Mean Black Smoke Concentration and Data Capture for 2008

The data capture is low for Bradford Town Hall (55.1%) as the LSO frequently missed the routine weekly visit, which resulted in two weeks data loss each time due to double exposures. Data capture is also low for Sunderland (67.2%) as the site is in a school and access is difficult in school holidays, which resulted in some LSO visits being missed.

The annual average concentrations are presented as a bar graph (Figure 11) to aid the intercomparison of sites:

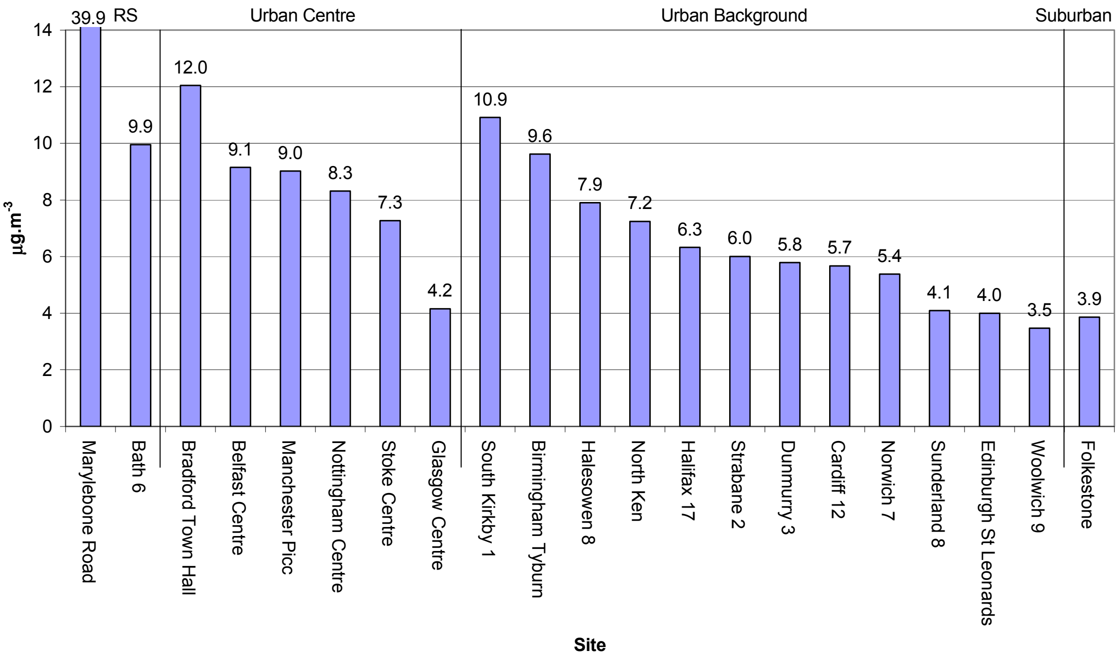


Figure 11 **Annual Average Black Smoke Concentrations For 2008.**

5.1.3 Weekly Periodicity

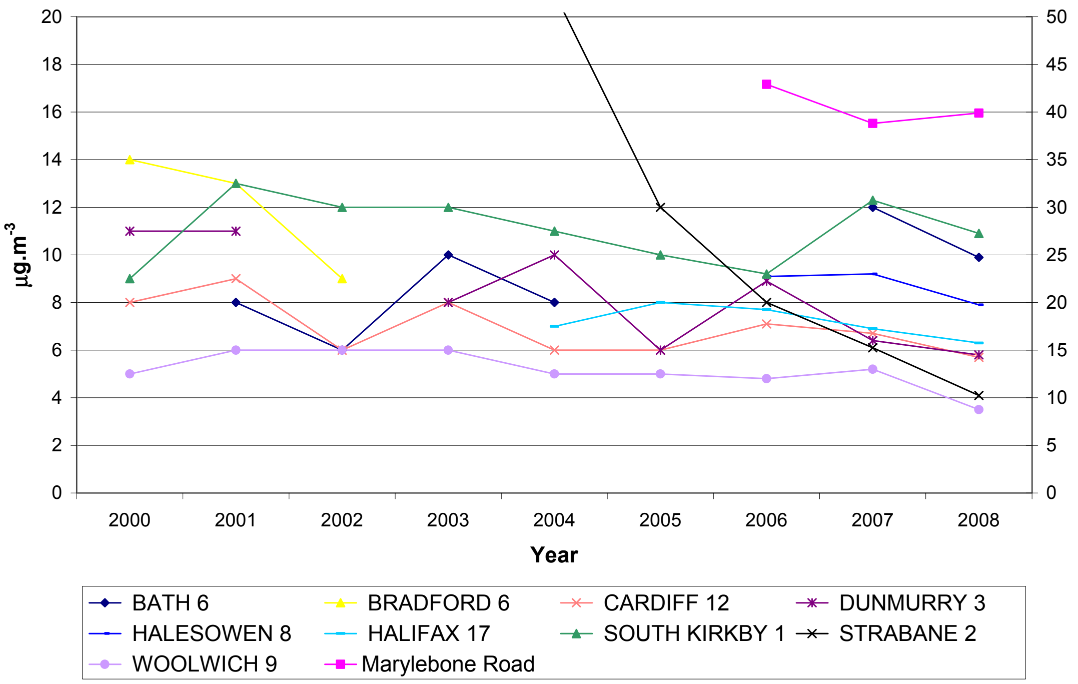
Plots of the average concentrations on each day of the week for Roadside, Urban Centre, Urban Background and Suburban site classifications respectively can be seen in Appendix 1. Table 14 shows the difference between the Monday to Friday average concentration and the Sunday average concentration. The sites have been sorted into site classification and are in descending order of annual average in each site classification.

Site	Monday - Friday	Sunday	Ratio
Roadside			
Marylebone Road	44.7	25.9	1.73
Bath 6	11.0	6.8	1.62
Urban Centre			
Bradford Town Hall	13.0	7.9	1.65
Belfast Centre	9.7	7.2	1.35
Manchester Piccadilly	9.4	7.3	1.29
Nottingham Centre	8.7	7.4	1.18
Stoke Centre	7.5	6.0	1.25
Glasgow Centre	4.8	2.3	2.09
Urban Background			
South Kirkby 1	12.1	8.0	1.51
Birmingham Tyburn	10.4	7.5	1.39
Halesowen 8	8.5	6.3	1.35
North Kensington	8.2	8.1	1.01
Halifax 17	6.8	5.1	1.33
Strabane 2	6.4	5.0	1.28
Dunmurry 3	6.0	5.7	1.05
Cardiff 12	5.9	4.8	1.23
Norwich 7	5.6	5.0	1.12
Sunderland 8	4.3	3.4	1.26
Edinburgh St Leonard's	4.3	3.1	1.39
Woolwich 9	3.6	3.0	1.20
Suburban			
Folkestone	3.9	3.7	1.05

Table 14 Daily Average Concentrations of Black Smoke.

5.1.4 Trends Since 2000

Figure 12 shows the trend in Black Smoke concentration from 2000 to 2008 for those sites operating over most of that period.



2004 Strabane 2 concentration = 21 $\mu g.m^{-3}$
Marylebone Road concentrations are on the right hand axis.

Figure 12 Trends in Black Smoke concentration from 2000 to 2008

The drop in the Strabane 2 Black Smoke concentration since 2004 is attributable to the installation of oil fired central heating (generally replacing coal burning) in the estate of houses that surround the monitoring site on three sides. Central heating replacement started in 2003.

Apart from Strabane 2 there are no significant trends in this recent data, given the relatively large measurement uncertainty.

There is no evidence of discontinuity in the data as a result of the handover of Network operation in 2006.

5.1.5 Comparisons With Other Pollutants

To assess the relationship between Black Smoke measurements and other pollutant concentrations, linear regressions were calculated between Black Smoke data and data for PM_{10}, total NO_x (expressed as NO_2) and particle number concentrations. The results can be seen in Tables 15to 18.

Black smoke = Particulate Site * M + C

Black Smoke Site	Particulate Site	Instrument	Size Fraction, PM	Instrument Annual Mean, µg.m^{-3}	M	C	R^2
Nottingham Centre	Nottingham Centre	FDMS TEOM	10	17.9	0.63	-3.14	0.70
Marylebone Road	Marylebone Road	FDMS TEOM	10	46.8	1.06	-9.43	0.65
South Kirkby 1	South Kirkby 1	TEOM - VCM	10	20.1	0.80	-2.72	0.61
Woolwich 9	Bexley	FDMS TEOM	2.5	11.1	0.47	-1.60	0.58
Halifax 17	Leeds Centre	FDMS TEOM	10	23.6	0.43	-3.89	0.57
Manchester Piccadilly	Manchester Piccadilly	FDMS TEOM	10	20.1	0.43	0.34	0.56
Cardiff 12	Cardiff Centre	FDMS TEOM	10	21.4	0.33	-1.51	0.51
North Kensington	North Kensington	FDMS TEOM	10	23.5	0.44	-3.10	0.47
Belfast Centre	Belfast Centre	FDMS TEOM	10	17.8	0.61	-1.64	0.45
Stoke on Trent	Stoke on Trent	FDMS TEOM	10	18.6	0.27	2.21	0.43
Birmingham Tyburn	Birmingham Tyburn	FDMS TEOM	10	21.1	0.51	-1.84	0.32
Folkestone	Folkestone	TEOM - VCM	10	17.0	0.25	-0.22	0.32
Strabane 2	Strabane 2	BAM MetOne	10	16.9	0.34	0.81	0.28
Sunderland 8	Newcastle Centre	FDMS TEOM	10	17.9	0.23	0.37	0.25
Glasgow Centre	Glasgow Centre	FDMS TEOM	10	21.3	0.15	0.85	0.23
Dunmurry 3	Dunmurry 3	FDMS TEOM	10	15.8	0.28	0.64	0.15
Edinburgh St Leonard's	Edinburgh St Leonard's	FDMS TEOM	10	15.0	0.22	0.69	0.12

Table 15 Relationship between Black Smoke and PM_{10} concentrations in order of decreasing correlation

Black smoke = NO_x site * M + C

Black Smoke Site	NO_x Site	Instrument Annual Mean, µg.m^{-3}	M	C	R^2
Manchester Piccadilly	Manchester Piccadilly	75.1	0.12	0.34	0.95
Nottingham Centre	Nottingham Centre	55.3	0.15	-0.02	0.92
South Kirkby 1	South Kirkby 1	60.3	0.16	0.69	0.88
North Kensington	North Kensington	48.7	0.13	0.359	0.87
Birmingham Tyburn	Birmingham Tyburn	64.1	0.14	1.11	0.83
Belfast Centre	Belfast Centre	54.0	0.17	-0.25	0.83
Sunderland 8	Sunderland Silksworth	20.6	0.22	-0.65	0.80
Marylebone Road	Marylebone Road	313.6	0.12	3.88	0.78
Stoke on Trent	Stoke on Trent	39.5	0.15	1.25	0.77
Cardiff 12	Cardiff Centre	39.9	0.17	-1.19	0.72
Folkestone	Folkestone	29.4	0.11	0.68	0.68
Glasgow Centre	Glasgow Centre	71.4	0.04	1.10	0.63
Halifax 17	Leeds Centre	64.3	0.08	1.02	0.57
Woolwich 9	Bexley	103.1	0.03	0.77	0.55
Edinburgh St Leonard's	Edinburgh St Leonard's	53.4	0.04	1.84	0.34

Table 16 Relationship between Black Smoke and total oxides of nitrogen concentrations in order of decreasing correlation

Black smoke = Particulate Number Site * M + C

Black Smoke Site	Particle Number Site	Particle Number Mean Particles.cm^{-3}	M	C	R^2
Marylebone Road	Marylebone Road	32607	0.001	10.46	0.56
North Kensington	North Kensington	13904	0.0006	- 1.42	0.46

Table 17 Relationship between Black Smoke and particle number concentrations

Black smoke = Elemental Carbon * M + C

Black Smoke Site	Elemental Carbon Site	Elemental Carbon µg.m^{-3}	M	C	R^2
Marylebone Road	Marylebone Road	8.0	2.82	14.74	0.40
North Kensington	North Kensington	1.4	1.18	5.47	0.11

Table 18 Relationship between Black Smoke and elemental carbon concentrations

It can be seen that in general the best correlation is between Black Smoke concentration and total NO_x. Some comparative time series plots are given in Figures 13 and 14.

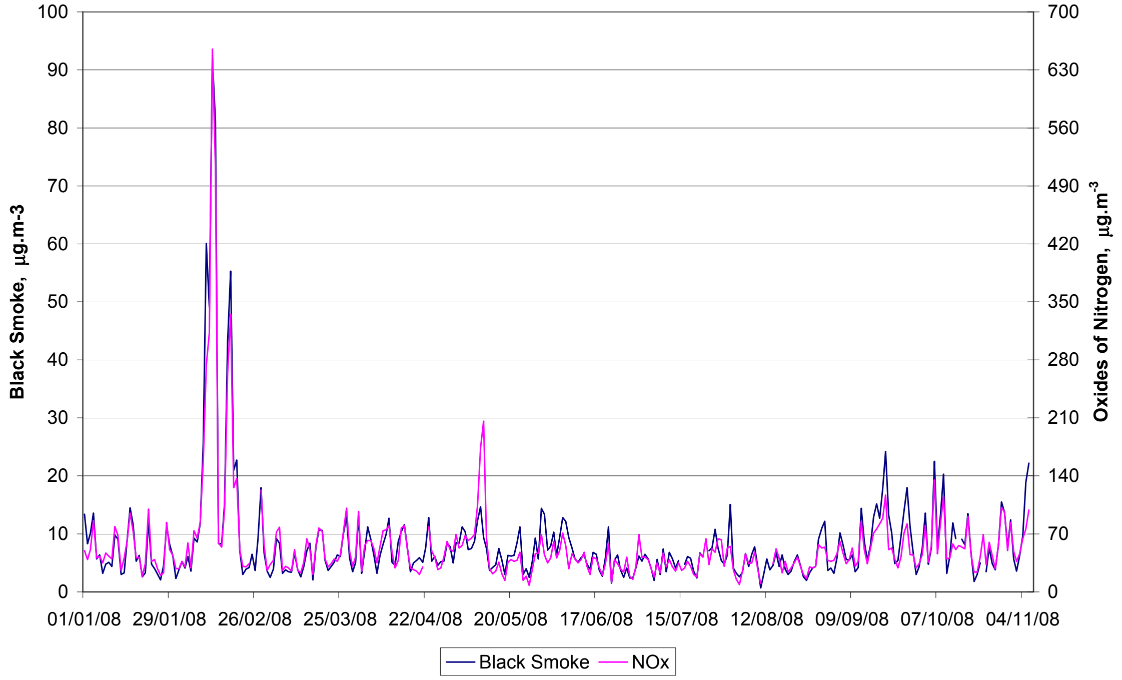


Figure 13 Black Smoke and NO_x concentrations measured at Nottingham

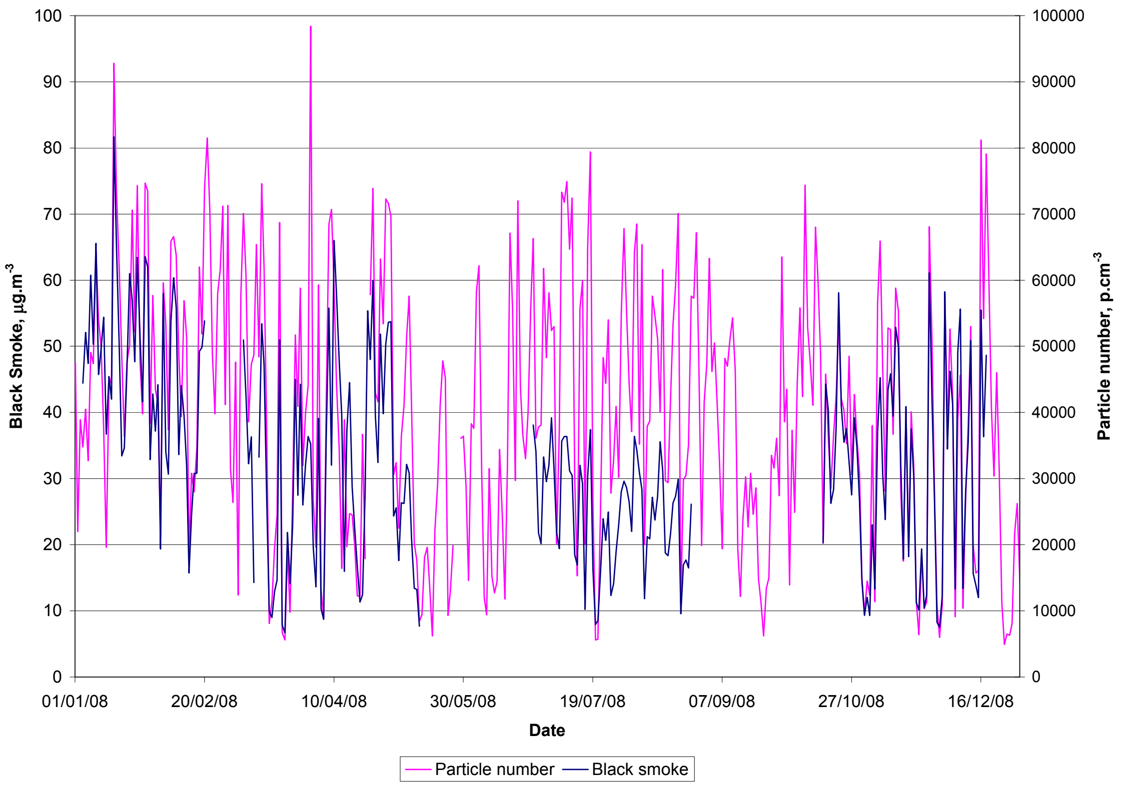


Figure 14 Black Smoke and particle number concentrations measured at Marylebone Road in 2008

5.1.6 Affiliate Sites

Two further Councils, Gloucester and Manchester, have submitted their data for inclusion in this report, but this data has not undergone any QA/QC by NPL. These sites have been listed as affiliate sites.

5.1.6.1 Time Series

Figure 15 shows the Black Smoke concentrations measured by the individual affiliate Councils for 2008.

