NPL REPORT AS 52

2009 Annual Report for the UK Black Carbon Network

D Butterfield, S Beccaceci, B Sweeney, D Green, J Alexander, A Grieve

May 2010

2009 Annual Report for the UK Black Carbon Network

May 2010

D Butterfield, S Beccaceci and B Sweeney
NPL

D Green, J Alexander and A Grieve
Environmental Research Group, King's College London

ISSN 1754-2928

National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

Approved on behalf of the Managing Director, NPL
by Martyn Sene, Operations Director

Executive Summary

This report covers the operation of the UK Black Carbon Network and the data collected by the Network in 2009. The Aethalometer instrument used on the Network makes measurements of Black Carbon (BC) and UV component.

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. By 2007 the network was making measurements at 21 sites.

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. In 2009 Aethalometers were installed in the Norwich and Harwell AURN sites. The site at Harwell is part of Defra's Particle Counting and Speciation Network, but the reporting of the data has been included in this report for completeness. Monitoring in Bradford ceased in October 2009 when Defra reassessed its monitoring requirements.

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 were made for the whole of 2009. Results from the parallel running of the two measurements show good agreement at all sites except Marylebone Road. There are good scientific reasons for the disagreement at Marylebone Road and these will be presented in a paper later in 2010.

The 2009 data capture for Aethalometer measurements was 90.5%. This shows good performance for the Network it its first full year of operation and is comparable with other Automatic Networks.

Measured annual average Black Carbon concentrations ranged from 1.0 $\mu g.m^{-3}$ measured at Folkestone to 10.0 $\mu g.m^{-3}$ measured at Marylebone Road, while Harwell reported an average concentration of 0.4 $\mu g.m^{-3}$ during its two months of operation. The network mean for Black Carbon concentration was 2.1 $\mu g.m^{-3}$.

As with black smoke in previous years, black carbon concentrations show reasonable agreement between sites located in similar regions of the country showing that there is a regional component to the Black Carbon concentration. The highest concentrations were measured at Marylebone Road, followed by urban centre sites and urban background sites giving comparable measurements, with the lowest measurements being made at the Harwell (rural) and Folkestone (suburban) sites.

Daily averages of the measurements show that the highest concentrations of Black Carbon 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 in Northern

Ireland). Both these sites show elevated levels from 15:00hrs to 23:00hrs, which is probably due to local domestic heating.

Measured annual average UV component concentrations ranged from 0.0 $\mu g.m^{-3}$ measured at Marylebone Road to 0.9 $\mu g.m^{-3}$ measured at Strabane. However, if the negative values measured at Marylebone Road are removed, its annual average concentration is comparable to the other sites. All sites close to the roadside showed significant negative spikes in this parameter. The network mean for the UV component concentration was 0.3 $\mu g.m^{-3}$.

From the diurnal plots it can be seen that the main driver behind the UV component concentrations is domestic fuel use, with elevated concentrations in the evenings at the urban background sites. Sites in Northern Ireland show the largest evening effect due to the higher use of oil and solid fuel for domestic heating. From the daily averages it can be seen that the UV component concentration is fairly consistent over the week.

Comparisons between black carbon concentrations and elemental carbon concentrations showed good agreement between the measurements at the north Kensington and Marylebone Road sites.

Contents

1.0 Introduction ... 1
1.1 General ... 1
1.2 Black Carbon ... 1
1.2 Measurement Method ... 2
1.2.1 Black Carbon - Aethalometer ... 2
1.2.2 Sampling ... 3

2.0 Network Infrastructure ... 3
2.1 Network Design ... 3
2.2 Network Operation ... 5
2.3 Changes To The Network ... 7

3.0 Quality Assurance and Quality Control (QA/QC) ... 8
3.1 Site Audits ... 8
3.1.1 Sampler Leak Rate and Calibration of Sample Flow ... 8
3.1.2 Optical Calibration ... 10

4.0 Measurement Uncertainty ... 12
4.1 Sample Volume ... 12
4.2 Measurement of Absorption ... 12
4.3 Correction for Spot Darkening ... 13
4.4 Preliminary Overall Measurement Uncertainty ... 13

5.0 Results ... 14
5.1 Black Carbon ... 14
5.1.1 Time Series ... 14
5.1.2 Averages and Data Capture ... 17
5.1.3 Diurnal Periodicity ... 19
5.1.4 Weekly Periodicity ... 27
5.1.5 Comparisons With Other Pollutants ... 36
5.2 UV Component ... 38
5.2.1 Time Series ... 38
5.2.2 Averages and Data Capture ... 41
5.2.3 Diurnal Periodicity ... 42
5.2.4 Weekly Periodicity ... 50

References ... 59

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. In 2009 Aethalometers were installed in the Norwich and Harwell AURN sites. The site at Harwell is part of Defra's Particle Counting and Speciation Network, but the reporting of the data has been included in this report for completeness. Monitoring in Bradford ceased in October 2009 when Defra reassessed its monitoring requirements.

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 were be made for the whole of 2009. The preliminary results from the parallel running trial for the period November 2008 to April 2009 were reported to Defra in the NPL Report: "Summary Of Measurements Of Black Smoke, Black Carbon And Elemental Carbon Performed By Defra Networks"[1]. The results for the whole of 2009 will be published as a paper later in 2010.

This report presents the data collected in 2009 from the Aethalometer only.

Comparisons are also made with other measurements colocated with the Aethalometers.

1.2 Black Carbon

Black Carbon (BC) is a measure of airborne soot-like carbon (in $\mu g.m^{-3}$) based on the optical absorption of specific wavelengths by particulates collected on a filter. Ideally it is a similar metric to Elemental Carbon (EC), as determined by thermo-optical techniques, though in practice the EC fraction of total carbon depends strongly on the method chosen. BC should have a close relationship to the Black Smoke measure monitored by the network and its predecessors for many decades before the installation of the aethalometers[2], though again this can be strongly affected by the instruments and circumstances.

BC is typically formed through the incomplete combustion of fossil fuels, biofuel, and biomass, and is emitted in both anthropogenic and naturally occurring soot. It consists of pure carbon in several forms. Black carbon warms the planet by absorbing heat in the atmosphere and by reducing albedo (the ability to reflect sunlight) when deposited on snow and ice. Black carbon stays in the atmosphere for periods of days to weeks, whereas CO_2 has an atmospheric lifetime of more than 100 years.

1.2 Measurement Method

The following section describes the measurement methodology for the aethalometer that performs the Black Carbon measurements.

1.2.1 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 can be used as a tracer for oil and solid fuel emissions.

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[3] 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 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

The following sections present the design of the Network, describe its operation and the changes to the Network in 2009.

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 Dudley Central site replaced the Halesowen site and the Norwich 7 site was relocated to the new Norwich Lakenfields AURN site. The reasoning behind these changes is presented in the 2008 Annual Report on the Network[4].

In addition to replacing all of the existing 8-port samplers with aethalometers, an aethalometer was installed in the Harwell AURN site as part of the Particle Number and Speciation Network.