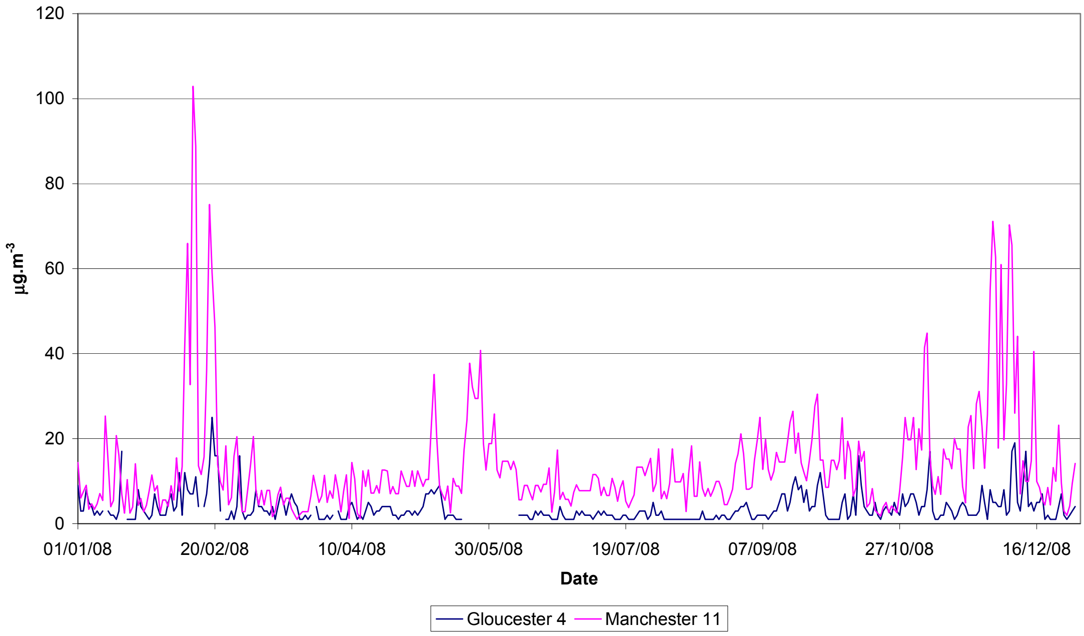


Figure 15 Black Smoke concentrations measured by affiliate Councils for 2008

5.1.6.2 Annual Averages and Data Capture

Table 19 gives the annual mean measurement for Black Smoke in 2008 for each site.

Site	Black Smoke Concentration, $\mu g.m^{-3}$	Data Capture %
Gloucester 4	3.7	92.9
Manchester 11	13.6	100.0

Table 19 Annual mean Black Smoke concentration measured at affiliate sites

5.2 Black Carbon

All of the aethalometer (Black Carbon) data in this report is VALIDATED ONLY as ratified data will not be available until the parallel running trial with black smoke measurements has been completed. QA/QC procedures for the black carbon data are currently being developed.

5.2.1 Time Series

The following charts show the Black Carbon concentrations measured by the UK Black Smoke Network for 2008. The time resolution of the measurements is hourly. Data has been split into regions of the UK for presentation purposes.

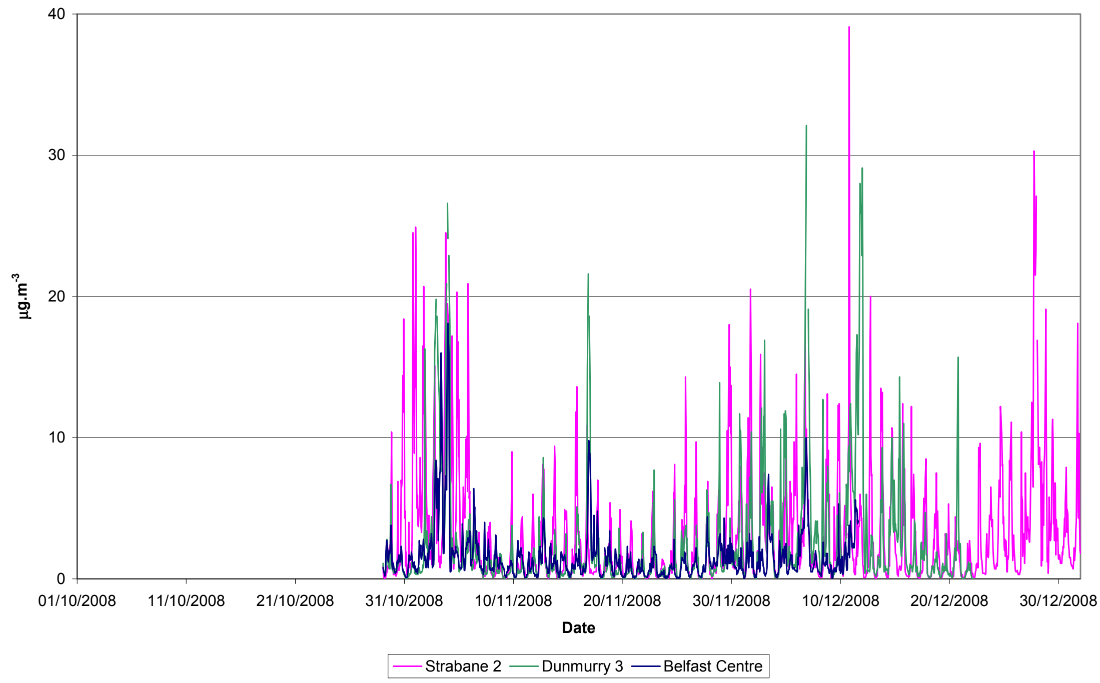
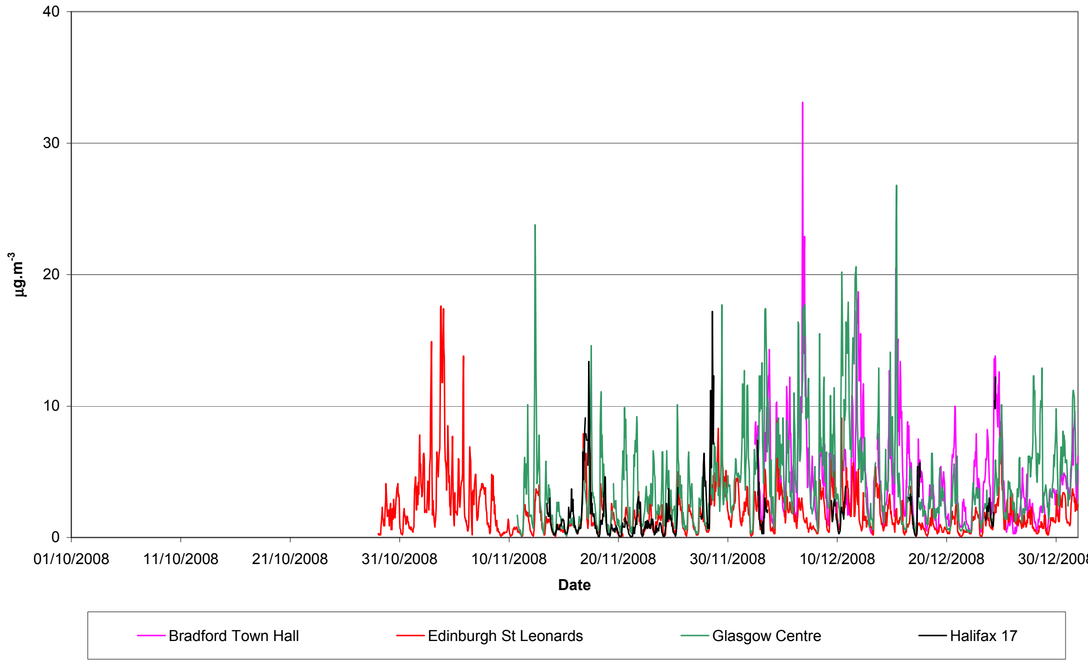


Figure 16 Black Carbon concentrations during 2008 in Northern Ireland



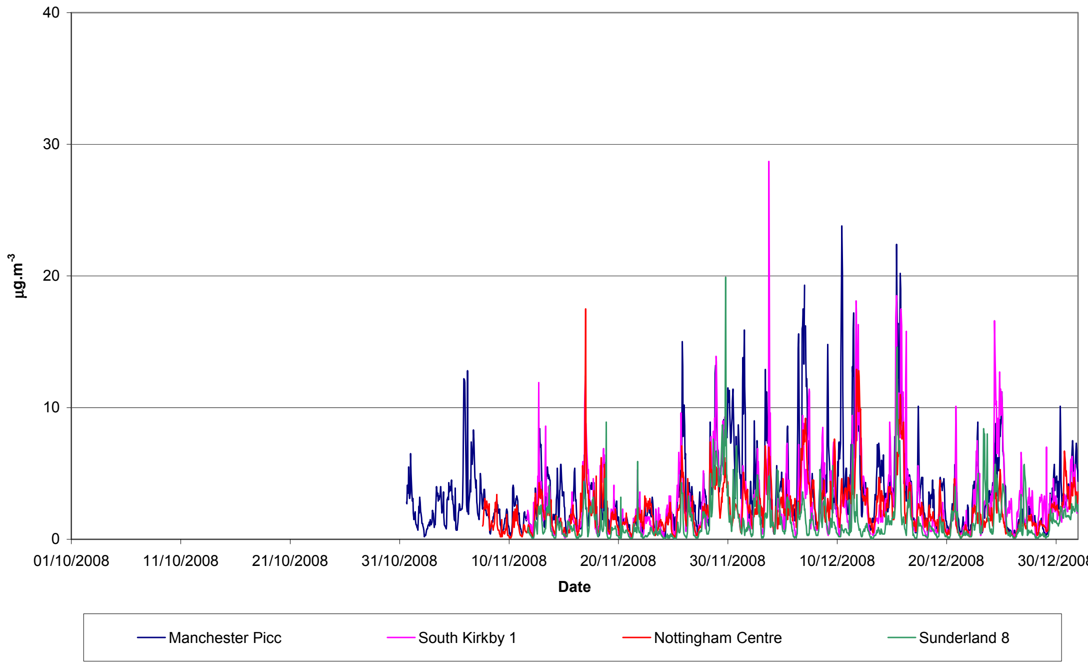
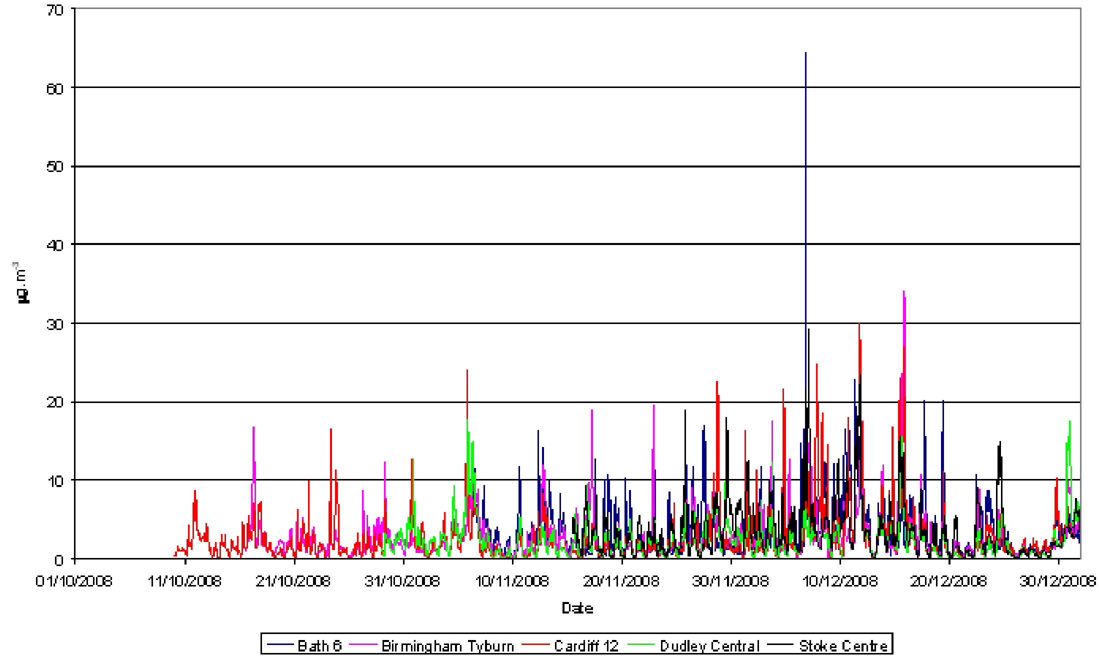


Figure 17 + 18 **Black Carbon concentrations during 2008 in Scotland and Northern England**



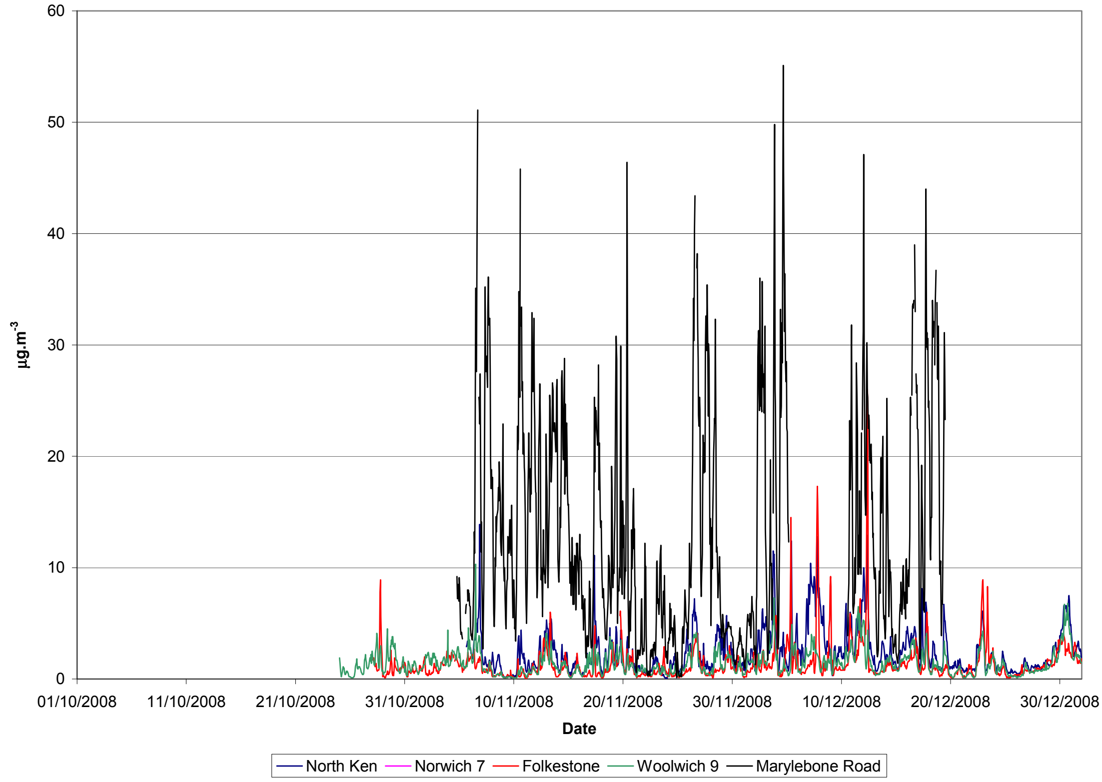


Figure 19 + 20 **Black Carbon concentrations during 2008 in Southern England and Wales**

5.2.2 Averages and Data Capture

Table 20 gives the period averages and data capture for each site for 2008.

Site	Black Carbon Concentration, µg.m^{-3}	Data Capture %
Bath 6	3.5	96.2
Belfast Centre	1.6	68.0
Birmingham Tyburn	2.9	98.8
Bradford Town Hall	4.5	98.2
Cardiff 12	2.6	97.4
Dunmurry 3	2.5	84.2
Edinburgh St Leonard's	1.9	99.9
Folkestone	1.3	99.9
Glasgow Centre	4.2	98.3
Dudley Central	2.3	96.7
Halifax 17	1.8	34.1
Manchester Picc	3.5	98.8
Marylebone Road	13.2	67.7
North Kensington	2.4	98.7
Nottingham Centre	2.3	99.0
South Kirkby 1	3.0	96.0
Stoke Centre	3.5	98.8
Strabane 2	3.2	99.7
Sunderland 8	1.4	98.4
Woolwich 9	1.4	99.8

Averages and data capture are calculated over the period that Black Carbon measurements were made.

Note: Only 2 –3 months measurement in the winter.

Table 20 Average Black Carbon Concentration And Data Capture For 2008

The low data capture at Halifax was due to the repeated crashing of the analyser. The instrument had to be power cycled by the LSO to restore operation. The instrument was replaced in early January 2009.

The low data capture at Belfast Centre (68%) was due the analyser reporting very low values and not responding to increased concentrations seen at sites in close geographical proximity (Dunmurry and Strabane). The analyser was replaced in January 2009.

The low data capture at Marylebone Road (68%) was due to the tape running out over the Christmas period and then repeated crashing of the analyser. The equipment support unit visited the site in early to investigate the problem.

The low data capture at Dunmurry (84%) was due to a communication problem with the analyser leading to the data being unrecoverable between 22/12/08 to the first LSO visit in early January 09.

The average concentrations are presented as a bar graph (Figure 21) to aid the intercomparison of sites:

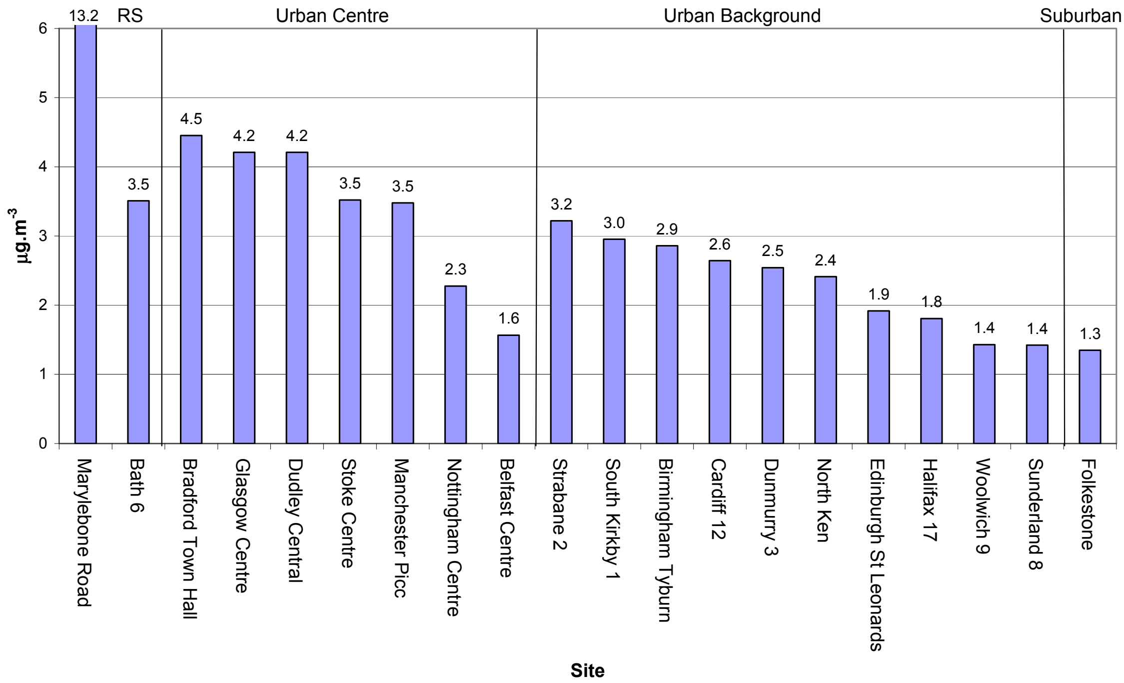


Figure 21 Mean Black Carbon Concentrations For 2008.

5.2.3 Hourly Periodicity

Due to the short period of time that the aethalometers were running during 2008, diurnal but not weekly periodicity analysis has been carried out.

Plots of the average concentrations on each hour of the day for Roadside, Urban Centre, Urban Background and Suburban site classifications respectively can be seen in figures 22 to 25.

Daily Periodicity

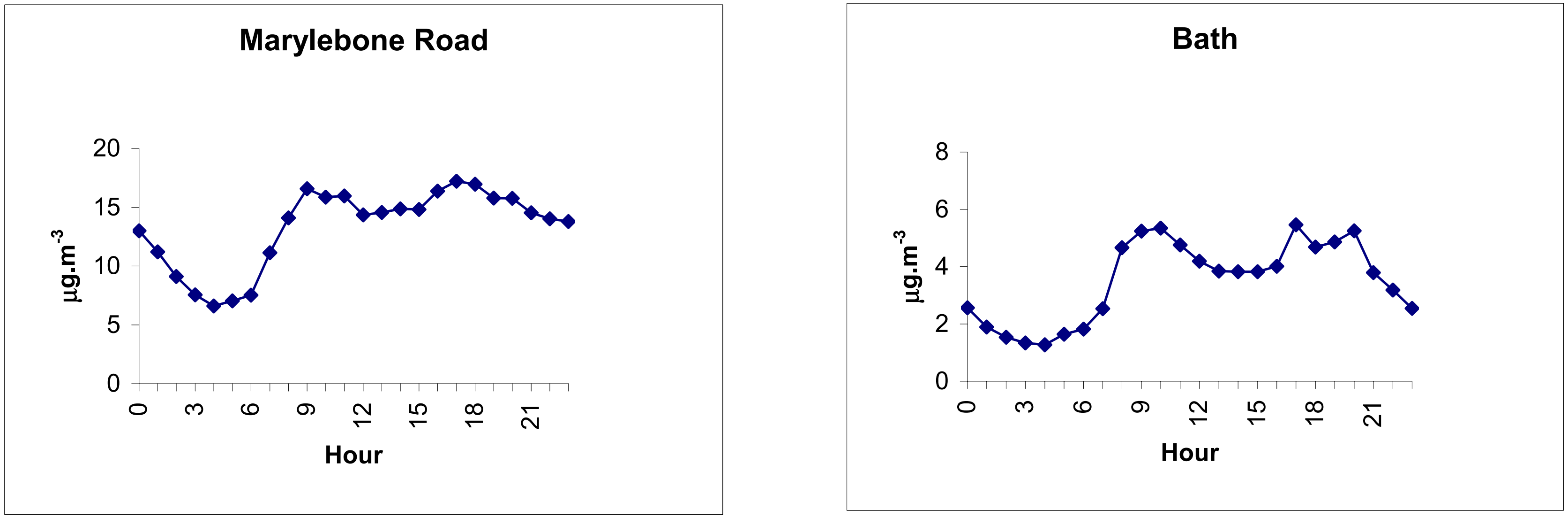
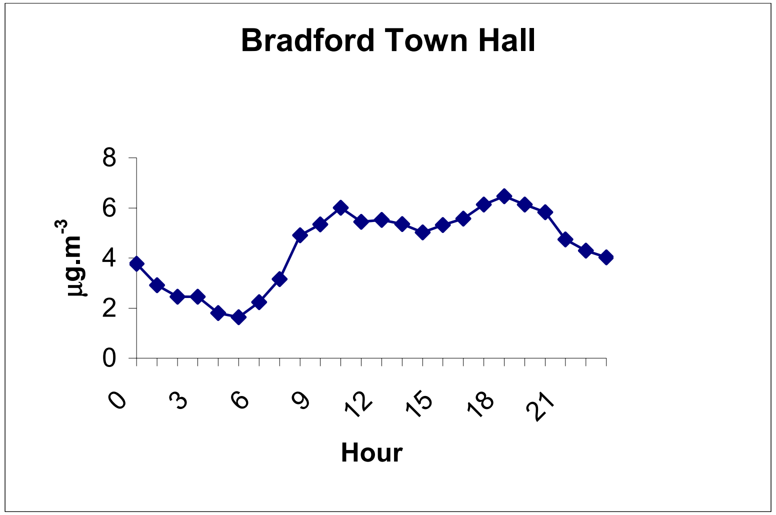
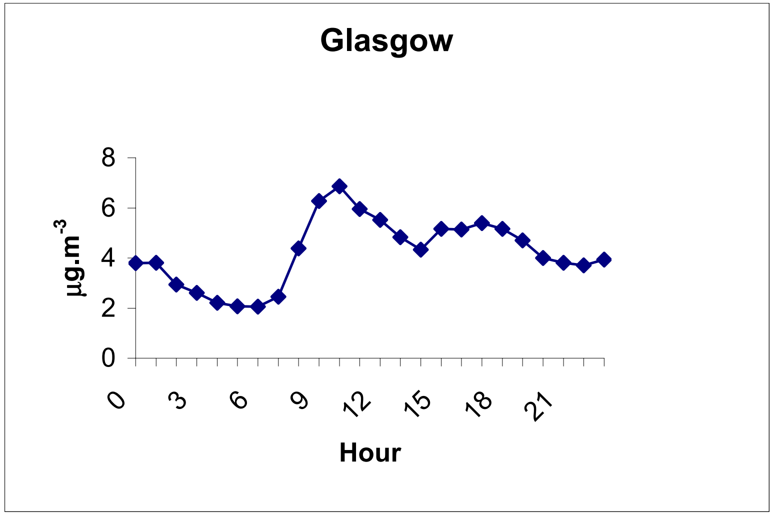
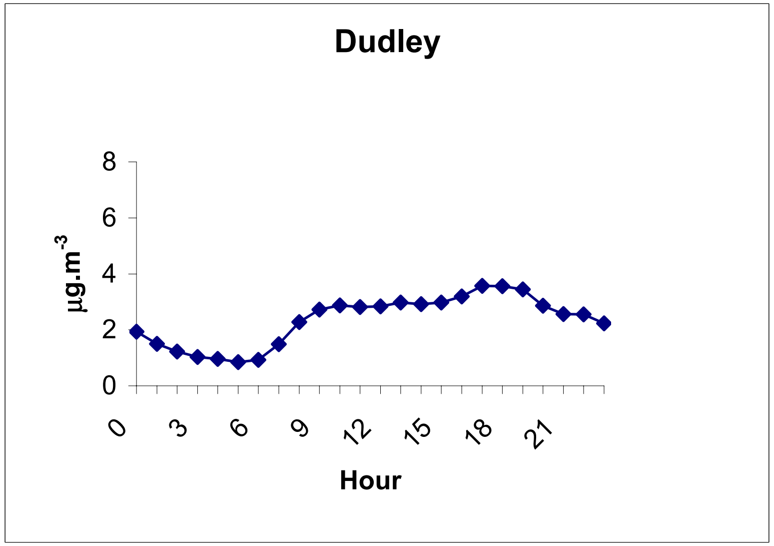
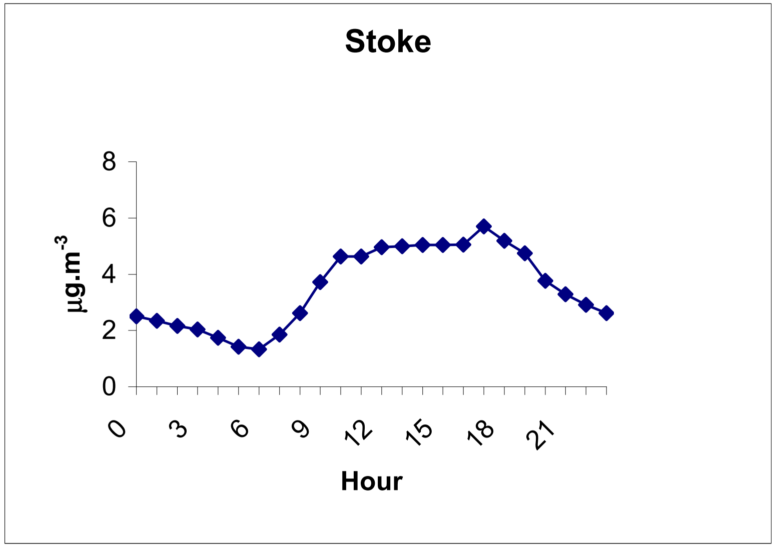


Figure 22 Diurnal Concentrations At Roadside Sites


Bradford Town Hall
µg.m-3
0
2
4
6
8
0
3
6
9
12
15
18
21
Hour


Glasgow
µg.m-3
0
2
4
6
8
0
3
6
9
12
15
18
21
Hour


Dudley
µg.m-3
0
2
4
6
8
0
3
6
9
12
15
18
21
Hour


Stoke
µg.m-3
0
2
4
6
8
0
3
6
9
12
15
18
21
Hour

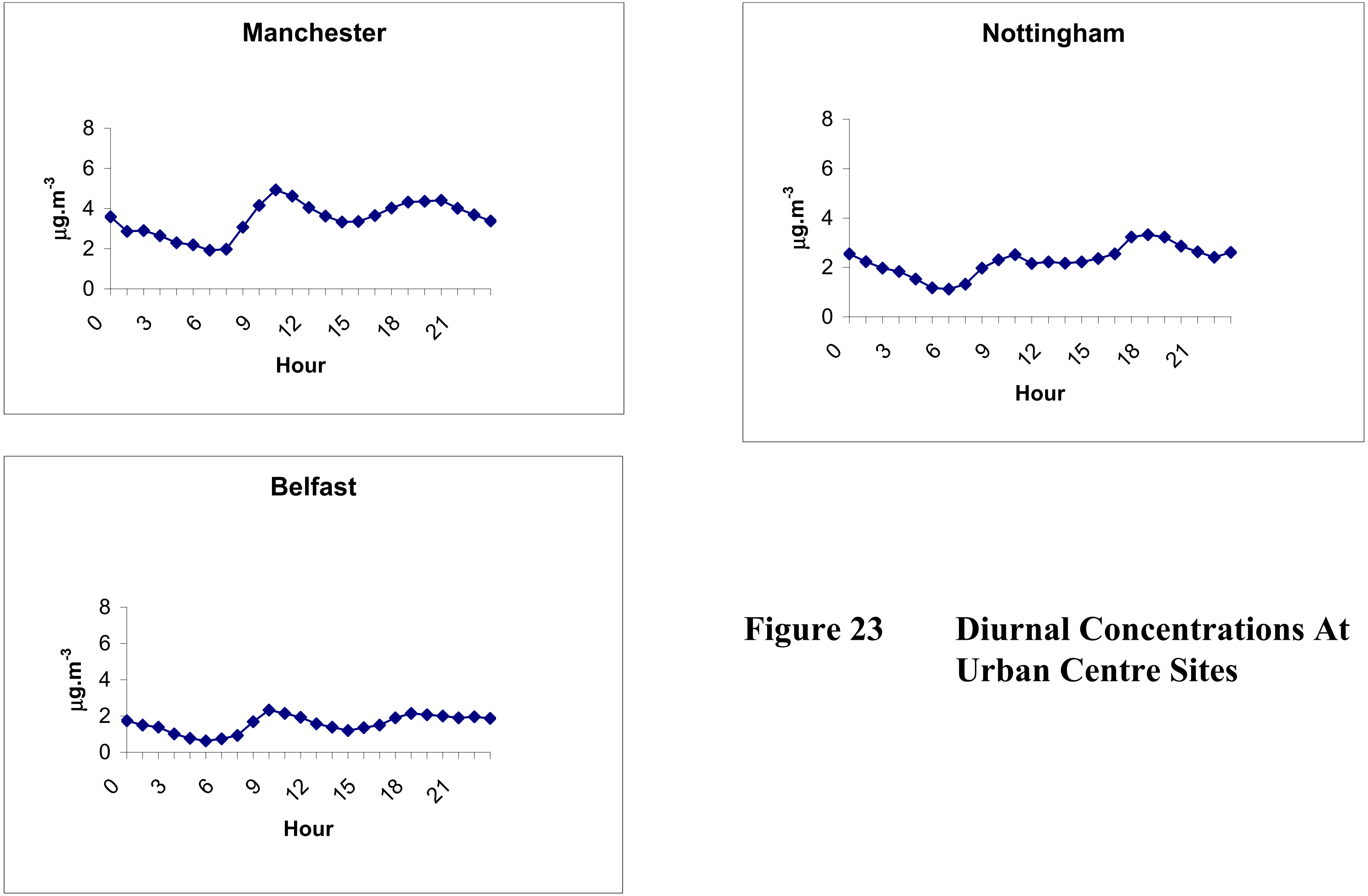
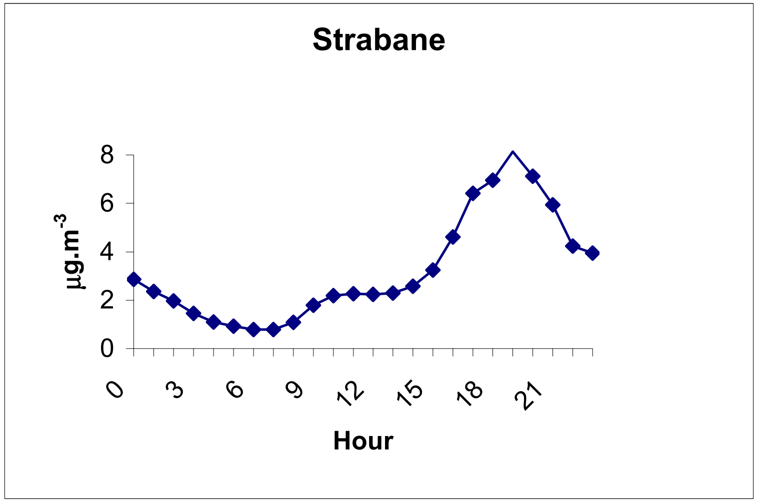
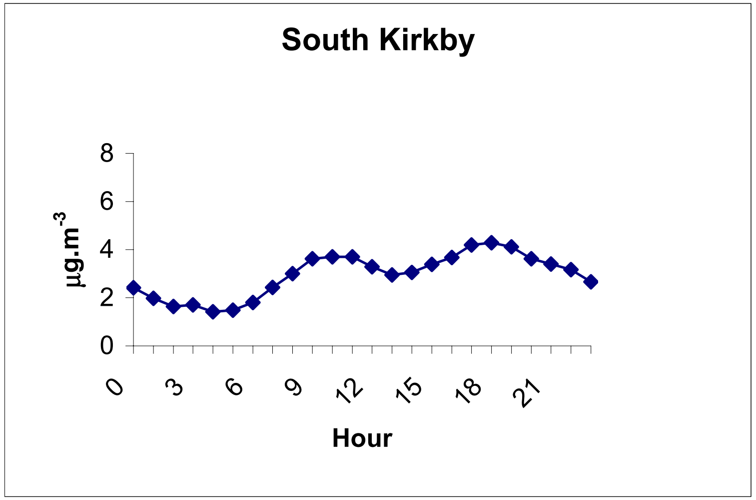
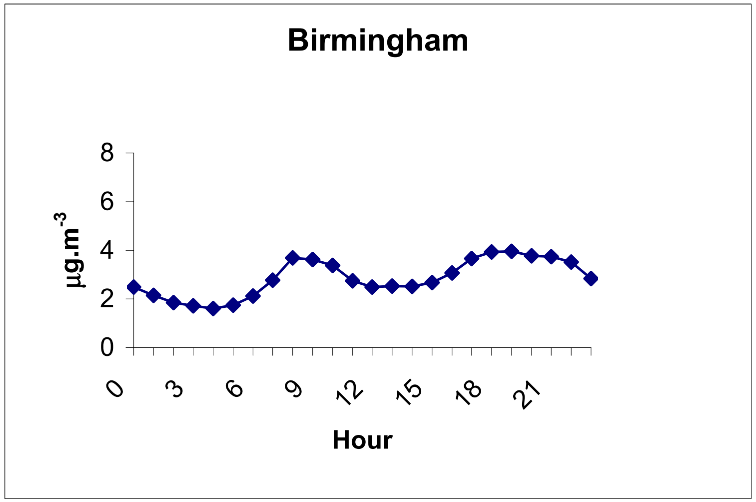
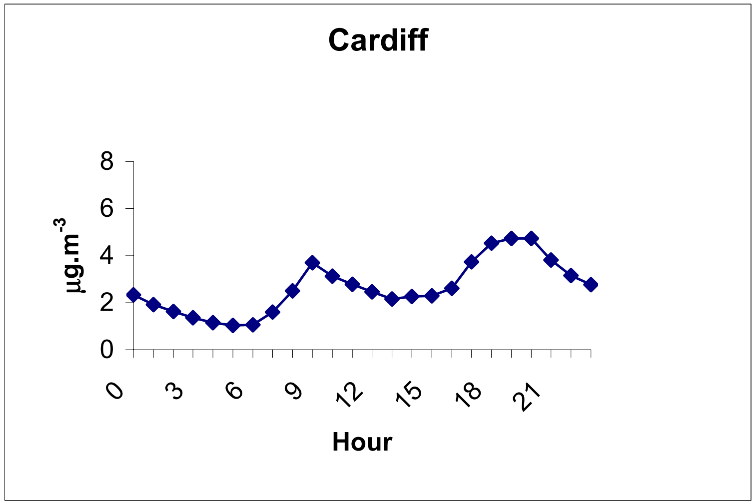


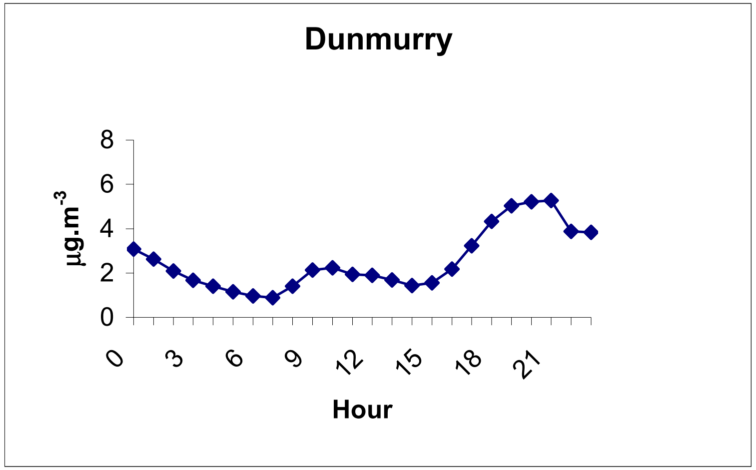
Figure 23 Diurnal Concentrations At Urban Centre Sites