Figure 1 shows the locations of the aethalometers:

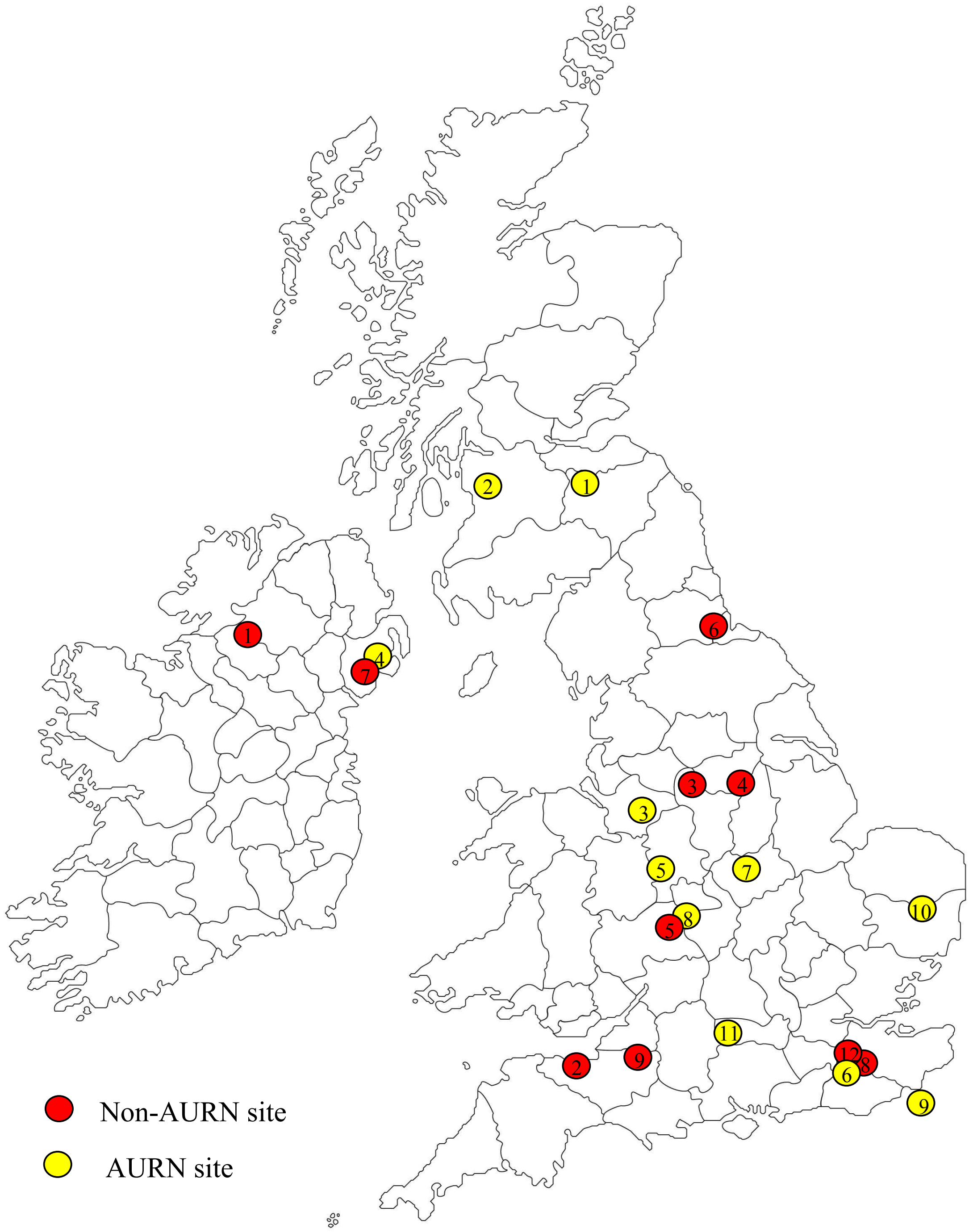


Figure 1 Location of Aethalometers making up the UK Black Carbon Network

Tables 1 and 2 below give the site names and classifications for the UK Black Carbon 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

Table 1 Non-AURN

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

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 Environmental Research Group at King's College London (KCL) carries out the CMCU activities. 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 $\mu g\ m^{-3}$); 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 2. 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.

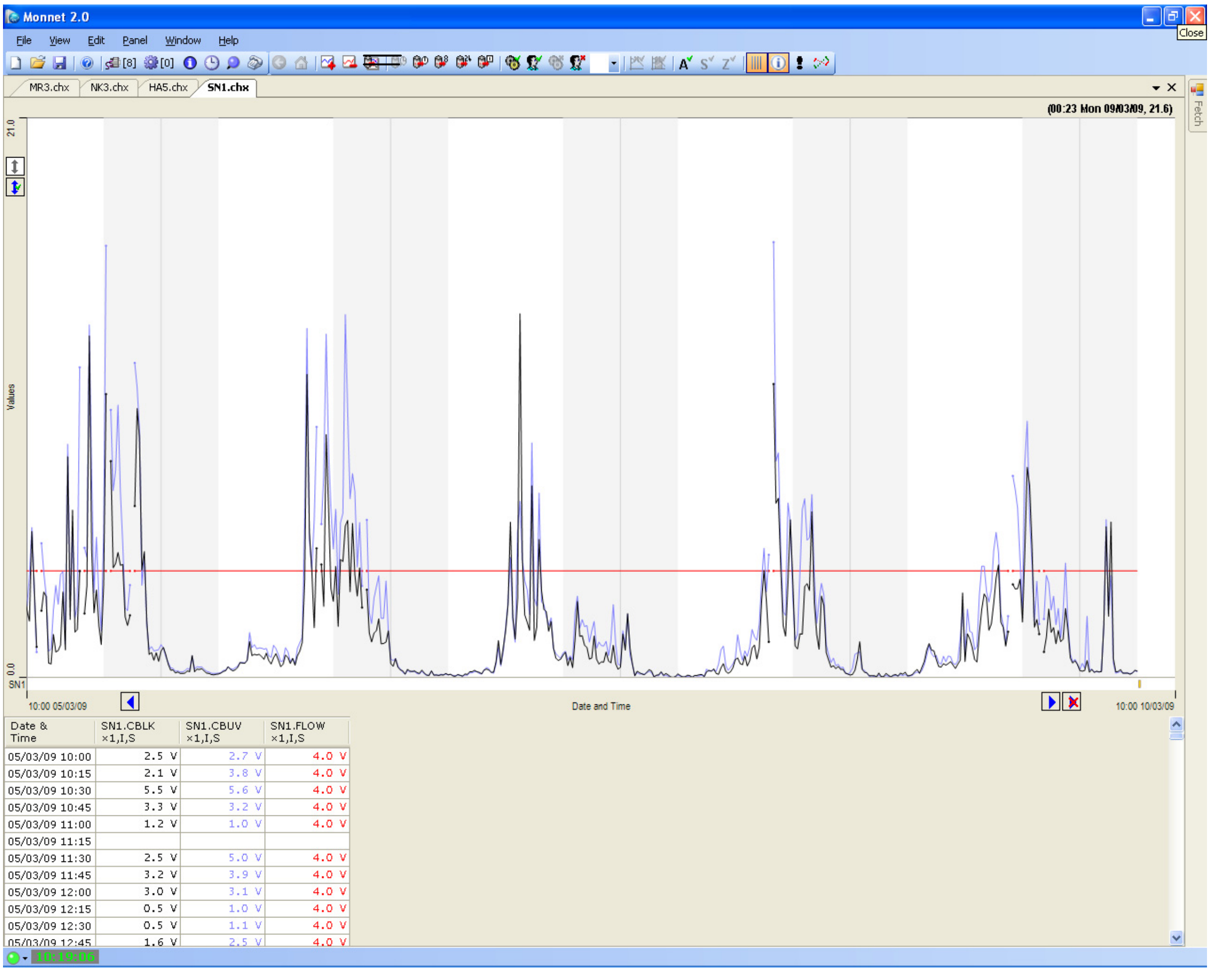


Figure 2 MONNET data checking graph

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.