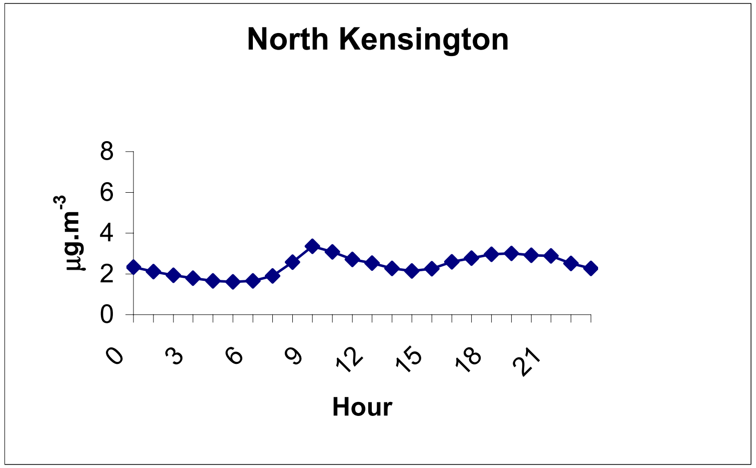

Strabane
μg.m-3
8
6
4
2
0
0
3
6
9
12
15
18
21
Hour

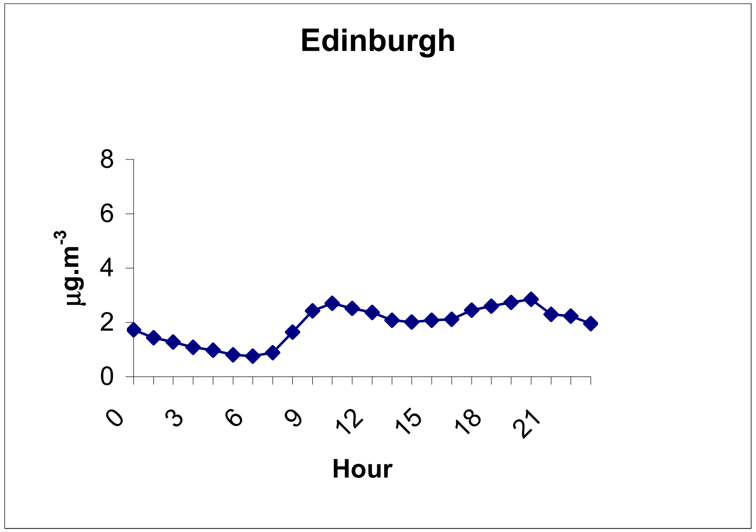

South Kirkby
μg.m-3
8
6
4
2
0
0
3
6
9
12
15
18
21
Hour

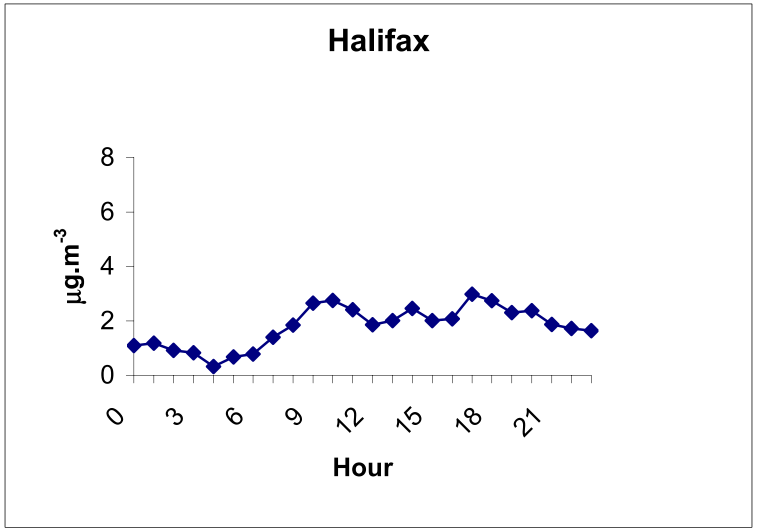

Birmingham
μg.m-3
8
6
4
2
0
0
3
6
9
12
15
18
21
Hour

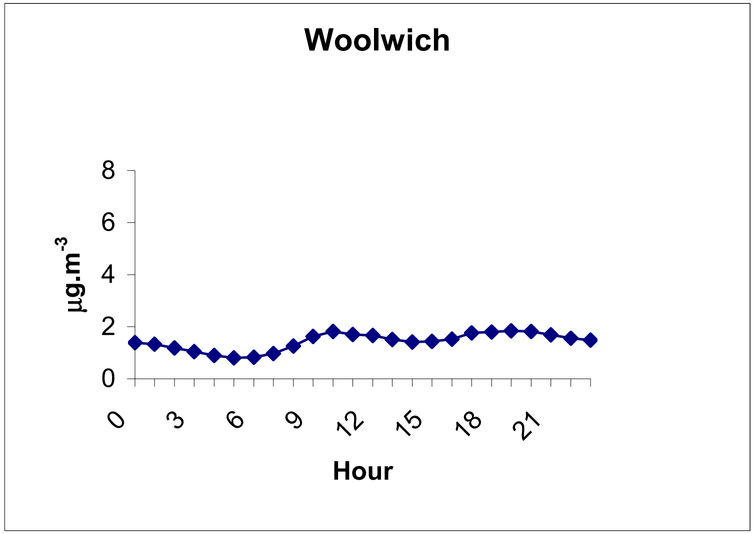

Cardiff
μg.m-3
8
6
4
2
0
0
3
6
9
12
15
18
21
Hour


Dunmurry
μg.m-3
0
2
4
6
8
0 3 6 9 12 15 18 21
Hour


North Kensington
μg.m-3
0
2
4
6
8
0 3 6 9 12 15 18 21
Hour


Edinburgh
μg.m-3
0
2
4
6
8
0 3 6 9 12 15 18 21
Hour


Halifax
μg.m-3
0
2
4
6
8
0 3 6 9 12 15 18 21
Hour



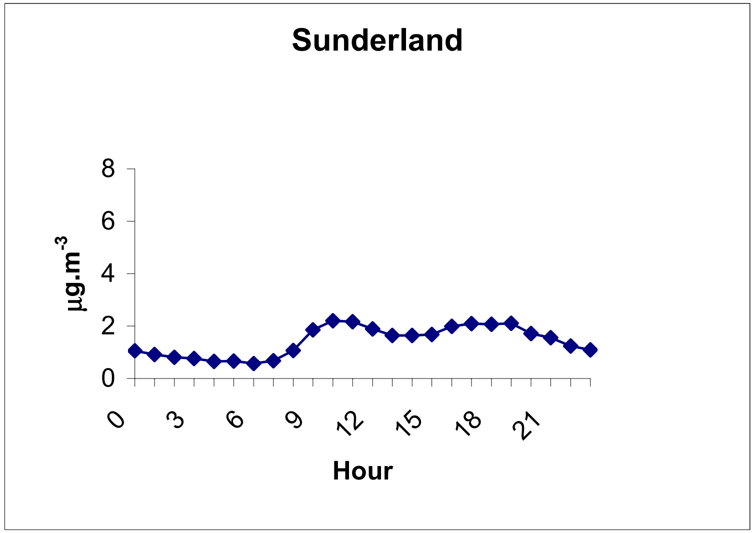


Figure 24 Diurnal Concentrations At Urban Background Sites

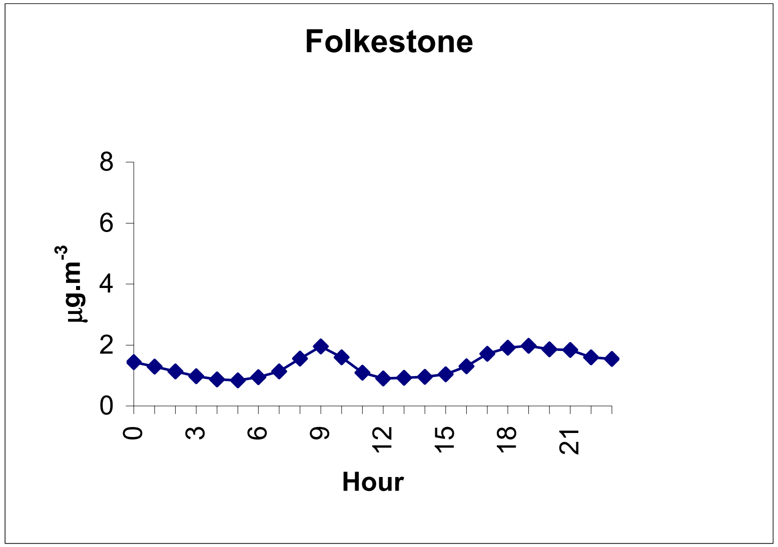


Figure 25 Diurnal Concentrations At Suburban Site

5.2.4 Comparisons With Other Pollutants

To assess the relationship between Black Carbon measurements and other pollutant concentrations, linear regressions were calculated between Black Carbon data and data for PM_{10}, total NO_x (expressed as NO_2) and particle number concentrations. The results can be seen in Tables 21 to 24.

Black Carbon = Particulate Site * M + C

Black Smoke Site	Particulate Site	Instrument	Size Fraction, PM	Instrument Annual Mean, $\mu g.m^{-3}$	M	C	R^2
Marylebone Road	Marylebone Road	FDMS TEOM	2.5	17.3	1.01	-3.89	0.73
Dunmurry 3	Dunmurry 3	FDMS TEOM	2.5	17.4	0.20	-0.83	0.72
Belfast Centre	Belfast Centre	FDMS TEOM	2.5	12.7	0.13	-0.05	0.68
Glasgow Centre	Glasgow Centre	FDMS TEOM	2.5	16.5	0.15	1.05	0.56
Nottingham Centre	Nottingham Centre	FDMS TEOM	10	17.8	0.13	0.11	0.49
Manchester Piccadilly	Manchester Piccadilly	FDMS TEOM	10	18.6	0.15	0.64	0.46
North Kensington	North Kensington	FDMS TEOM	10	21.4	0.12	-0.10	0.44
South Kirkby 1	South Kirkby 1	TEOM - VCM	10	17.1	0.21	0.09	0.42
Stoke on Trent	Stoke on Trent	FDMS TEOM	2.5	16.0	0.18	0.56	0.42
Strabane 2	Strabane 2	BAM MetOne	10	22.1	0.14	0.17	0.37
Cardiff 12	Cardiff Centre	FDMS TEOM	2.5	14.4	0.21	0.01	0.37
Woolwich 9	Bexley	FDMS TEOM	2.5	14.0	0.08	0.35	0.36
Halifax 17	Leeds Centre	FDMS TEOM	10	21.0	0.11	-0.29	0.31
Birmingham Tyburn	Birmingham Tyburn	FDMS TEOM	2.5	14.1	0.13	0.99	0.23
Folkestone	Folkestone	TEOM	10	13.2	0.11	-0.02	0.21
Edinburgh St Leonard's	Edinburgh St Leonard's	FDMS TEOM	2.5	12.1	0.05	1.36	0.12
Sunderland 8	Sunderland Silksworth	FDMS TEOM	2.5	11.4	0.04	0.91	0.08

Table 21 Relationship Between Black Carbon and PM Concentrations in order of decreasing correlation

Black Carbon = NO_x site * M + C

Black Smoke Site	NO_x Site	Instrument Annual Mean, µg.m^{-3}	M	C	R^2
Folkestone	Folkestone	38.3	0.03	0.37	0.88
North Kensington	North Kensington	72.5	0.03	0.46	0.86
Stoke on Trent	Stoke on Trent	89.5	0.04	0.27	0.84
Birmingham Tyburn	Birmingham Tyburn	77.3	0.03	0.59	0.84
Marylebone Road	Marylebone Road	298.2	0.04	1.13	0.84
Manchester Piccadilly	Manchester Piccadilly	128.5	0.02	0.48	0.81
South Kirkby 1	South Kirkby 1	82.4	0.03	0.35	0.81
Nottingham Centre	Nottingham Centre	83.3	0.03	0.15	0.80
Edinburgh St Leonard's	Edinburgh St Leonard's	53.4	0.03	0.30	0.77
Belfast Centre	Belfast Centre	78.3	0.02	0.25	0.71
Glasgow Centre	Glasgow Centre	132.2	0.03	0.63	0.68
Cardiff 12	Cardiff Centre	70.5	0.04	0.04	0.62
Sunderland 8	Sunderland Silksworth	30.8	0.05	0.04	0.61
Halifax 17	Leeds Centre	79.8	0.02	0.22	0.41
Woolwich 9	Bexley	130.4	0.01	0.69	0.34

Table 22 Relationship between Black Carbon and total oxides of nitrogen concentrations in order of decreasing correlation

Black carbon = Particulate Number Site * M + C

Black Carbon Site	Particle Number Site	Particle Number Mean Particles.cm^{-3}	M	C	R^2
Marylebone Road	Marylebone Road	31524	0.0004	0.11	0.91
North Kensington	North Kensington	19441	0.0002	- 0.52	0.61

Table 23 Relationship between Black Carbon and particle number concentrations

Black carbon = Elemental Carbon * M + C

Black Carbon Site	Elemental Carbon Site	Elemental Carbon µg.m^{-3}	M	C	R^2
Marylebone Road	Marylebone Road	7.6	1.035	3.66	0.65
North Kensington	North Kensington	1.8	0.29	1.94	0.07

Table 24 Relationship between Black Carbon and elemental carbon concentrations

It can be seen that in general the best correlation is between Black Carbon concentration and total NO_x. Some comparative time series plots are given in Figures 26 and 27.

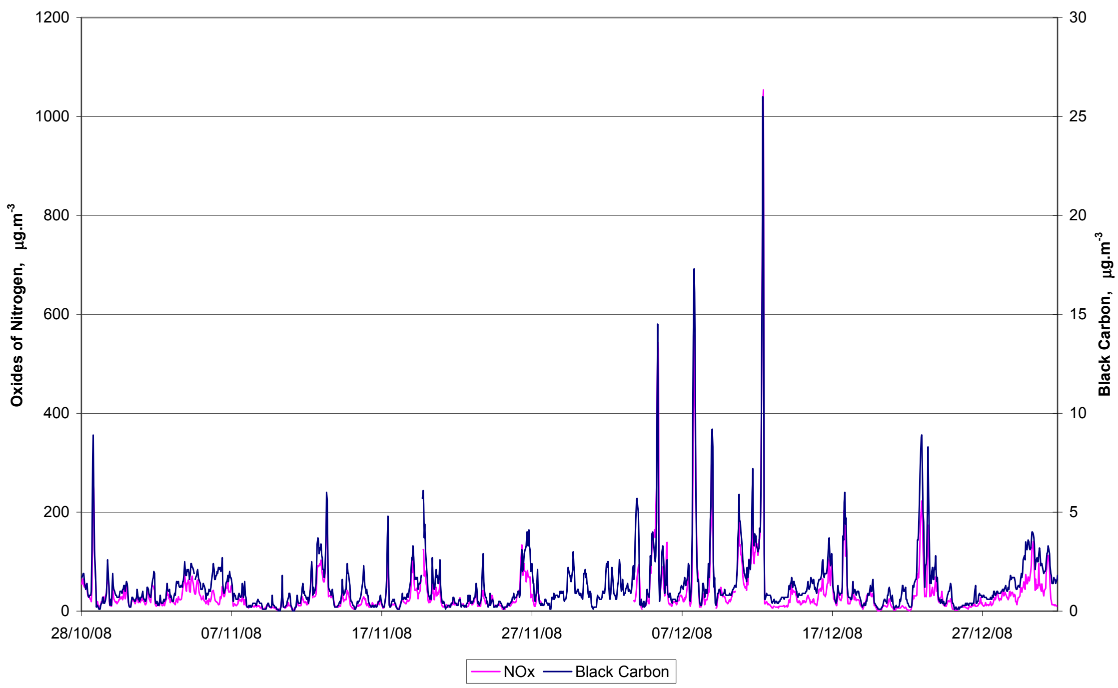


Figure 26 **Black Carbon and NO_x concentrations measured at Nottingham**

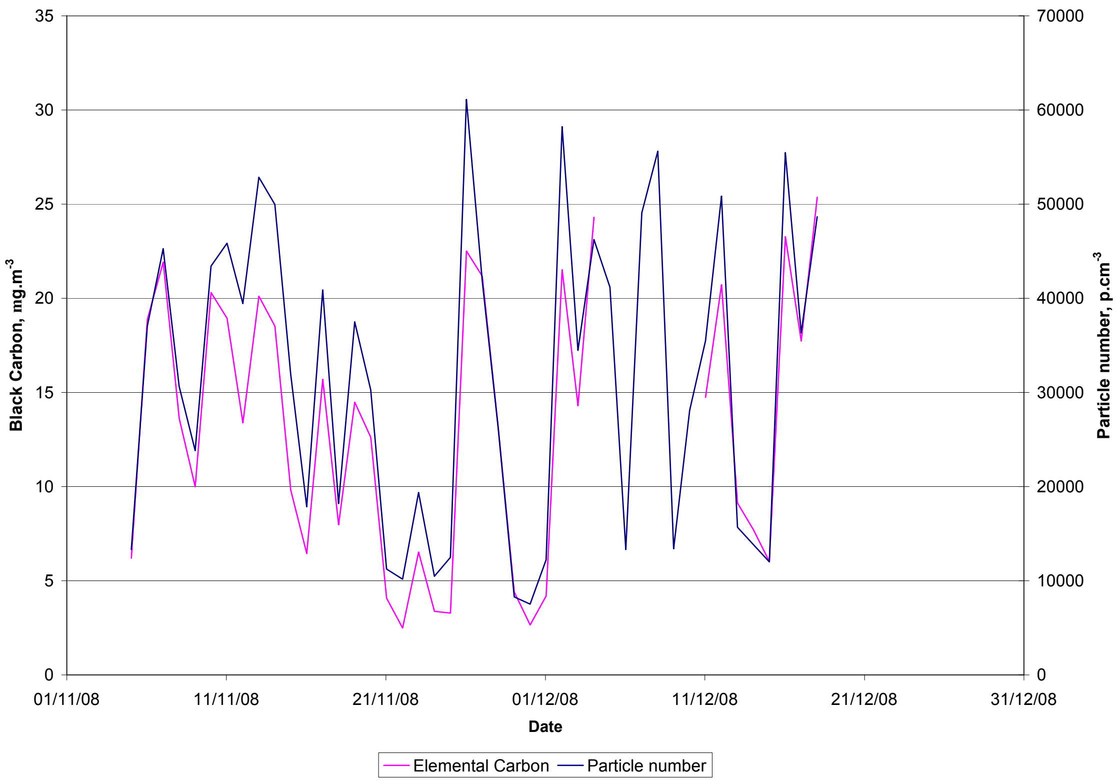


Figure 27 **Black Carbon and particle number concentrations measured at Marylebone Road in 2008**

5.3 UV Component of Black Carbon

All of the aethalometer (UV Component) data in this report is VALIDATED ONLY as ratified data will not be available until the parallel running trial with black smoke measurements has been completed. QA/QC procedures for the black carbon data are currently being developed.

5.3.1 Time Series

The following charts show the UV Component concentrations measured by the UK Black Smoke Network for 2008. The time resolution of the measurements is hourly. Data has been split into regions of the UK for presentation purposes.