2.3 Changes To The Network

In the summer of 2009 Defra decided to review the monitoring requirements of the Network and decided that monitoring should cease at the Bradford Town Hall site. Monitoring ceased on 2nd October.

An aethalometer was installed in the new Norwich Lakenfields AURN site and monitoring started on 8th October. An aethalometer was also installed into the Harwell AURN site as part of the Particle Numbers and Speciation Network and monitoring started on 11th November.

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 measured attenuation for Black Carbon.

NPL and the Aethalometer supplier, Air Monitors, collaborated in 2009 on methods to improve the auditing and optical calibration of the Aethalometer. The results from this calibration are currently being drafted and will be presented in a separate NPL report in 2010. The outcome of this collaboration will be implemented in the audit procedure for 2010.

3.1 Site Audits

Table 3 gives the site audit dates and serial numbers of the aethalometer audited.

Site	Date	Serial Number
Stoke	15/06/2009	861
Manchester	15/06/2009	858
Belfast	16/06/2009	863
Dunmurry	17/06/2009	862
Strabane	17/06/2009	848
Marylebone Road	24/06/2009	864
North Kensington	24/06/2009	850
Birmingham Tyburn	25/06/2009	859
Dudley Central	25/06/2009	849
Bath	26/06/2009	869
Cardiff 12	26/06/2009	868
Edinburgh St Leonard's	28/07/2009	866
Sunderland	28/07/2009	854
Glasgow Centre	29/07/2009	856
Woolwich	26/08/2009	865
Folkestone	12/10/2009	853
South Kirkby	03/11/2009	852
Nottingham	02/11/2009	857
Halifax	03/11/2009	860
Norwich Lakenham	11/11/2009	855
Harwell	02/02/2010	867

Table 3 Site Audit Date

3.1.1 Sampler Leak Rate and Calibration of Sample Flow

The leak rate for aethalometers is measured by simultaneously measuring the flow rate at the input and exhaust of the analyser and requires the use of two calibrated flow meters.

According to the manufacturer, the maximum acceptable leak rate is 20%. 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 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 4 gives the measured leak rates and sample flows for each site:

Site	% Leak Rate	Indicated Flow	Inlet Flow
Stoke	10.5	4.0	4.05
Manchester	12.4	4.0	3.87
Belfast	8.9	4.0	4.16
Dunmurry	10.9	4.0	4.07
Strabane	14.5	4.0	3.67
Marylebone Road	14.9	4.0	3.79
North Kensington	10.8	4.0	3.92
Birmingham Tyburn	8.2	4.0	4.08
Dudley Central	10.5	4.0	3.96
Bath	12.9	4.0	3.93
Cardiff 12	10.3	4.0	4.06
Edinburgh St Leonard's	7.6	4.0	4.05
Sunderland	15.1	4.0	3.96
Glasgow Centre	10.5	4.0	4.06
Woolwich	5.8	4.0	4.14
Folkestone	4.8	4.0	3.96
South Kirkby	13.3	4.0	3.76
Nottingham	10.1	4.0	4.00
Halifax	5.0	4.0	4.19
Norwich Lakenham	8.5	4.0	4.18
Harwell	N/A	4.0	Unstable

Table 4 Aethalometer leak rates and sample flows

The inlet and exhaust flow of the Harwell aethalometer were found to be unstable and therefore it was not possible to accurately measure the flow rates and calculate the leak rate. The ESU was called to fix the problem and traced the fault to an intermittent leak on the bypass filter, which they then fixed.

3.1.2 Optical 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 relative changes in optical transmission. However, there is an inbuilt routine in the aethalometer to measure the Optical Test Ratio (OTR), so that performance of the instrument can be monitored. This is much less accurate than the routine measurement procedure, because the insertion of the test strip causes unavoidable changes to the optical system that are absent in the normal measurement process.

To enable the test to be performed, 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 test is used to show that the aethalometer is linear over large changes in attenuation and is not a direct measurement of the instrument's ability to accurately measure attenuation. As the aethalometer's measurement procedure relies on its ability to measure small relative changes in attenuation and not accurately measure the absolute attenuation, the test shows that the instrument is performing within specification and cannot be used to calibrate aethalometers.

Table 5 shows the audit results for each aethalometer challenged with the NPL test strip.

Site	Sensing Beam Value	Reference Beam Value	Optical Test Ratio
Stoke	48.68	59.80	0.81
Manchester	48.70	60.16	0.81
Belfast	45.95	53.62	0.86
Dunmurry	52.85	60.38	0.88
Strabane	50.01	61.45	0.81
Marylebone Road	48.00	50.56	0.95
North Kensington	50.46	62.80	0.80
Birmingham Tyburn	57.13	59.33	0.96
Dudley Central	58.07	65.59	0.89
Bath	51.69	58.02	0.89
Cardiff 12	54.04	59.61	0.91
Edinburgh St Leonard's	37.71	48.29	0.78
Sunderland	7.01	15.74	0.45
Glasgow Centre	44.59	52.50	0.85
Woolwich	41.71	56.50	0.74
Folkestone	41.85	56.06	0.75
South Kirkby	41.79	53.67	0.78
Nottingham	42.63	49.48	0.86
Halifax	46.07	63.78	0.72
Norwich Lakenham	36.17	47.23	0.77

The OTR was not measured for the Harwell aethalometer due to the flow fault

Table 5 Results Of The Optical Test Ratio Intercomparison

The low result at Sunderland cannot be easily explained. It is possible that the test strip was not aligned properly in the instrument during the test and that the site auditor should have noticed the spurious result. Checks on the Sunderland analyser diagnostics and the data did not reveal any significant operational problem.

The results from the Optical Test Ratio are better represented as a chart in Figure 3. The red lines show the expected range of the OTR results.

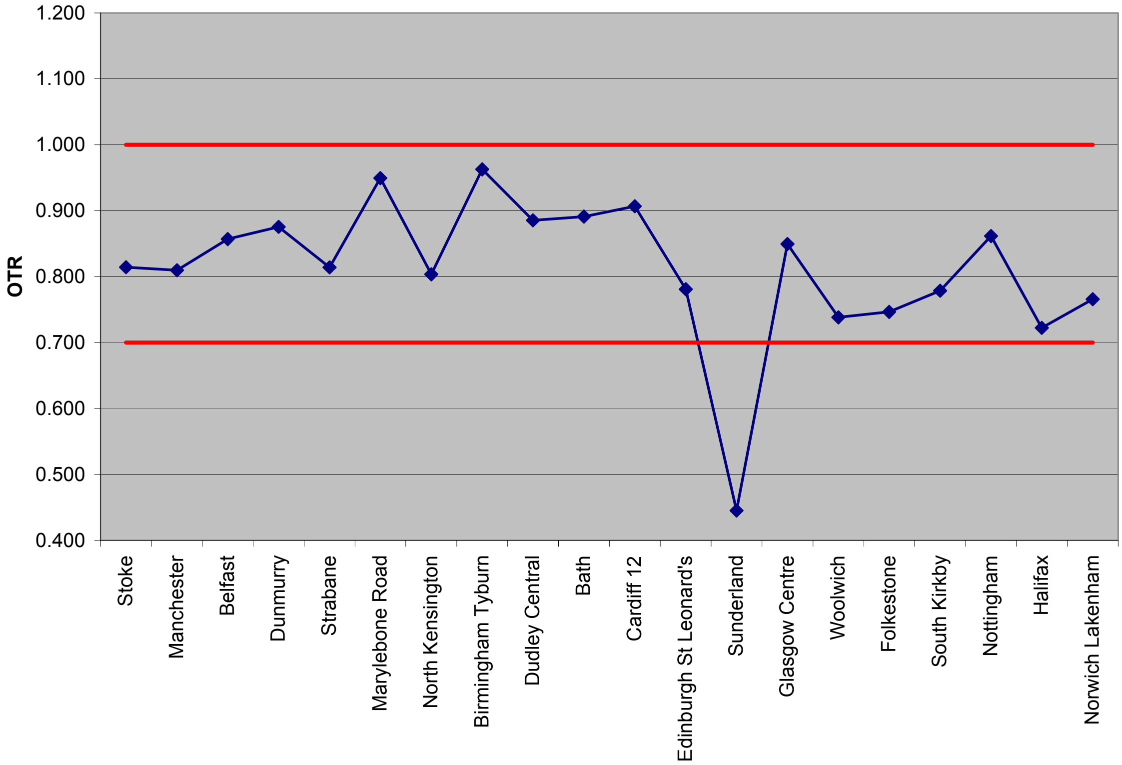


Figure 3 Optical Test Ratio Measured at the Site Audits

4.0 Measurement Uncertainty

4.1 Sample Volume

From measurements at the site audit the sample volume can be determined with an uncertainty of ±12.7%, 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 2009 audits was used. As leak rate is considered to be a rectangular distribution, its contribution to the standard uncertainty in sample volume is 5.9%.

4.2 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 relative changes in optical transmission. As the Optical Test Ratio test is a linearity test over a large change in attenuation it is not suitable to provide information on the uncertainty of the detector when measuring very small changes in attenuation.

Work is being done with both the instrument manufacturer (Magee) and the UK instrument supplier (Air Monitors) to come up with a meaningful way to assess the uncertainty in the measurement of absorption. This work will be published in 2010 and will be incorporated into the Networks QA/QC procedures.

4.3 Correction for Spot Darkening

The Virkkula model[3] 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.

4.4 Preliminary Overall Measurement Uncertainty

As QA/QC procedures are being developed, the overall measurement uncertainty is a preliminary value. Further work is being done in collaboration with the instrument supplier to develop these procedures and will be reported on later in 2010. Updated QA/QC field procedures from this collaboration have been implemented in the 2010 site audits.

When the contributions from sample volume and measurement of adsorption are combined, the overall measurement uncertainty for Black Carbon concentrations is 16.1%, 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 2009 audit data. The site specific overall measurement uncertainty may differ from this value.

5.0 Results

The concentration data for 2009 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[3].

5.1 Black Carbon

The following sections present the black carbon concentrations measured in 2009.

5.1.1 Time Series

The following charts show the Black Carbon concentrations measured by the UK Black Carbon Network for 2009. The time resolution of the measurements is hourly. Data has been split into regions of the UK for presentation purposes.