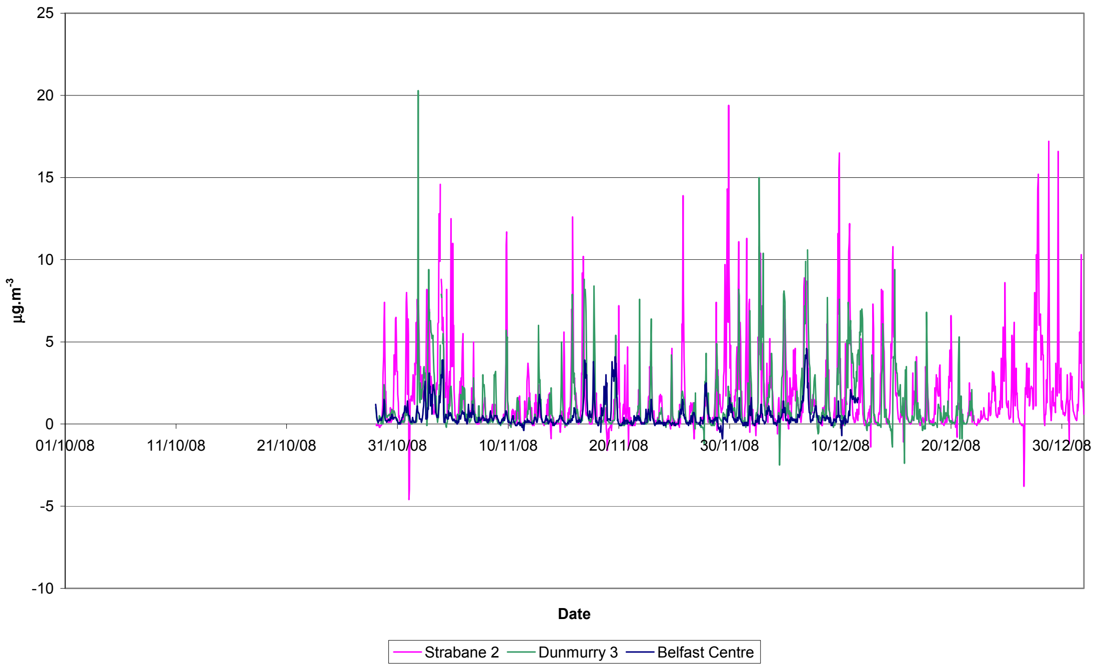
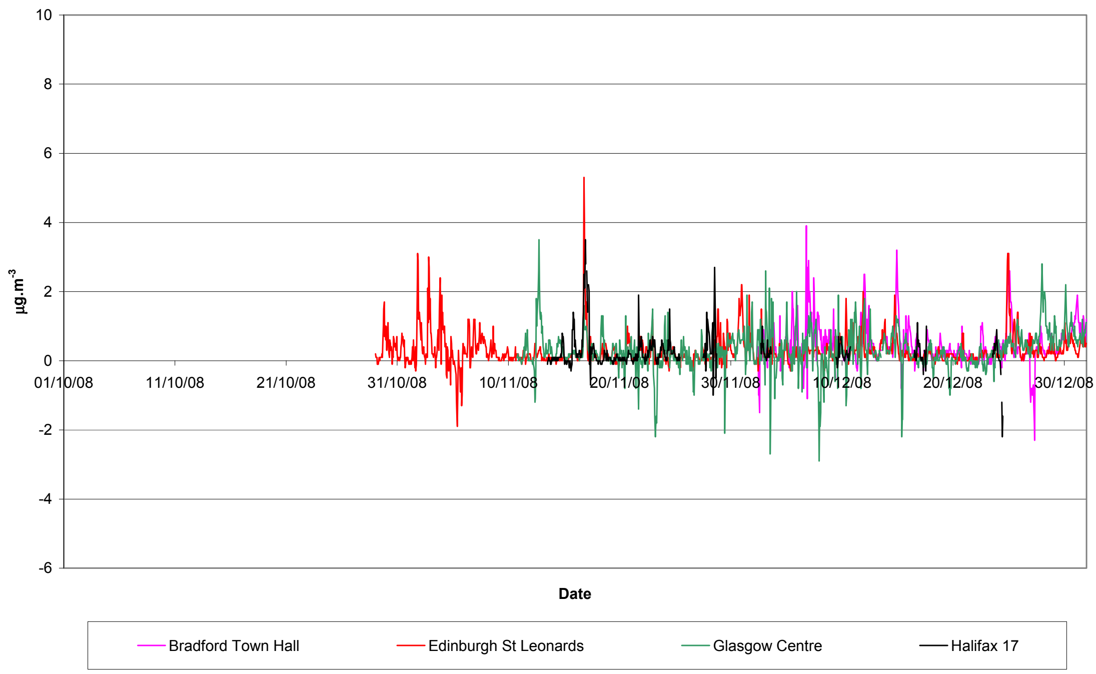


Figure 28 UV Component concentrations during 2008 in Northern Ireland



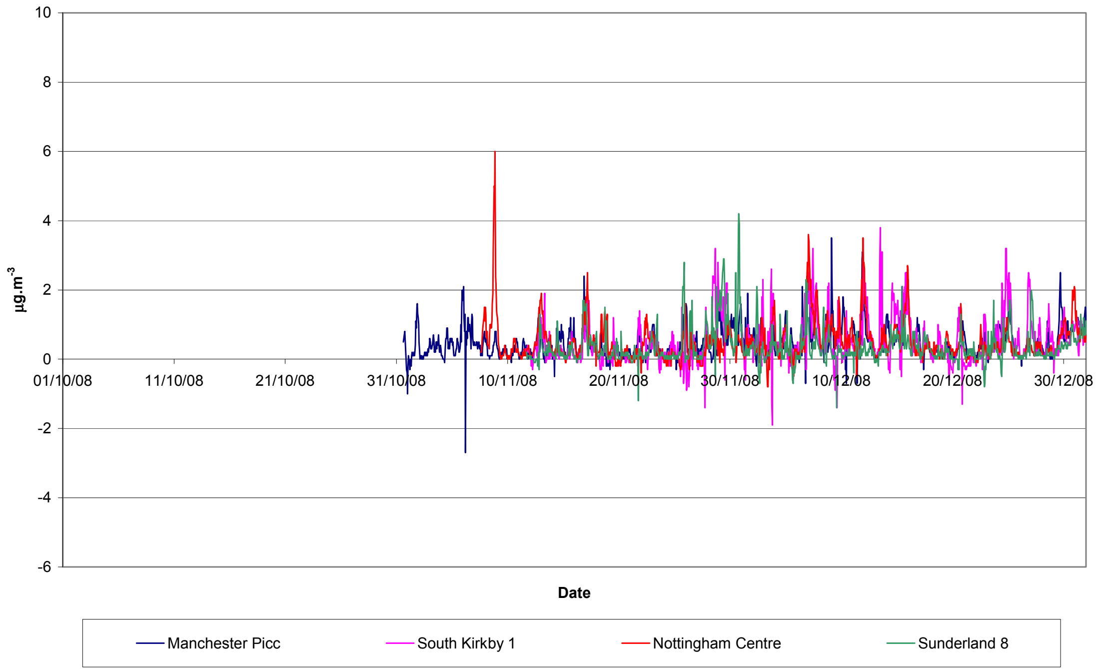
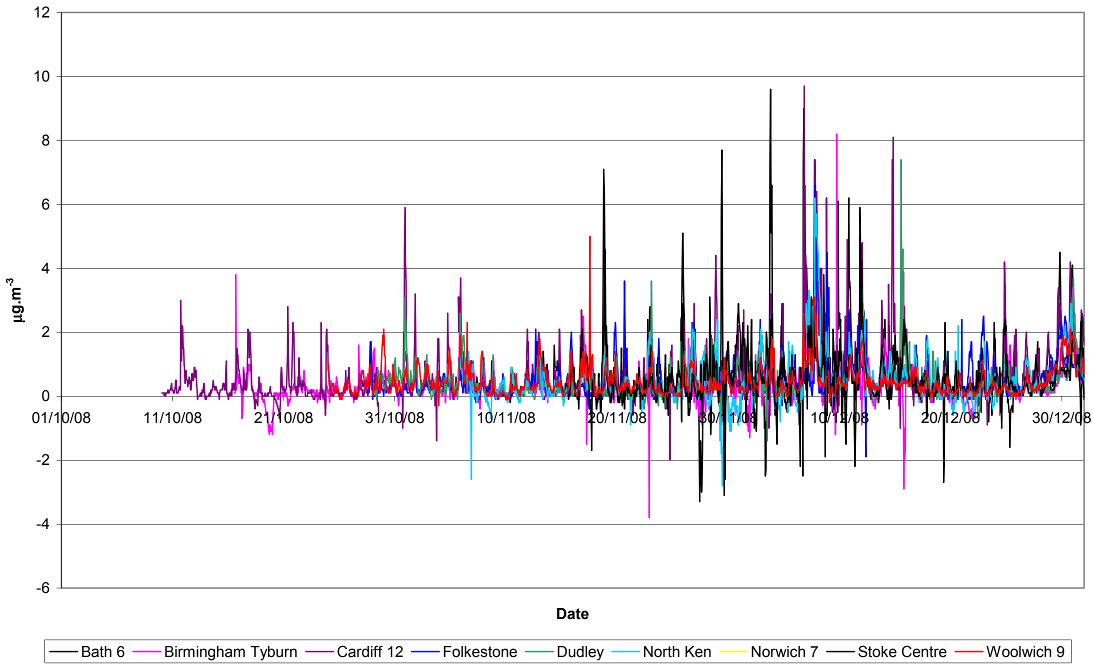


Figure 29 + 30 **UV Component concentrations during 2008 in Scotland and Northern England**



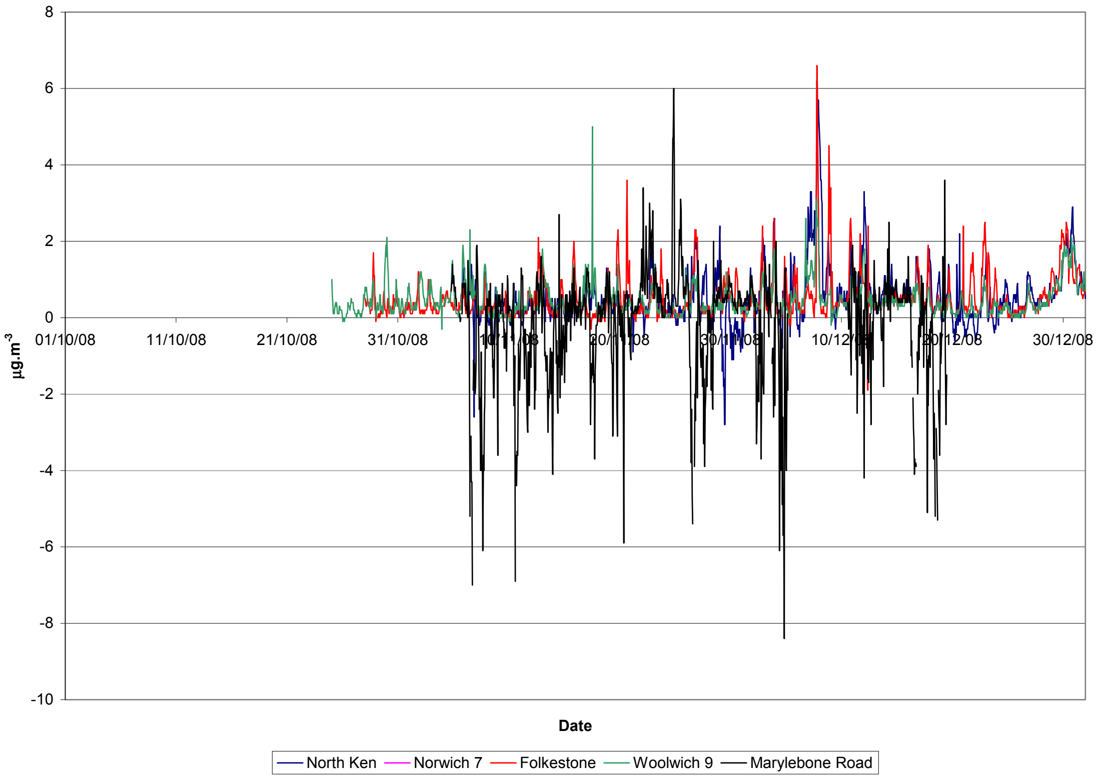


Figure 31 + 32 **UV Component concentrations during 2008 in Southern England and Wales**

5.3.2 Averages

Table 25 gives the period averages for each site for 2008.

Site	UV Component Concentration, $\mu g.m^{-3}$
Bath 6	0.63
Belfast Centre	0.50
Birmingham Tyburn	0.35
Bradford Town Hall	0.47
Cardiff 12	0.59
Dunmurry 3	1.18
Edinburgh St Leonard's	0.30
Folkestone	0.51
Glasgow Centre	0.30
Dudley Central	0.46
Halifax 17	0.26
Manchester Picc	0.48
Marylebone Road	-0.21
North Ken	0.54
Nottingham Centre	0.50
South Kirkby 1	0.50
Stoke Centre	0.61
Strabane 2	1.71
Sunderland 8	0.36
Woolwich 9	0.45

Averages are calculated over the period that Black Carbon measurements were made. Data capture is the same as for Black Carbon.

Note: Only 2 –3 months measurement in the winter.

Table 25 Average UV Component Concentration For 2008

The average concentrations are presented as a bar graph (Figure 33) to aid the intercomparison of sites:

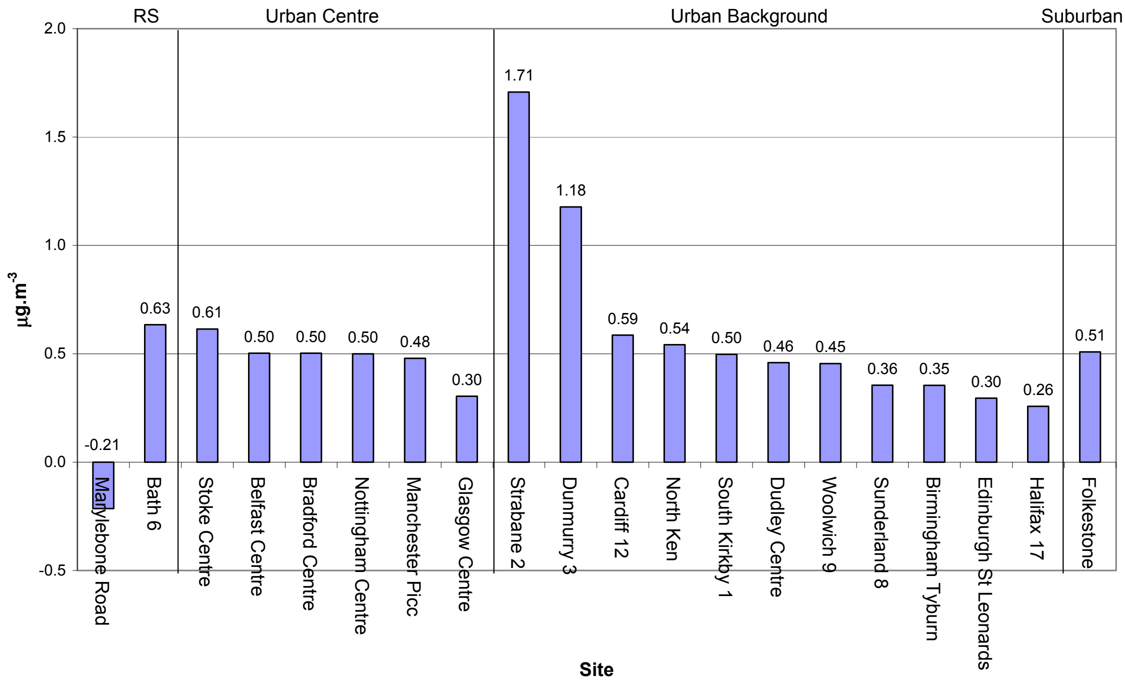


Figure 33 Average Black Carbon Concentrations For 2008.

5.3.3 Hourly Periodicity

Due to the short period of time that the aethalometers were running during 2008, diurnal but not weekly periodicity analysis has been carried out.

Plots of the average concentrations on each hour of the day for Roadside, Urban Centre, Urban Background and Suburban site classifications respectively can be seen in figures 34 to 37.

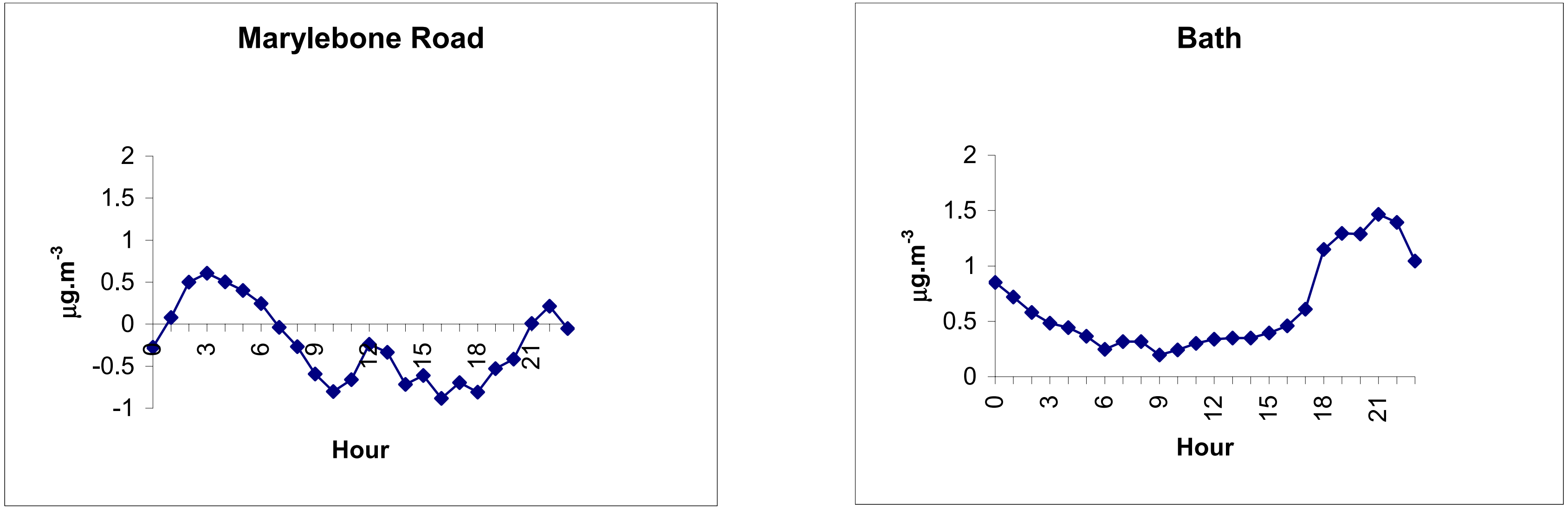
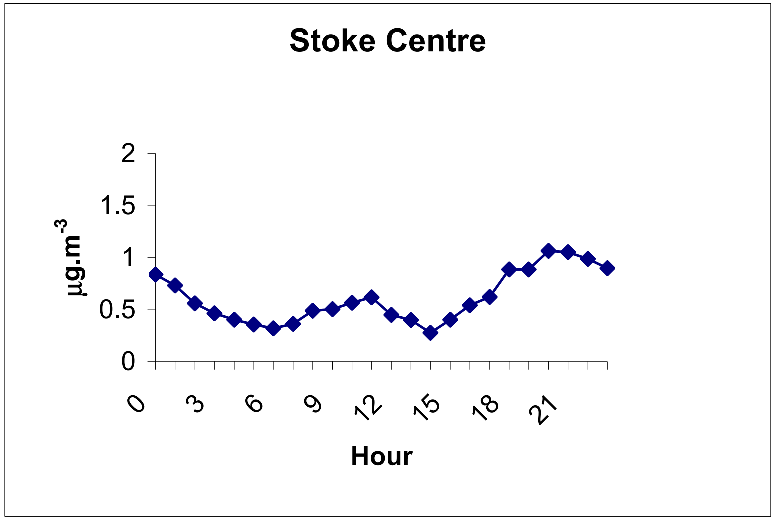
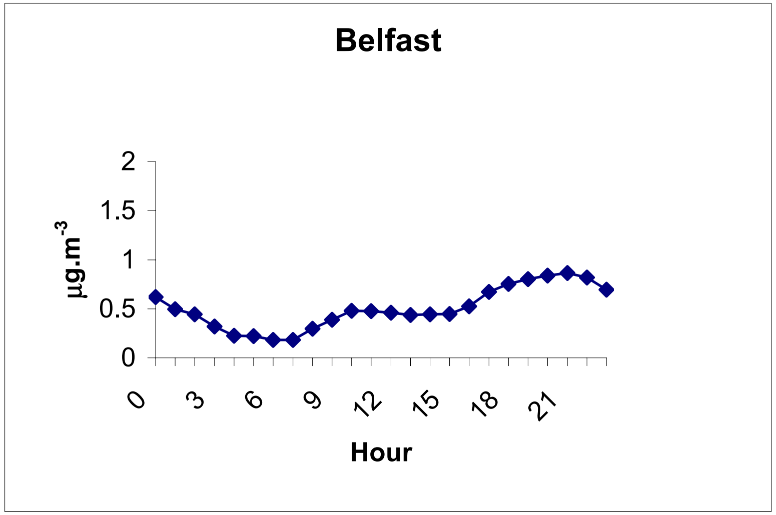
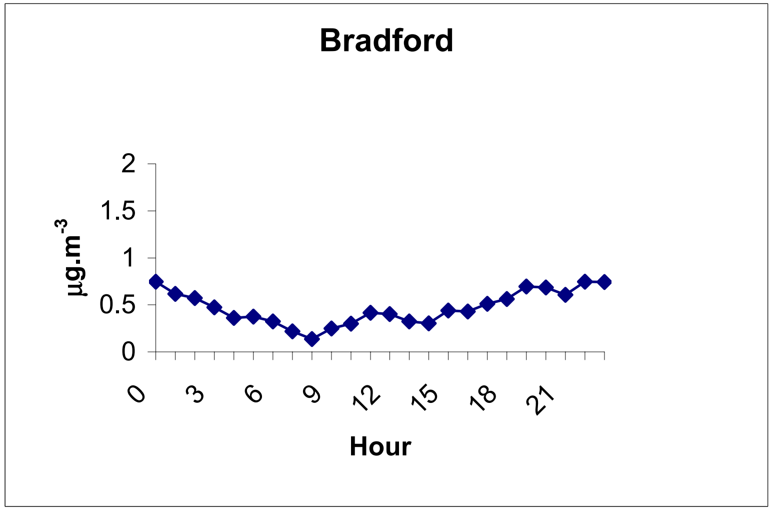
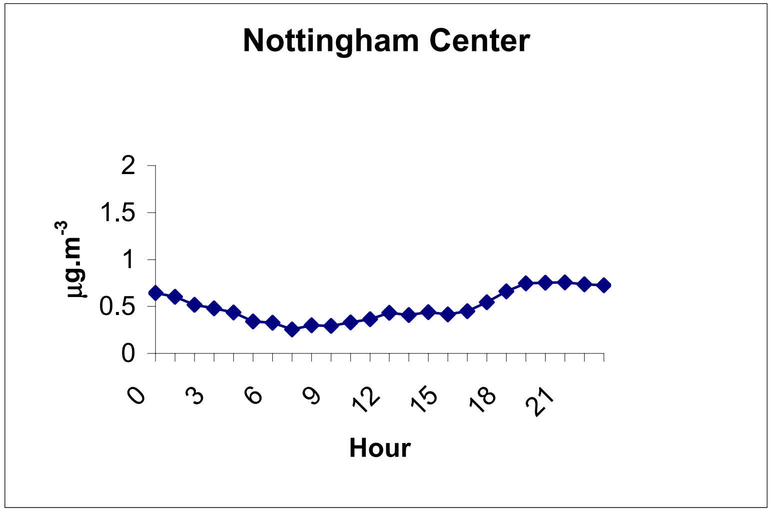


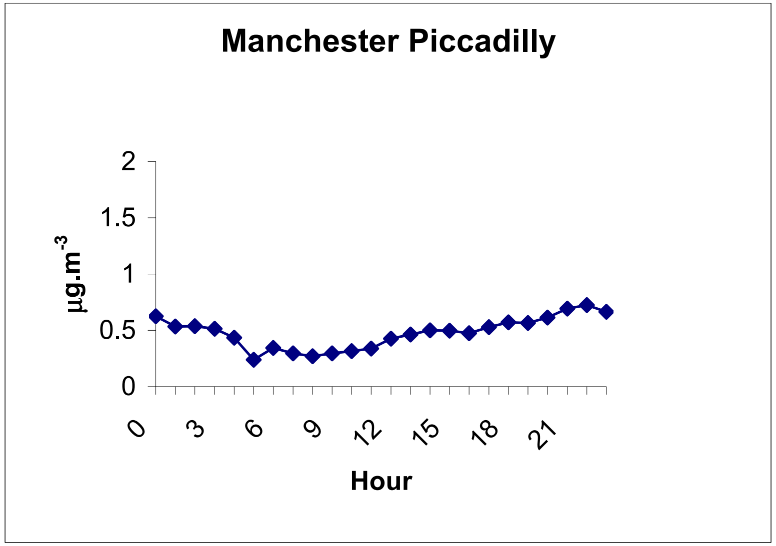
Figure 34 Diurnal UV Component Concentrations At Roadside Sites


Stoke Centre
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour


Belfast
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour


Bradford
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour


Nottingham Center
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour



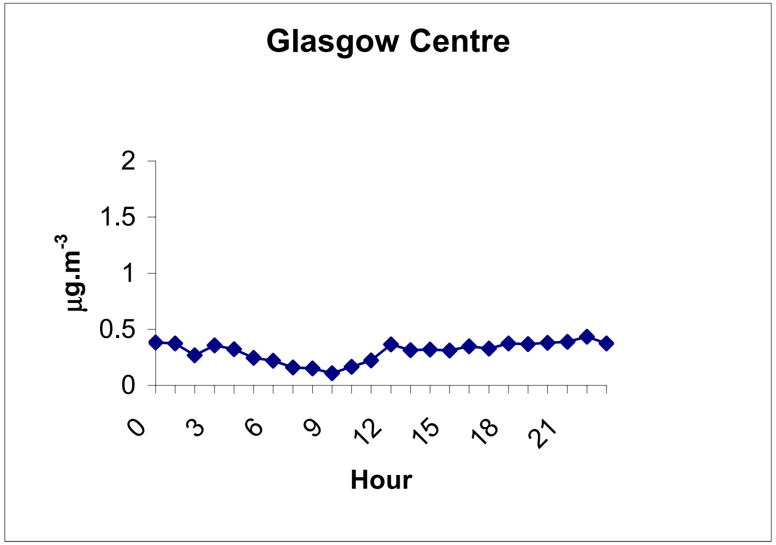
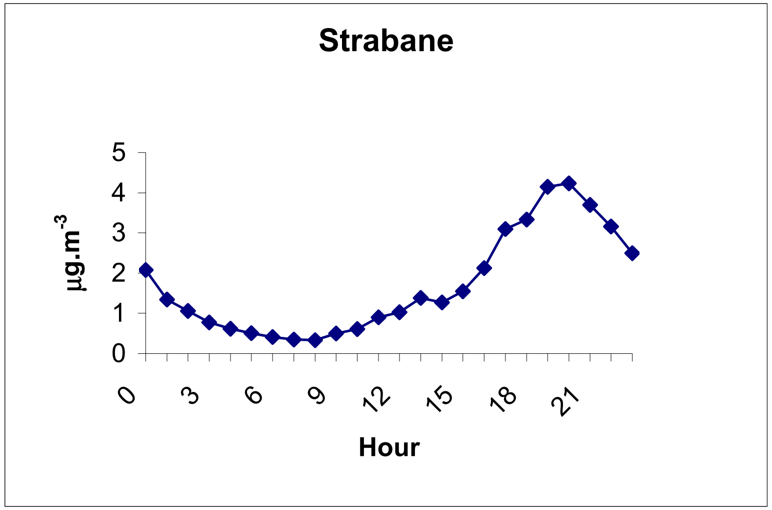
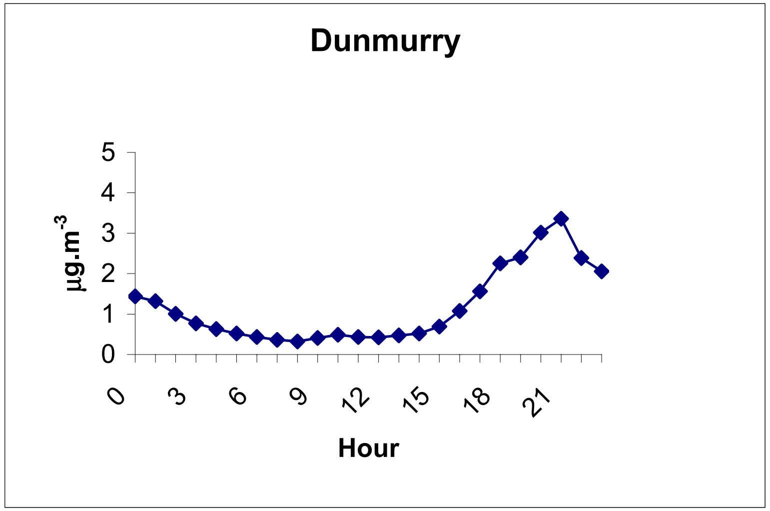
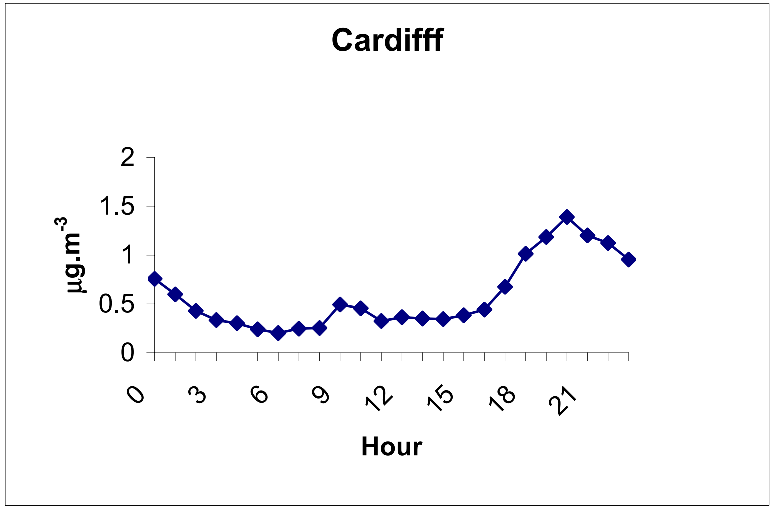
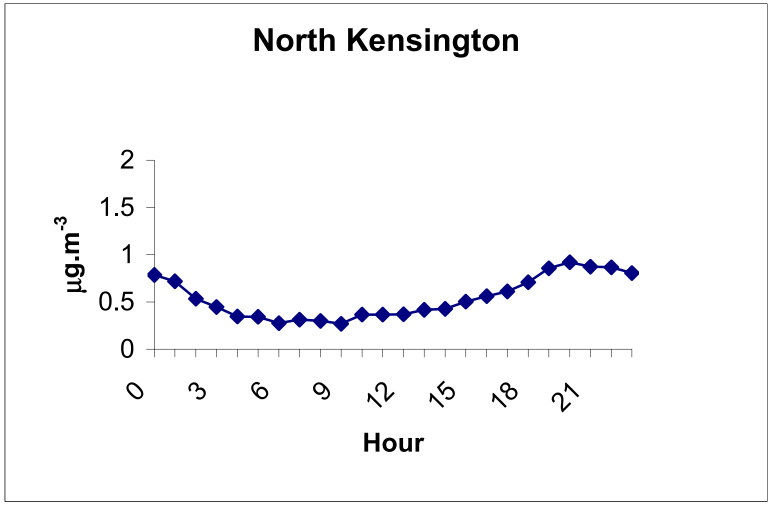


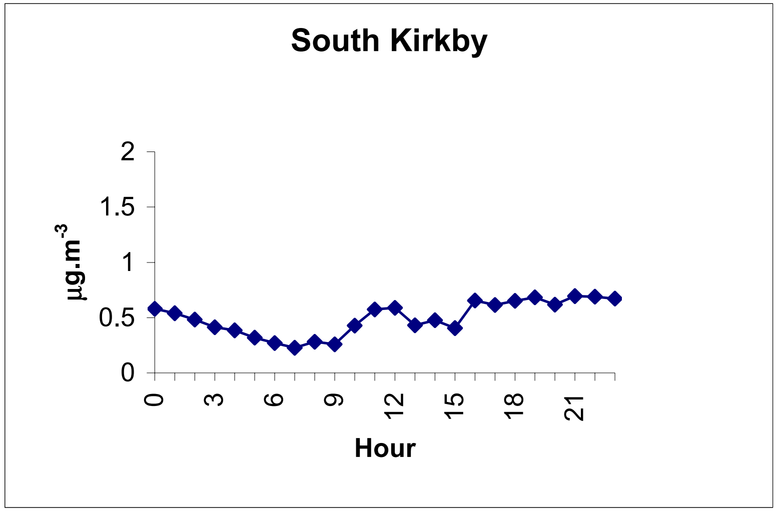
Figure 35 Diurnal UV Component Concentrations At Urban Centre Sites