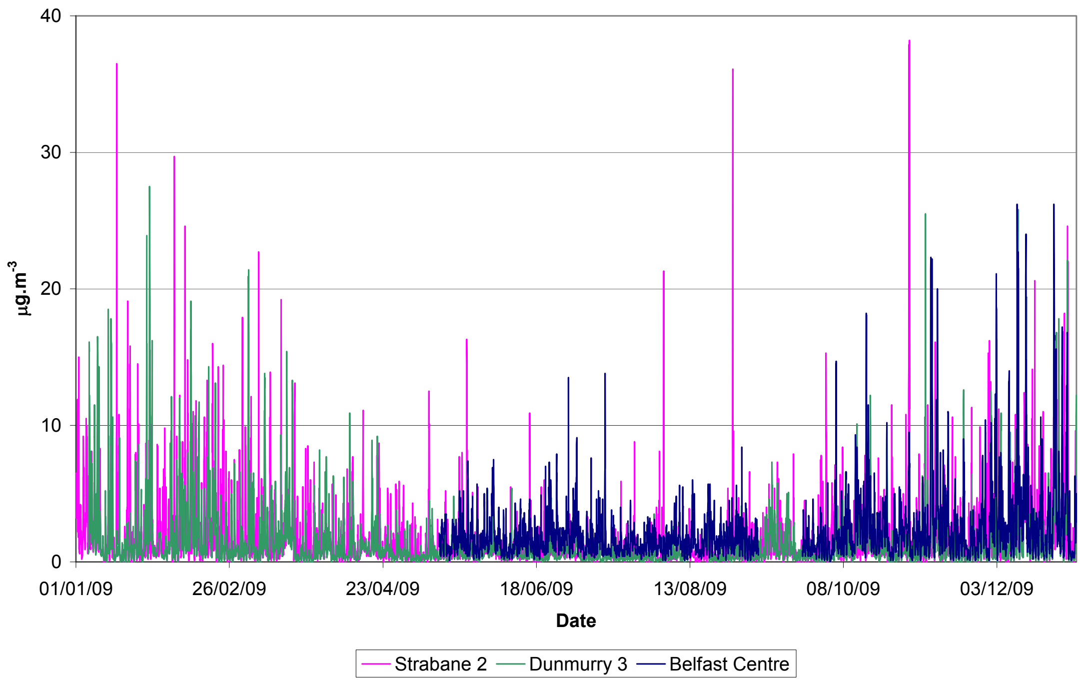
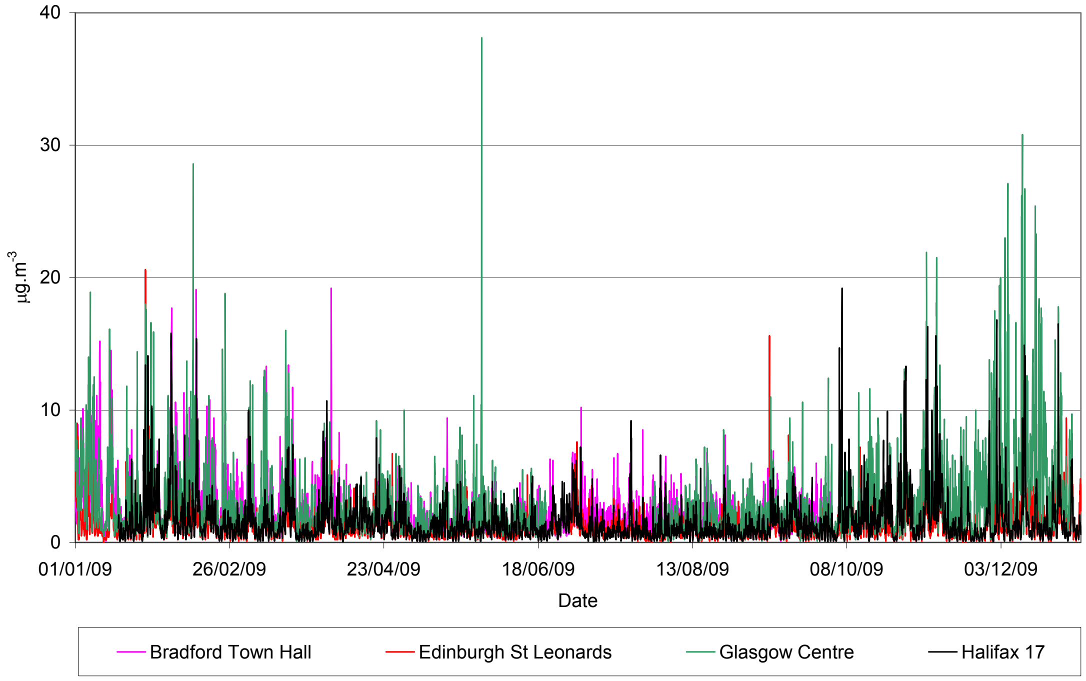
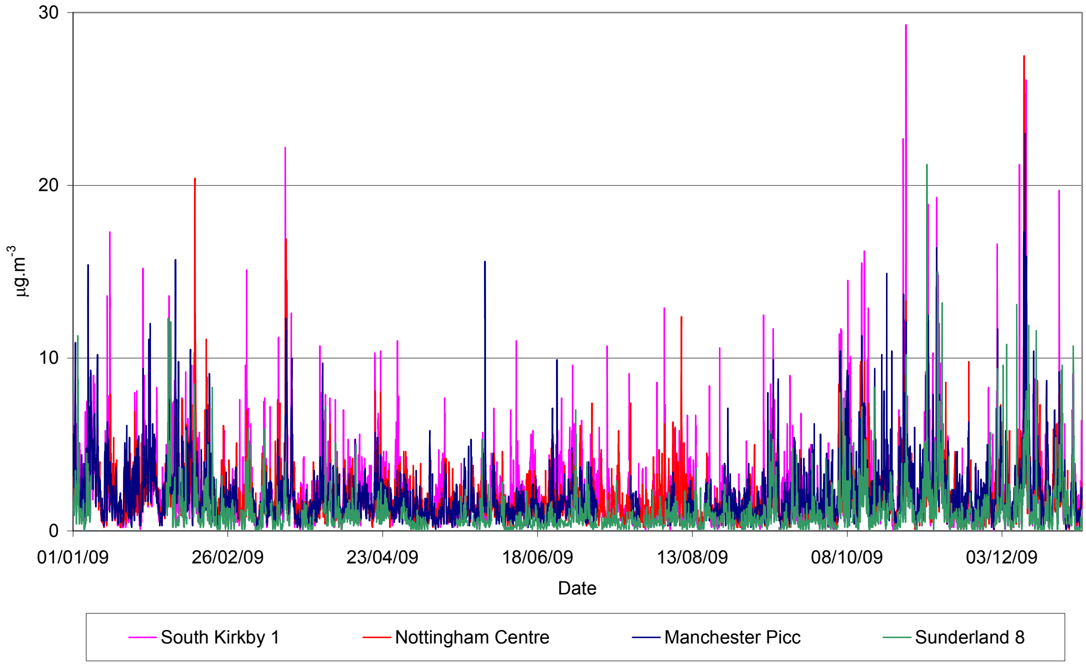
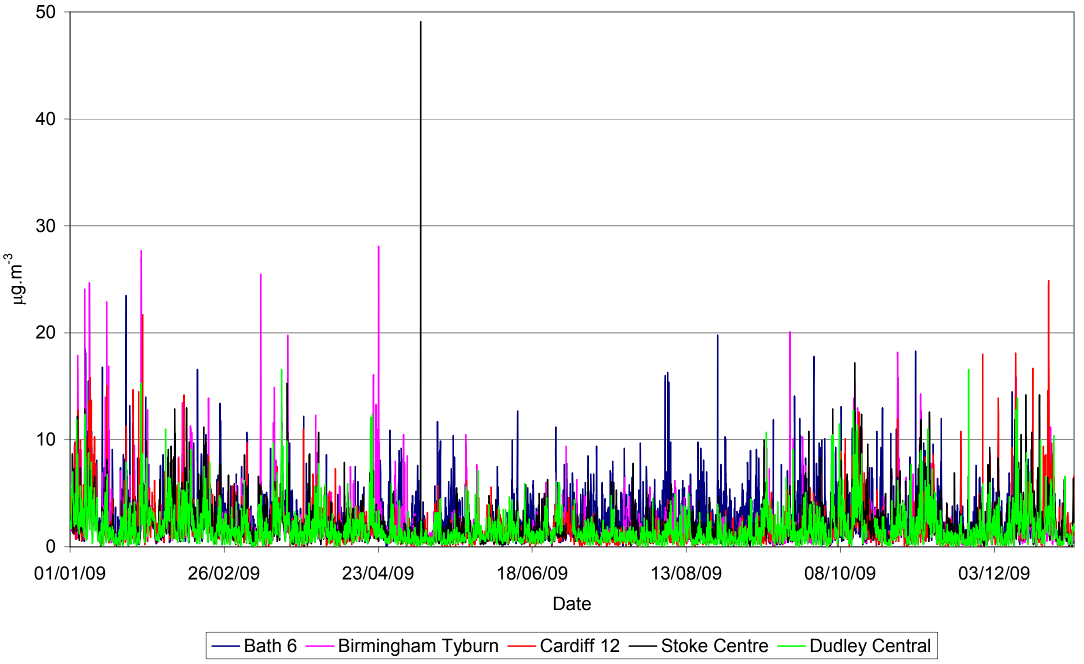


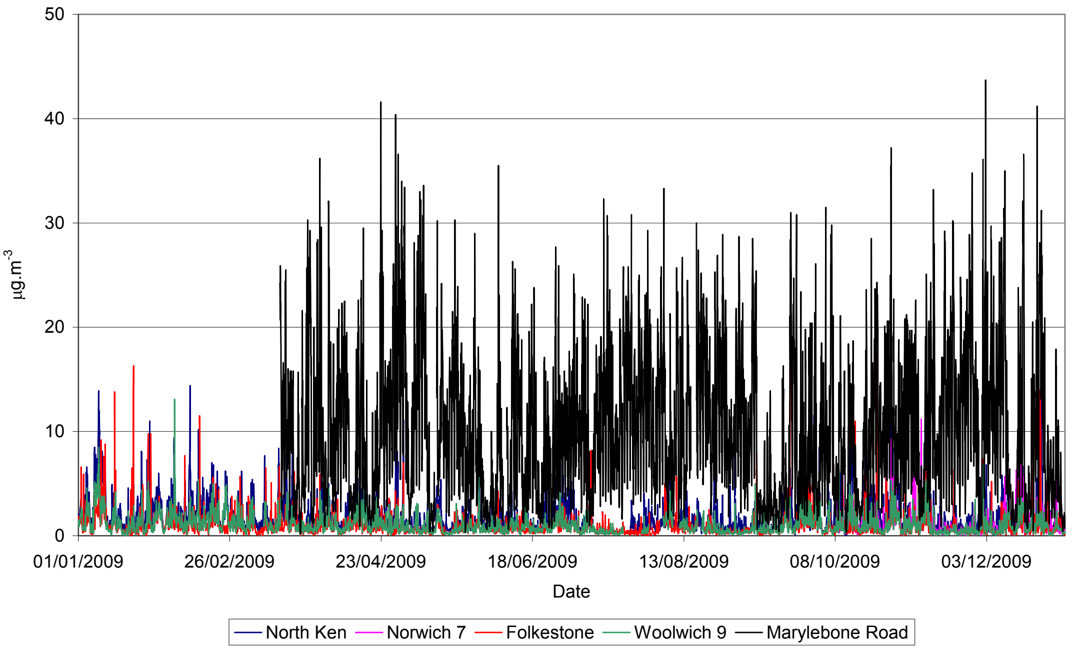
Figure 4 Black Carbon concentrations during 2009 in Northern Ireland





Figures 5 + 6 **Black Carbon concentrations during 2009 in Scotland and Northern England**





Figures 7 + 8 **Black Carbon concentrations during 2009 in Southern England and Wales**

The high concentration spike measured at Stoke Centre on 8th May was also seen by the AURN $PM_{2.5}$ FDMS analyser. The hourly concentration measured by the Aethalometer was 49.1 $\mu g.m^{-3}$ and the hourly FDMS concentration was 198 $\mu g.m^{-3}$.