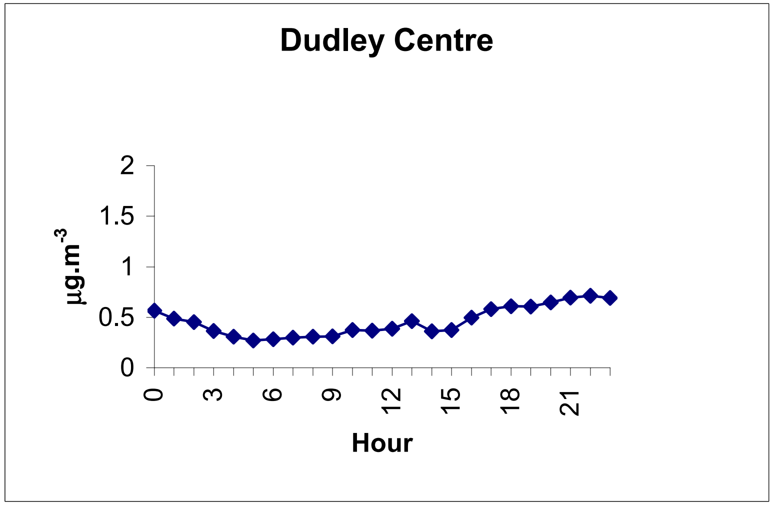

Strabane
µg.m-3
0
1
2
3
4
5
0
3
6
9
12
15
18
21
Hour

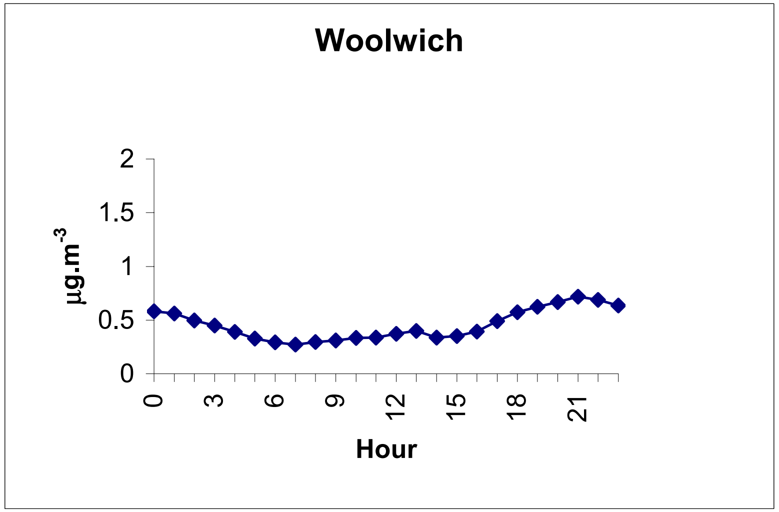

Dunmurry
µg.m-3
0
1
2
3
4
5
0
3
6
9
12
15
18
21
Hour

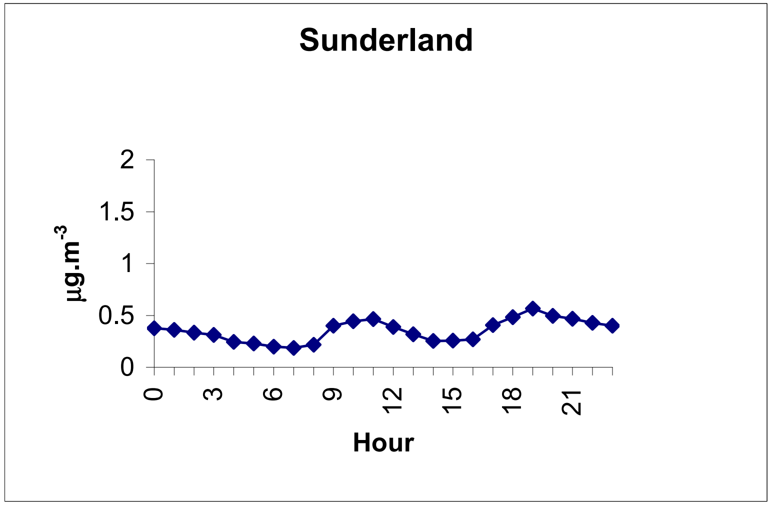

Cardifff
µg.m-3
0
0.5
1
1.5
2
0
3
6
9
12
15
18
21
Hour

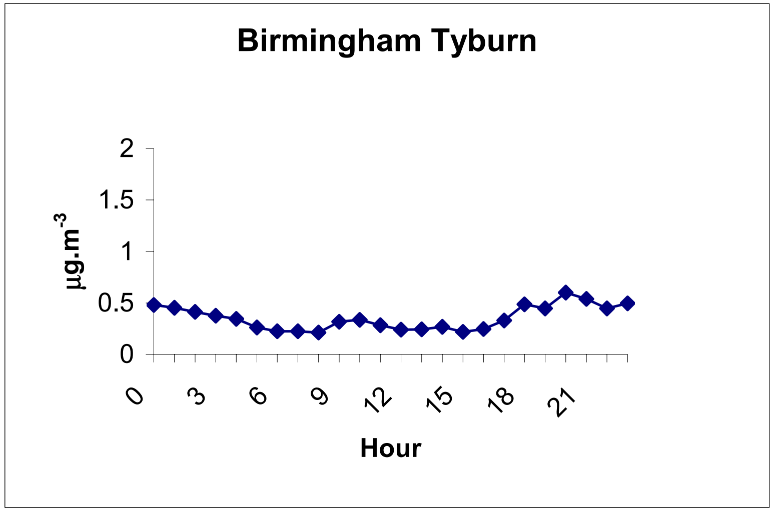

North Kensington
µg.m-3
0
0.5
1
1.5
2
0
3
6
9
12
15
18
21
Hour

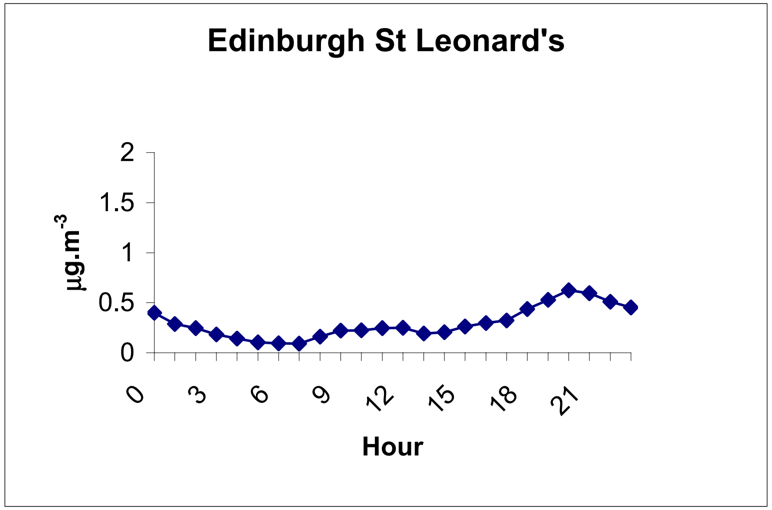

South Kirkby
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour


Dudley Centre
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour


Woolwich
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour


Sunderland
µg.m-3
2
1.5
1
0.5
0
0
3
6
9
12
15
18
21
Hour





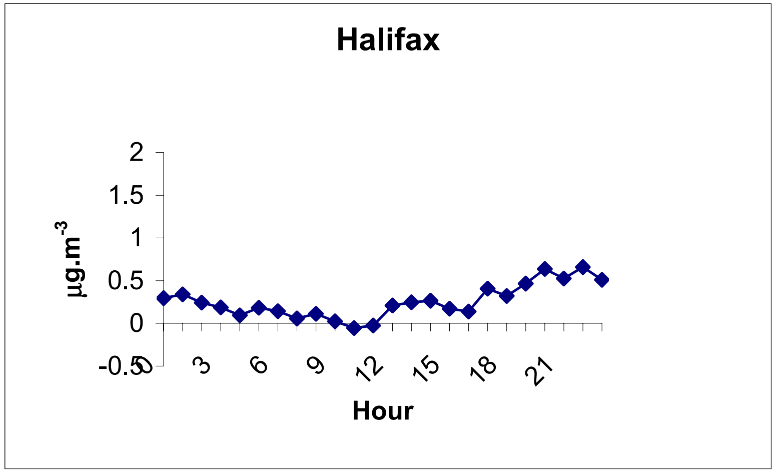


Figure 36 **Diurnal UV Component Concentrations At Urban Background Sites**

Halifax concentrations may be compromised by low data capture

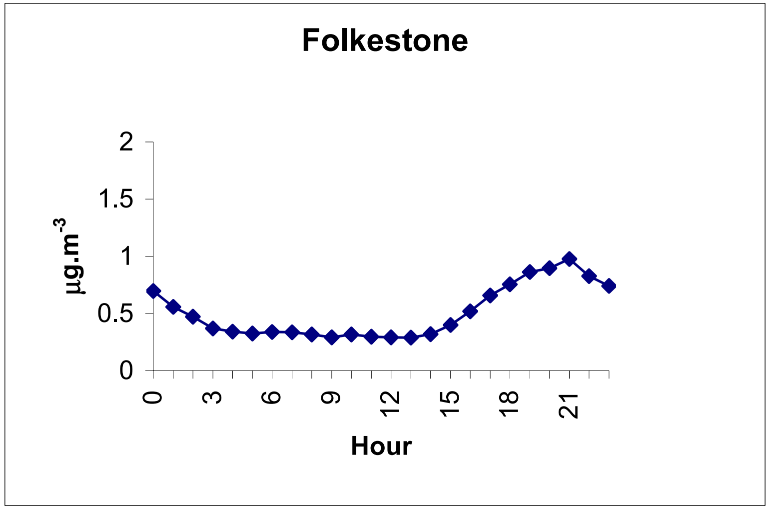


Figure 37 Diurnal UV Component concentrations At Suburban site

Disregarding the Strabane and Dunmurry sites, where the UV component follows the BC hourly trend, the UV component concentrations measured at urban centre, urban background and suburban locations is broadly similar. Marylebone Road gave an average negative UV component concentration, with some periods of negative concentration and significant negative spikes, while Bath gave concentrations similar to those at other site classifications, but with a few negative spikes like Marylebone Road. Stoke Centre, which is classified as an urban centre location, is close to a road and this site also showed similar negative spiking to other roadside locations.

5.4 Comparison Between Black Smoke and Black Carbon Measurements

Black smoke measurements were continued at the following sites when the aethalometer was installed: Edinburgh St Leonard's, Halifax, Birmingham Tyburn, North Kensington and Marylebone Road. The local council at the South Kirkby site also continued the Black Smoke measurements, but without the Network QA/QC controls being performed by NPL.

A full report on the intercomparison will be written at the end of the 6-month parallel running study. There is insufficient data collected in 2008 to provide any meaningful results for this comparison as some of the sites were only installed at the end of 2008.

6.0 Academic Paper

As a deliverable of the Black Smoke Network, the following paper has been submitted for publication in Atmospheric Environment and is expected to be published in the 1st half of 2009:

An evaluation of measurement methods for organic, elemental and black carbon in UK ambient air monitoring sites

The abstract from the paper is given below:

The carbonaceous components of Particulate Matter samples form a substantial fraction of their total mass, but their quantification depends strongly on the instruments and methods used. Within UK monitoring networks, hourly organic carbon (OC) and elemental carbon (EC) were determined at four sites between 2003 and 2007 using Rupprecht and Pattashnik (R & P) 5400 automatic instruments. Since 2007, daily OC/EC measurements have been made by manual thermo-optical analysis of filter samples using a Sunset Laboratory Carbon Aerosol Analysis instrument. In parallel, long term daily measurements of Black Smoke, a quantity directly related to black carbon (measured by aethalometers) and indirectly related to elemental carbon, have been made at many sites. The measurement issues associated with these techniques are evaluated in the context of UK measurements, making use of several sets of parallel data, with the aim of aiding the interpretation of network results. The main conclusions are that, from the results available, the R & P 5400 instruments greatly under read EC and total carbon (TC = OC+EC) at kerbside sites, probably due to the fact that the smaller particles are not sampled by the instrument; the R & P 5400 instrument is inherently difficult to characterise, so that all quantitative results need to be treated with caution; both aethalometer and Black Smoke (converted to black carbon) measurements can show reasonable agreement with elemental carbon results; and manual thermo-optical OC/EC results using the “Quartz” protocol may under read EC (and hence over read OC), whether either transmittance or reflectance is used for the pyrolysis correction, and this effect is significant at rural sites.

7.0 Summary

The data capture for Black Smoke measurements using the 8-port sampler was 92.9% covering the period of time that measurements were made. This figure is not for the whole of 2008 for all sites, as Black Smoke measurements ceased at the majority of the sites when the aethalometer was installed. Data capture for 2008 improved on the values delivered for 2007 and 2006, where data capture was 89% and 86% respectively.

Apart from Strabane 2 and Manchester 11 there are no significant trends in this recent data, given the relatively large measurement uncertainty.

As in previous years there is reasonable agreement between sites located in similar regions of the country showing that there is a regional component to the Black Smoke concentration. The highest concentrations were measured at the roadside (Marylebone Road and Bath), followed by urban centre sites and urban background sites giving comparable measurements, with the lowest measurements being made at the Woolwich 9 site. Both the Woolwich 9 and Folkestone sites are in predominantly suburban areas. Daily averages of the measurements show that the highest concentrations are found in the beginning of the week with the weekends generally having lower values. As in previous years there is a good time series comparison between Black Smoke concentrations and oxides of nitrogen concentrations.

Aethalometers were successfully installed at 20 of the 21 sites across the network in the last quarter of the year. An aethalometer was not installed at the Norwich site as the current site is unsuitable. The aethalometer will be installed in the Norwich AURN site when the installation of this site, by Bureau Veritas, is completed.

All of the aethalometer (Black Carbon) data in this report is VALIDATED ONLY as ratified data will not be available until the parallel running trial with black smoke measurements has been completed and QA/QC procedures are fully developed and tested.

The data capture for Black Carbon measurements using the aethalometer was 91.8% covering the period of time that measurements were made.

There is reasonable agreement between sites located in similar regions of the country showing that there is a regional component to the Black Carbon concentration, however this regional component is not seen in the UV component measurement. The highest Black Carbon concentrations were measured at roadside locations (Marylebone Road and Bath), while urban centre and urban background Black Carbon concentrations were similar. The lowest Black Carbon concentration was measured at Folkestone, which is a suburban site.

Hourly averages of Black Carbon broadly show a commuter traffic based signature with the exception of Strabane and Dunmurry. Both these sites show elevated levels from 15:00hrs to 23:00hrs, which is probably due to local domestic heating. Also the UV component at these sites was significantly higher than all of the other sites. This is probably due to fuel source used in the domestic heating.

As with Black Smoke, Black Carbon concentrations show a good time series agreement with oxides of nitrogen concentrations.

References

1 A Virkkula et al, A Simple Procedure for Correcting Loading Effects of Aethalometer Data, Journal of Air and Waste Management Association, 57:1214-1222, 2007.

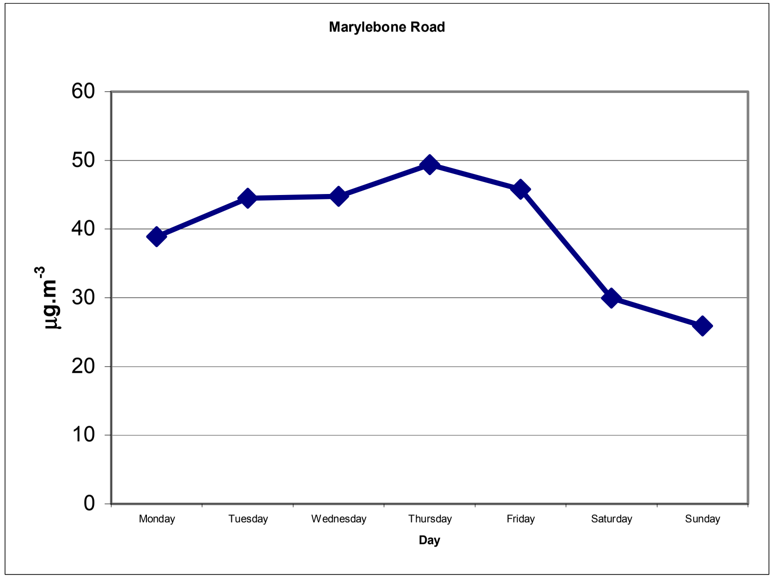
2 Local Site Operator Procedure Manual for the UK Black Smoke Network, DEFRA Black Smoke 001, Issue 1.1 December 2007.

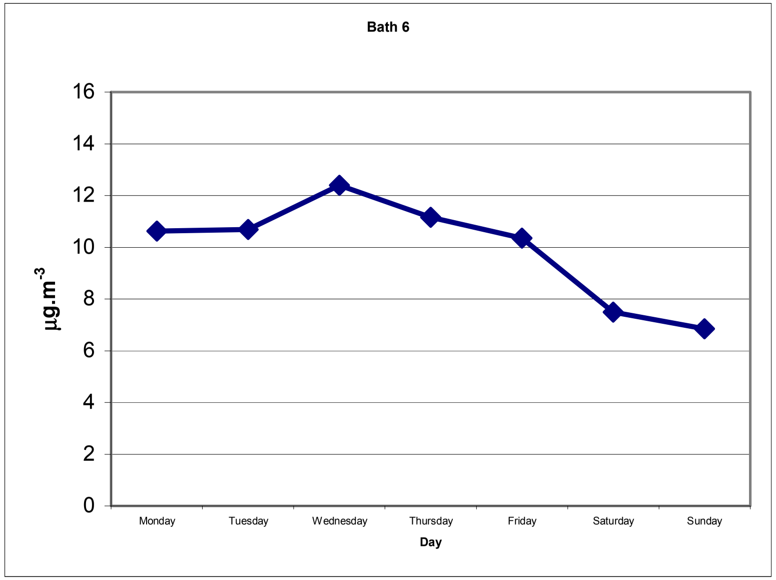
3. NPL Report AS 2, 2006 Annual Report for the UK Black Smoke Network, April 2007.

4. Paul Quincey, 2007, A relationship between Black Smoke Index and Black Carbon concentration, Atmospheric Environment 41, 7964 – 7968.

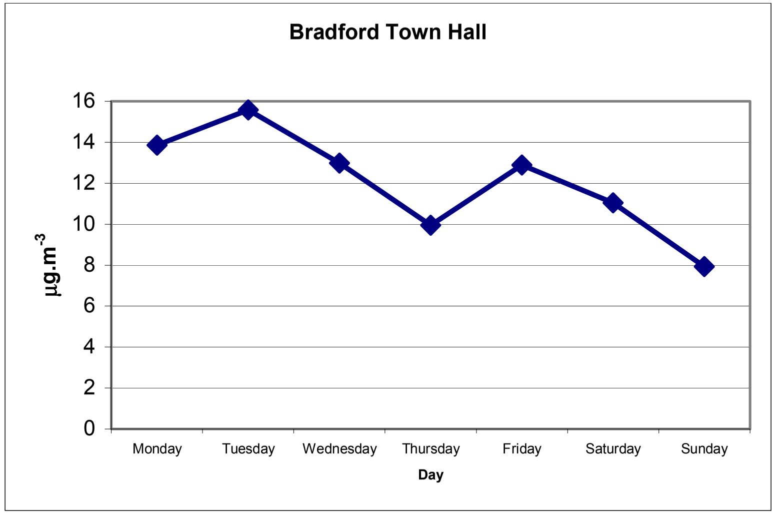
5. NPL Report AS 22, 2007 Annual Report for the UK Black Smoke Network, April 2008.

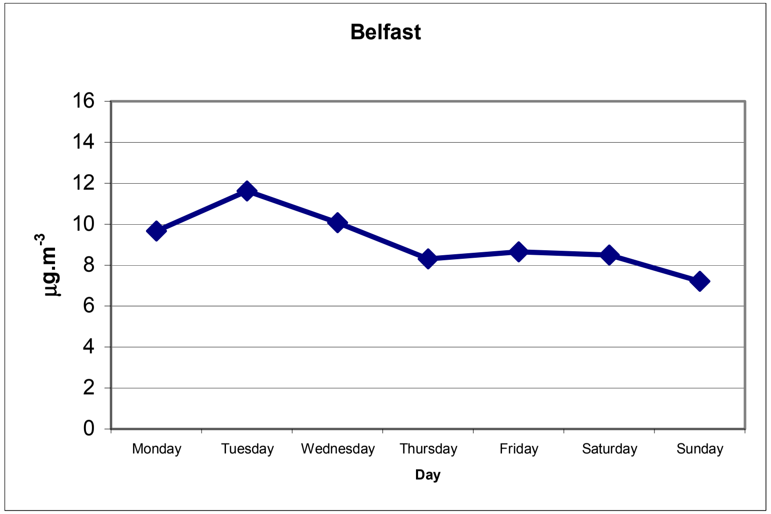
APPENDIX 1 Weekly Periodicity of Black Smoke Concentrations



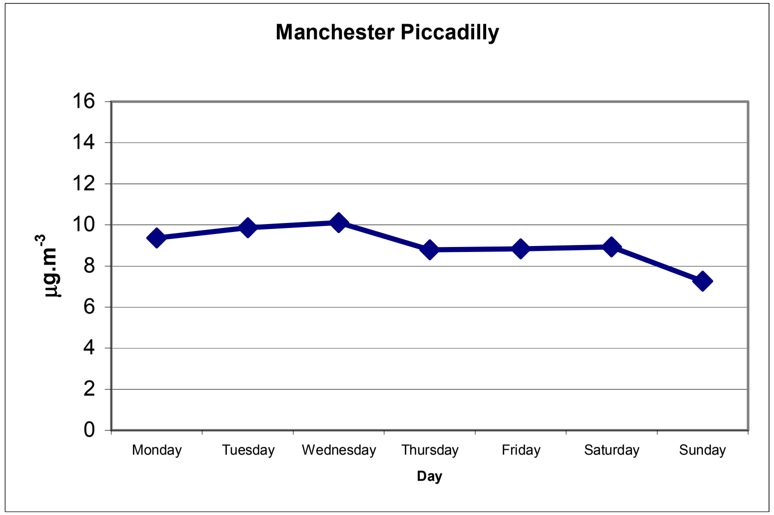


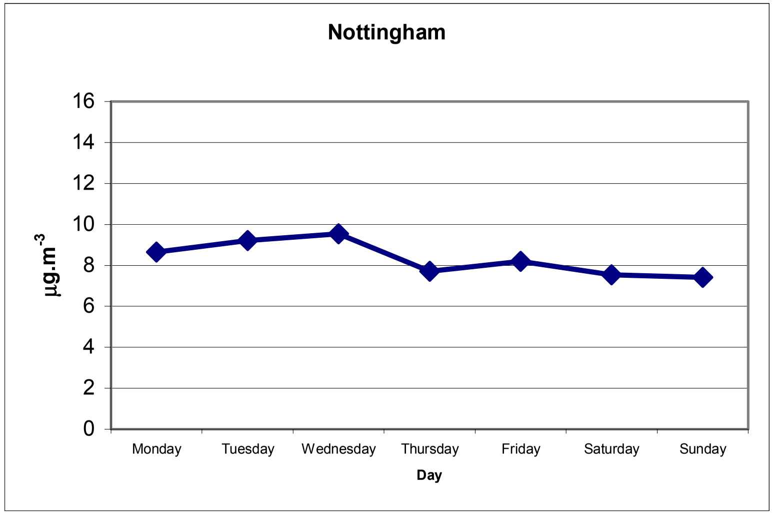
Daily Average Concentrations For Roadside Sites



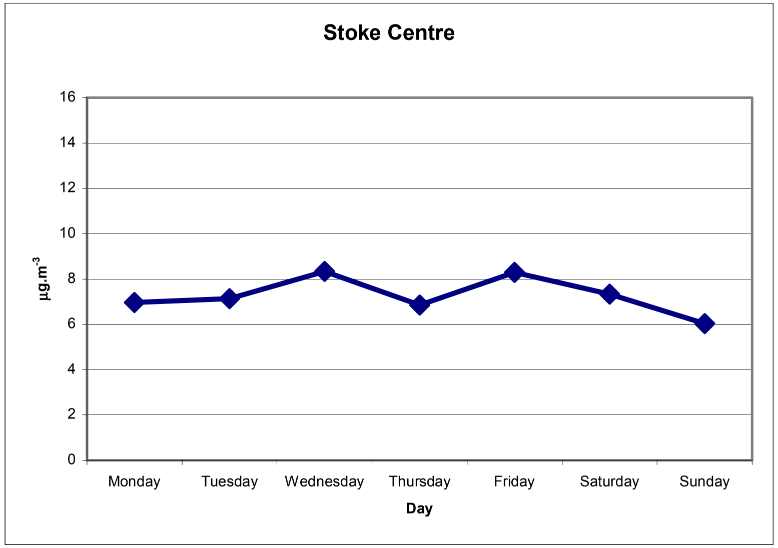


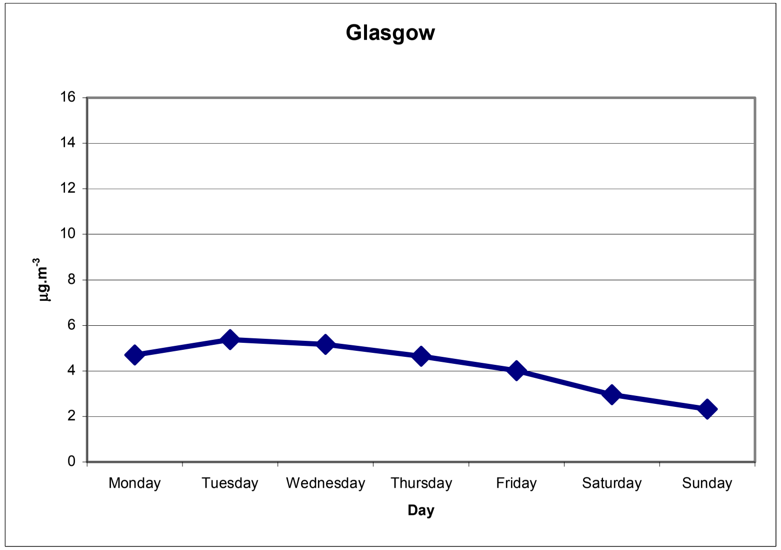
The depressed Thursday average concentration at Bradford Town Hall
may be as a result of the low data capture and not a true reflection of the average concentration on that day.