5.1.2 Averages and Data Capture

Table 6 gives the period averages and data capture for each site for 2009.

Site	Mean concentration $\mu g.m^{-3}$	Data Capture %
Bath 6	2.5	98
Belfast Centre	2.1	59
Birmingham Tyburn	2.0	90
Bradford Town Hall*	2.4	93
Cardiff 12	1.6	98
Dunmurry 3	1.3	97
Edinburgh St Leonard's	1.3	97
Folkestone	1.0	97
Glasgow Centre	2.9	88
Dudley Central	1.7	97
Halifax 17	1.5	96
Manchester Piccadilly	2.1	90
Marylebone Road	10.0	78
North Kensington	1.9	95
Norwich Lakenham *	1.3	98
Nottingham Centre	1.9	96
South Kirkby 1	2.2	96
Stoke Centre	2.0	91
Strabane 2	1.6	97
Sunderland 8	1.1	78
Woolwich 9	1.1	94
Harwell*	0.4	67

* The following sites were not operational for the whole of 2009. The operating periods are given below:

Bradford Town Hall 01/01/09 to 02/10/09
Norwich Lakenham 08/10/09 to 31/12/09
Harwell 10/11/09 to 31/12/09

Table 6 Annual Mean Black Carbon Concentration and Data Capture for 2009

The increments in concentration from the suburban site in Folkestone to the urban background sites in London (North Kensington and Woolwich) and from these to the Marylebone Roadside site in Central London are 0.5 $\mu g.m^{-3}$ and 8.5 $\mu g.m^{-3}$ respectively.

The annual mean concentrations are presented as a bar graph (Figure 9) to aid the comparison of sites:

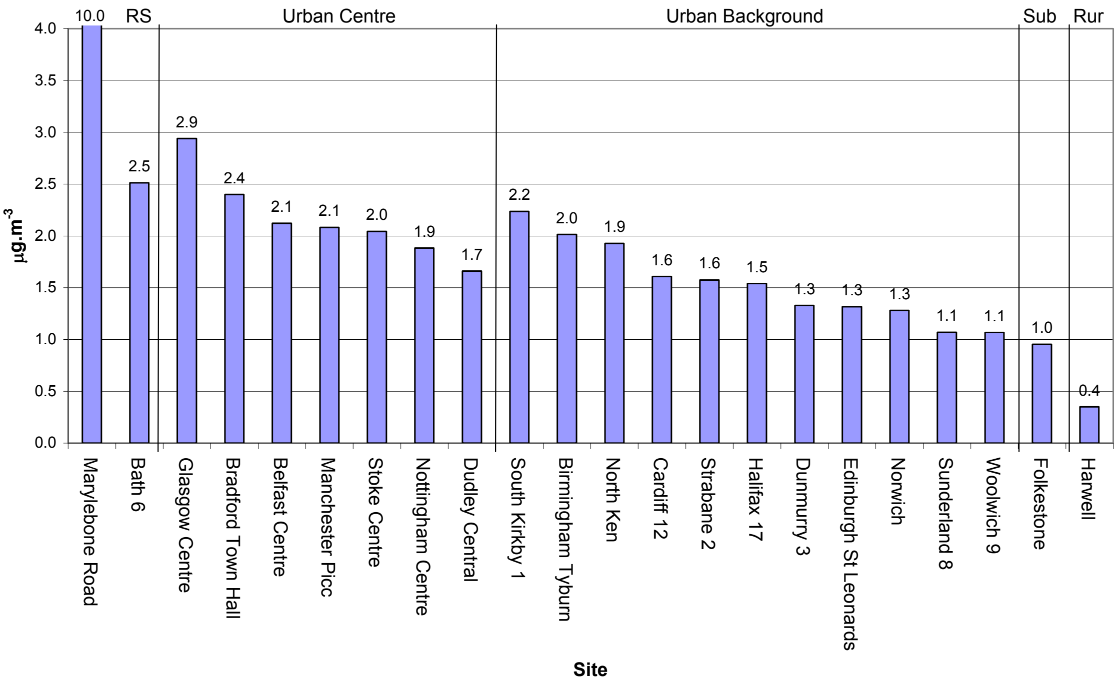


Figure 9 Annual Mean Black Carbon Concentration for 2009

The reasons for sites with data capture below 90% is given below:

Belfast Centre (59%)

The Aethalometer started to report uncharacteristically low concentrations in early January when compared to the other sites in Northern Ireland. The reason was not traced to a specific analyser fault and the aethalometer was replaced on 25/02/09. Unfortunately the replacement Aethalometer gave inconsistent results and suffered from communication errors and was replaced by a third unit on 19/05/09.

The outer housing of the site was clad with stone between 7th and 22nd September to help the site blend in with the surrounding buildings. This work caused excessive dust that artificially increased the measured concentrations so the data were not reported for this period.

Glasgow Centre (88%)

The Aethalometer tape ran out on 20th June and was not replaced by the LSO. NPL replaced the tape on 29th July at the annual audit and retrained the LSO on how to change the tape.

Marylebone Road (78%)

There was no valid data until 16th March due to various analyser faults that were finally traced to mains voltage problems at the site. An uninterruptible power supply / voltage conditioner was installed, which removed this fault.

Sunderland (78%)

There was a low flow fault with the analyser between 7th January and 3rd February, which resulted in invalid data. Various instrument faults between 14th April and 19th May led to the Aethalometer being replaced with another unit.

Harwell (67%)

Water ingress where the Aethalometer sample line entered the roof caused the instrument to flood. Data was lost from 24th November to 11th December while the leak was fixed. The delay in fixing the roof is due to only AEA-approved contractors being able to work on the Harwell site roof, and they were unavailable at the time.

5.1.3 Diurnal Periodicity

Plots of the average concentrations on each hour of the day for Roadside, Urban Centre, Urban Background, Suburban and Rural site classifications respectively can be seen in figures 10 to 13.