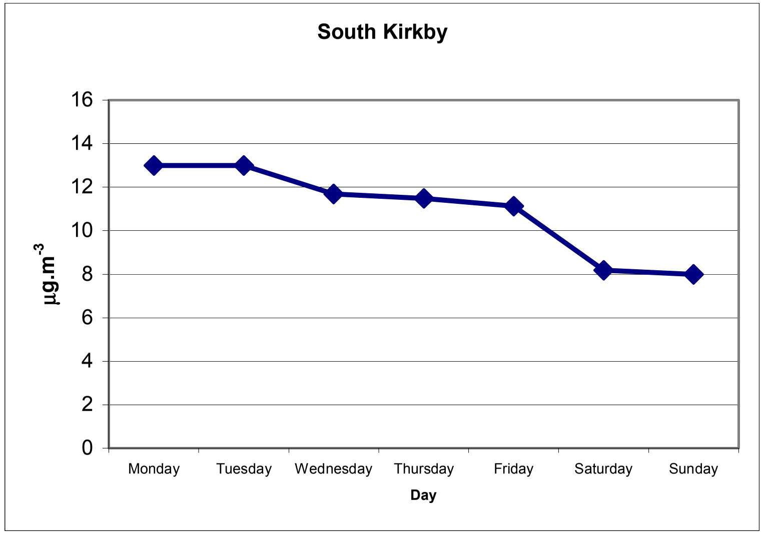


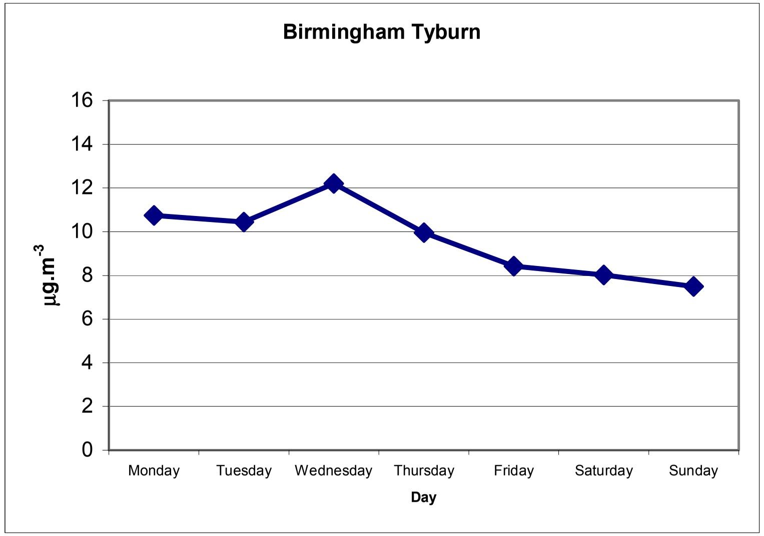
The depressed Thursday average concentration at Bradford Town Hall may be as a result of the low data capture and not a true reflection of the

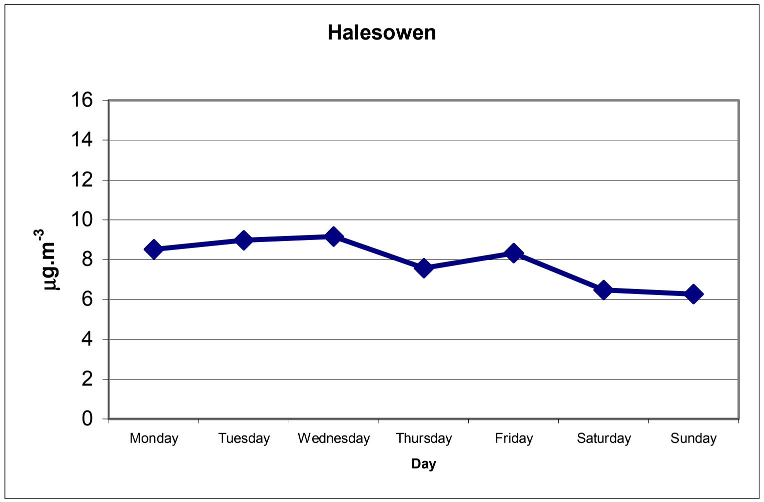


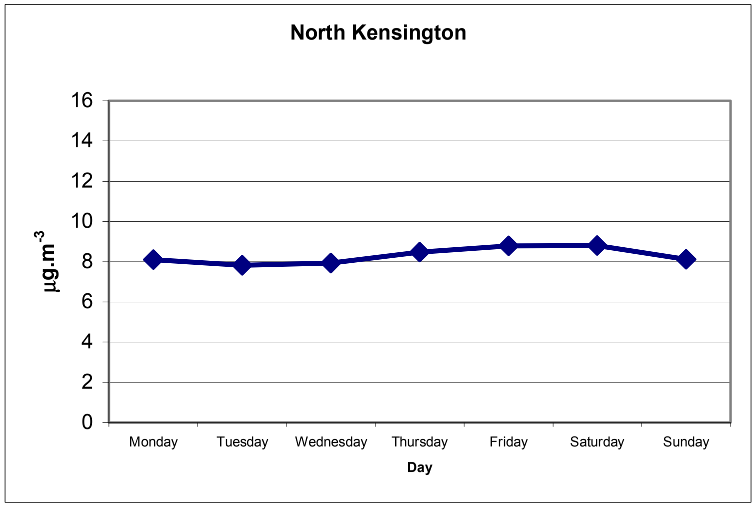


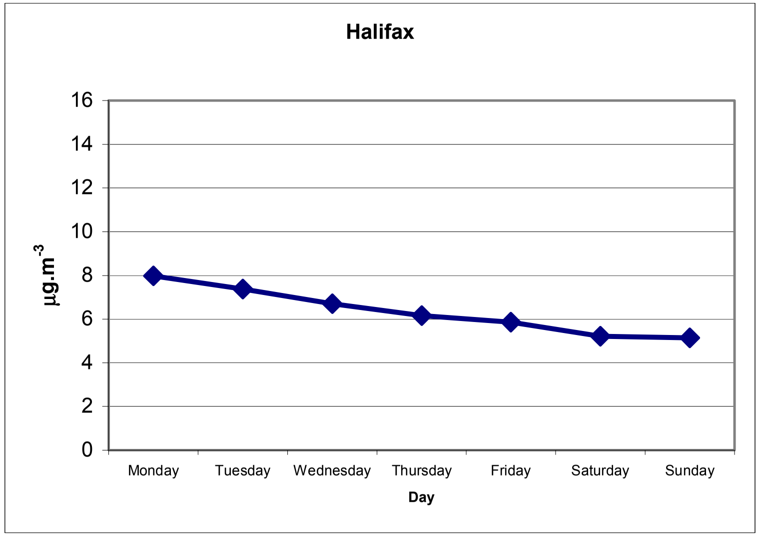
Daily Average Concentrations At Urban Centre Sites

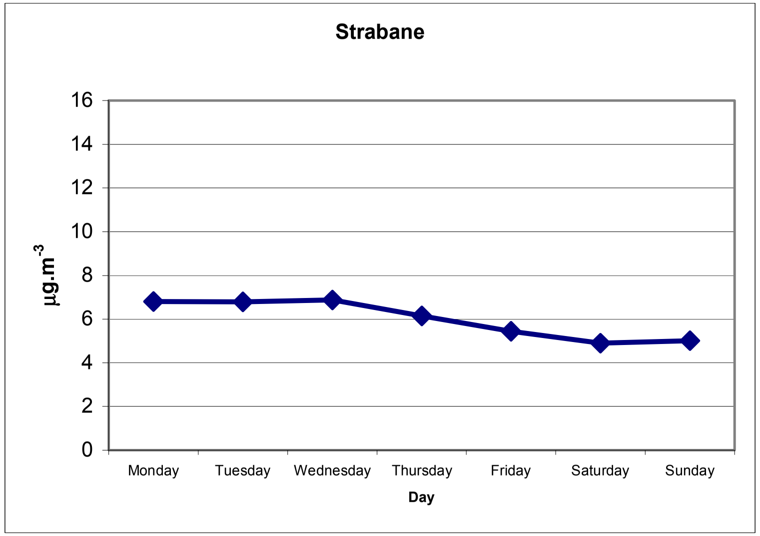

South Kirkby
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

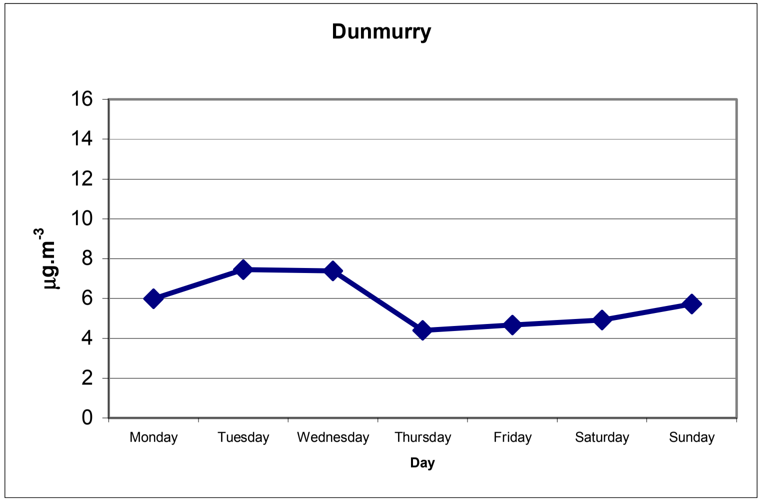

Birmingham Tyburn
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

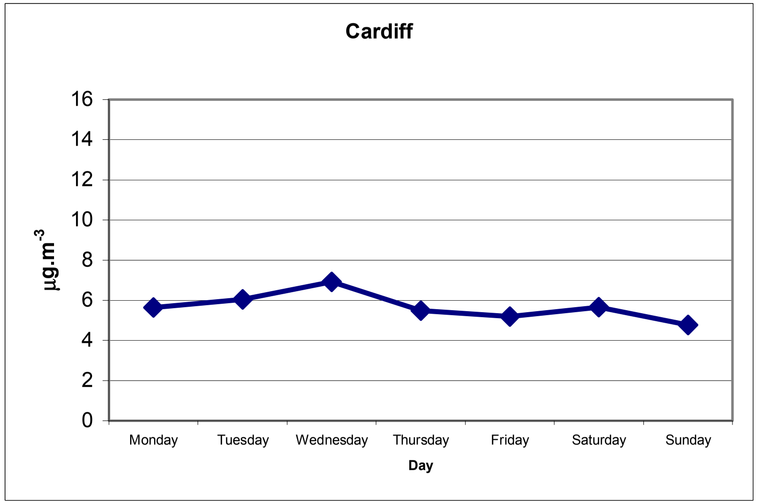

Halesowen
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

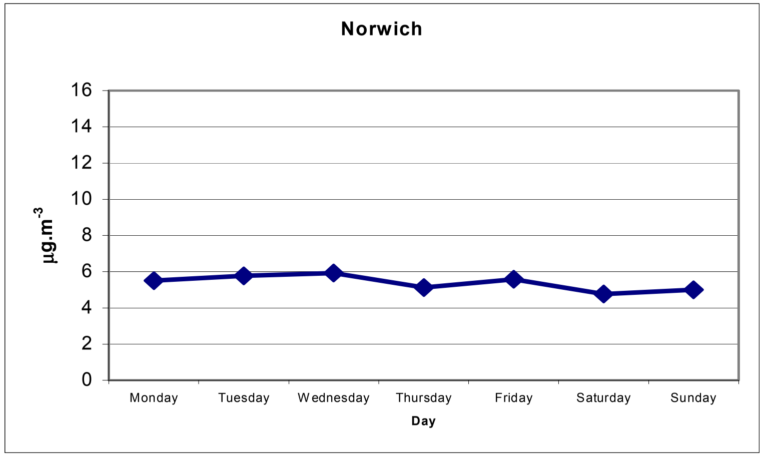

North Kensington
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

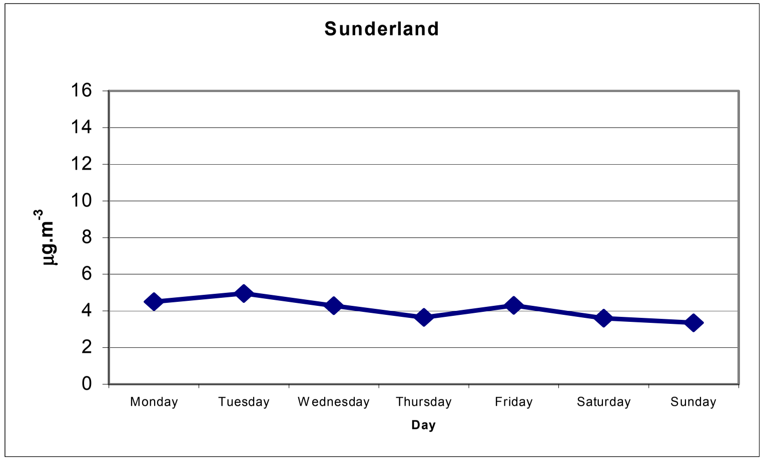

Halifax
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

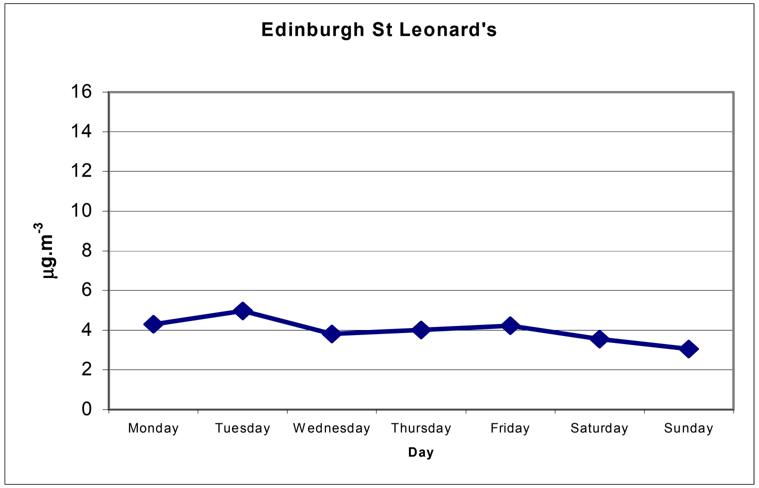

Strabane
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

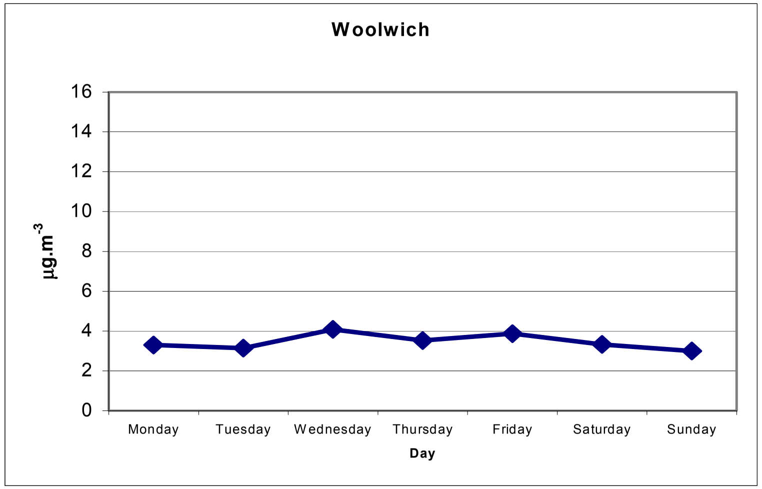

Dunmurry
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Cardiff
16
14
12
10
8
6
4
2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

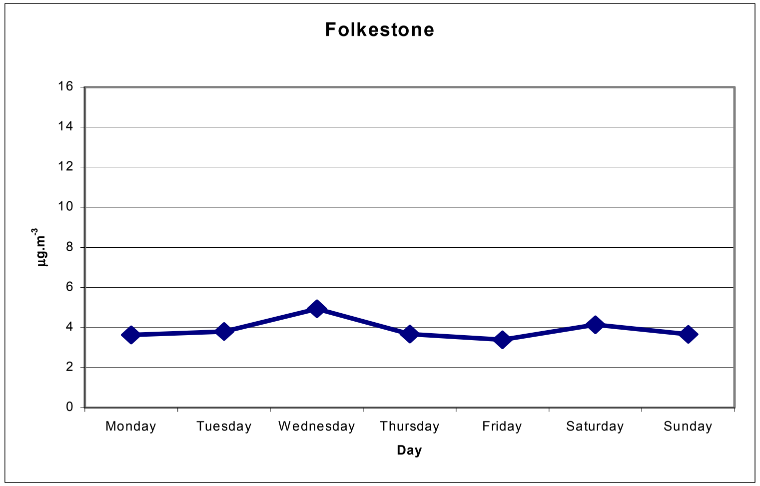








Daily Average Concentrations At Urban Background Sites



Daily Average Concentrations At Suburban Site