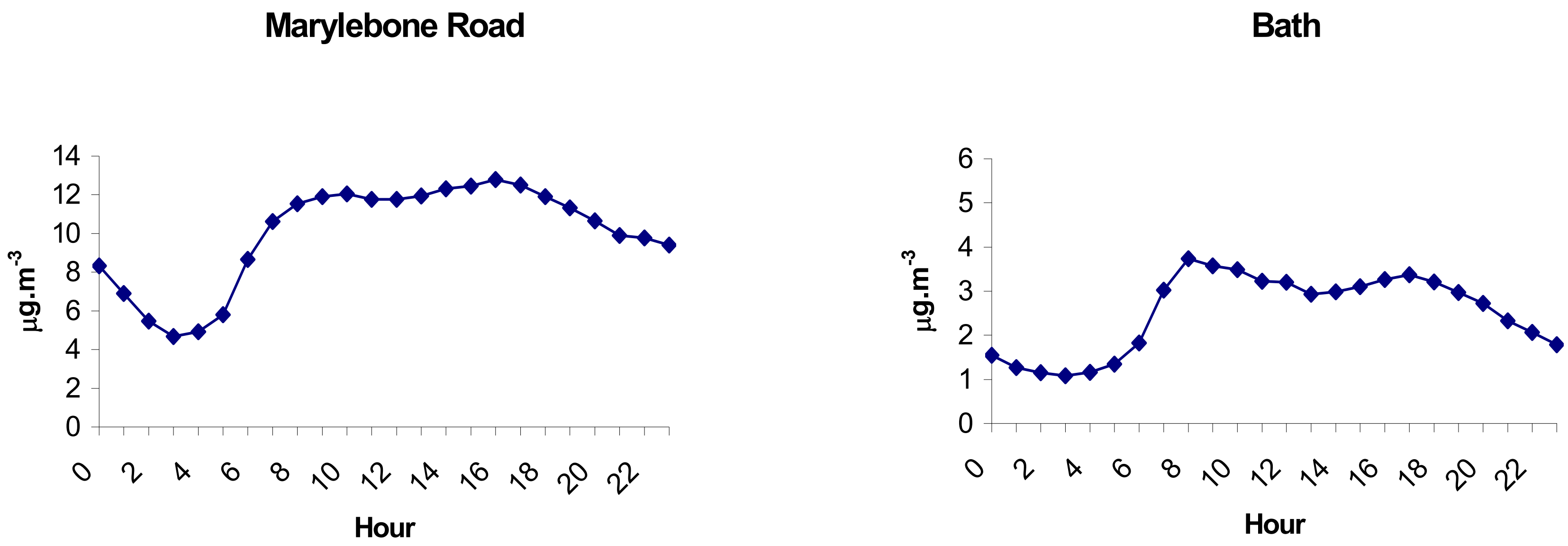
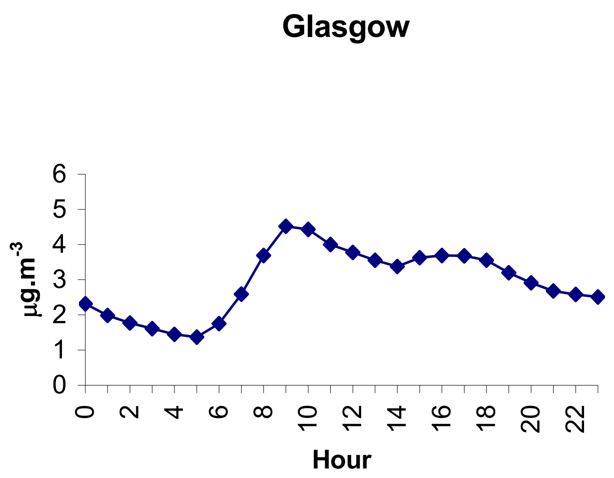
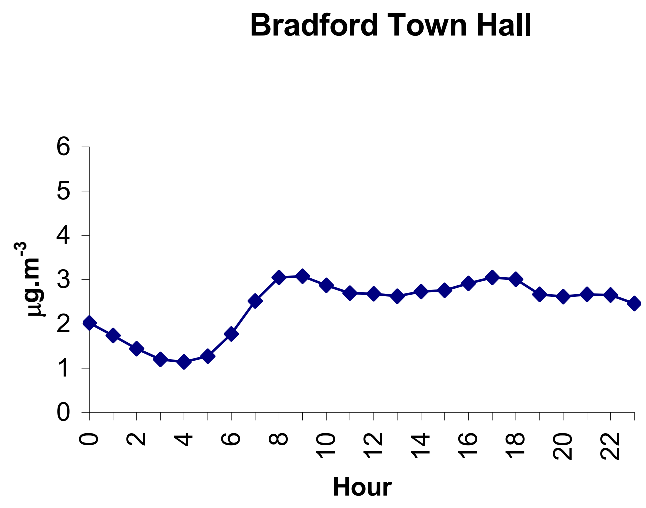
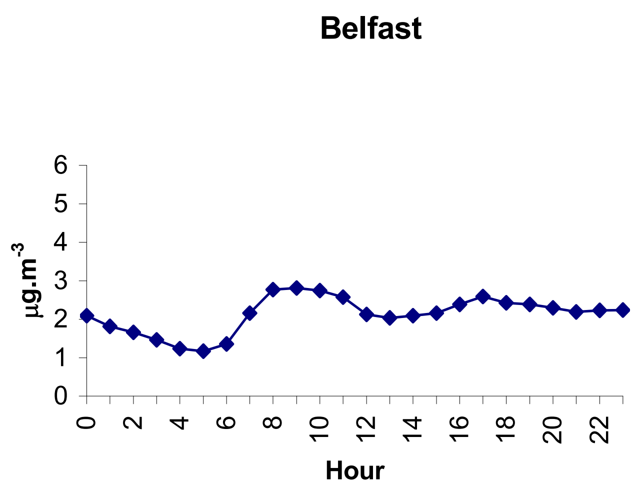
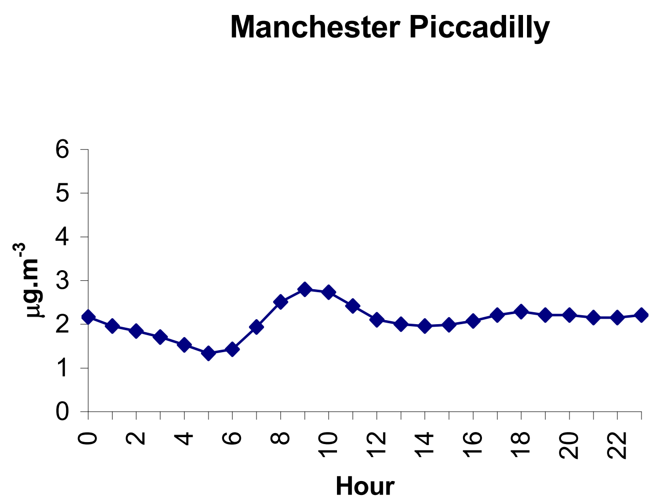


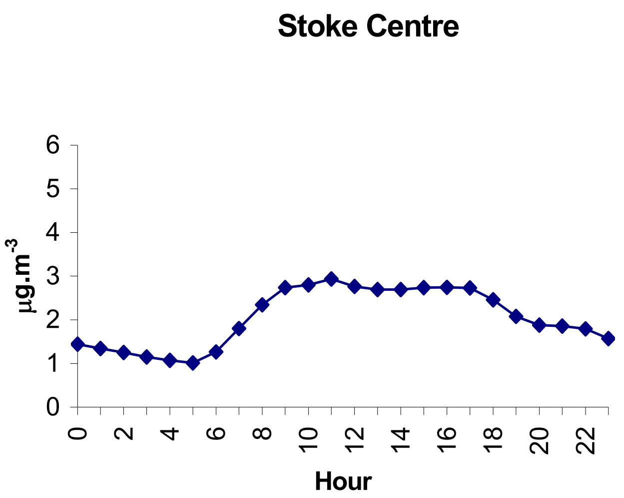
Figure 10 Roadside Locations

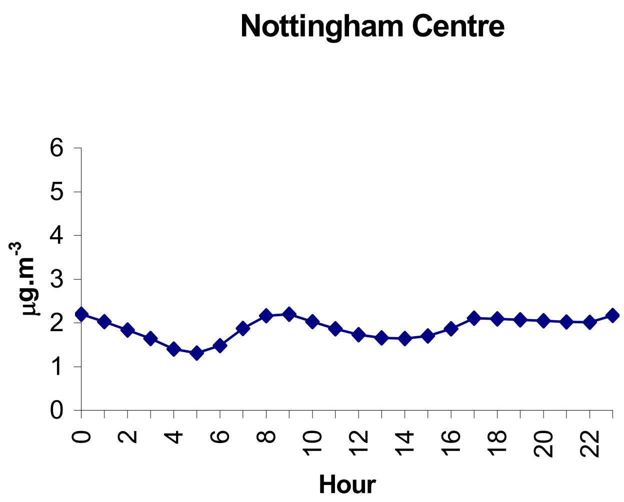

Glasgow
6
5
4
3
2
1
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Bradford Town Hall
6
5
4
3
2
1
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Belfast
6
5
4
3
2
1
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Manchester Piccadilly
6
5
4
3
2
1
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour





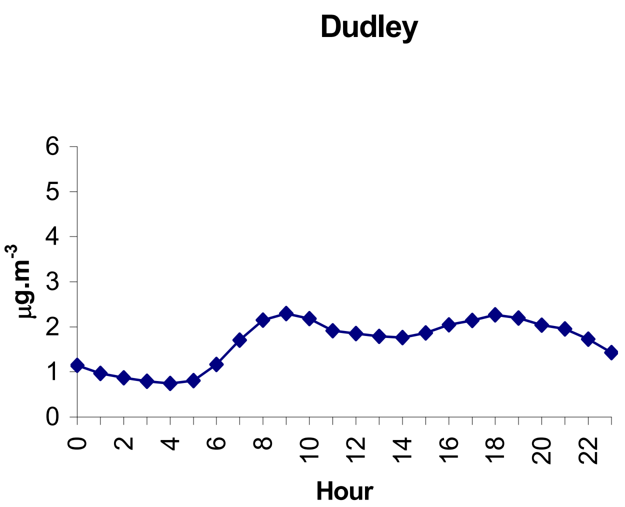
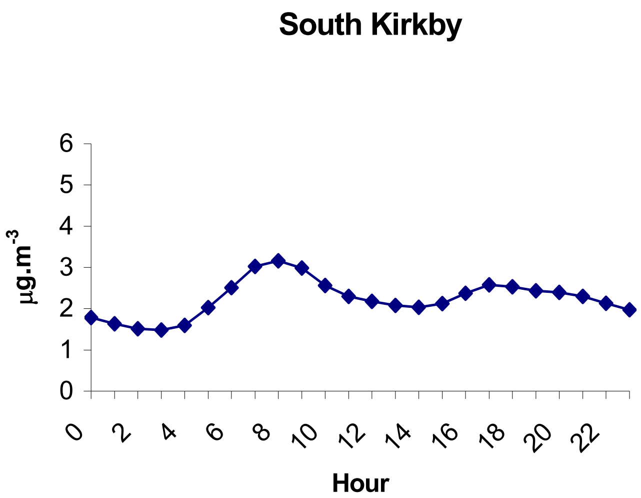
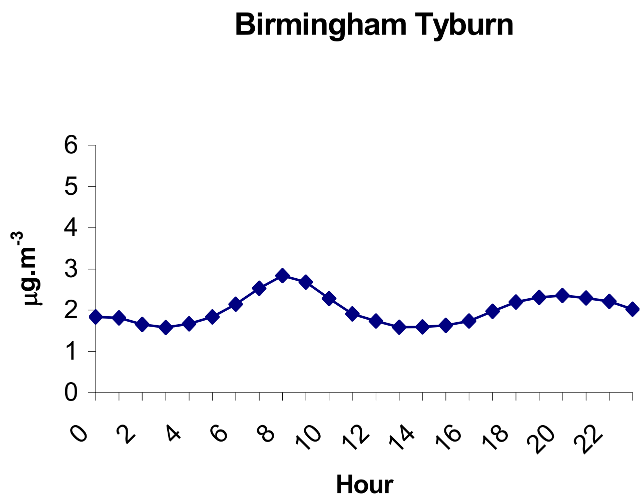
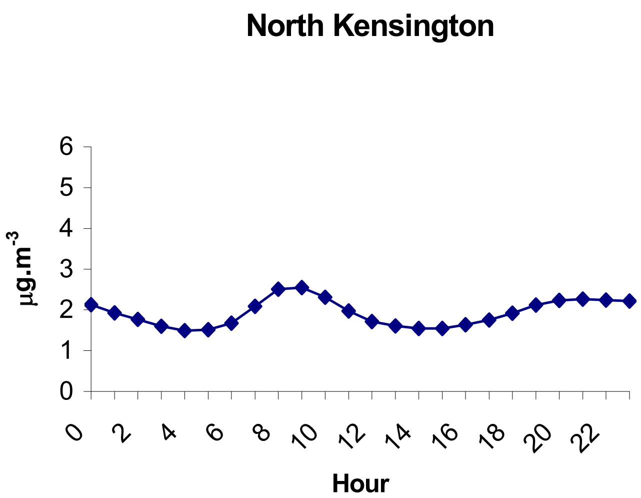
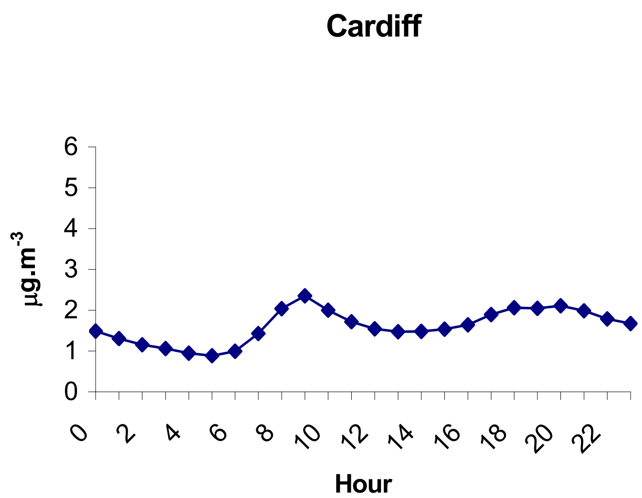


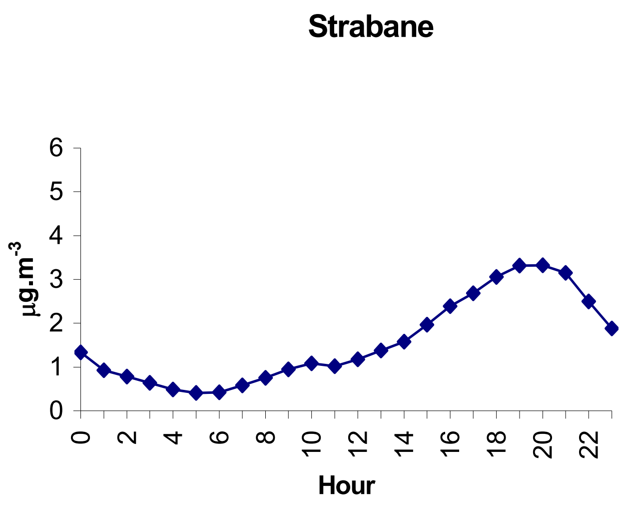
Figure 11 Urban Centre Locations

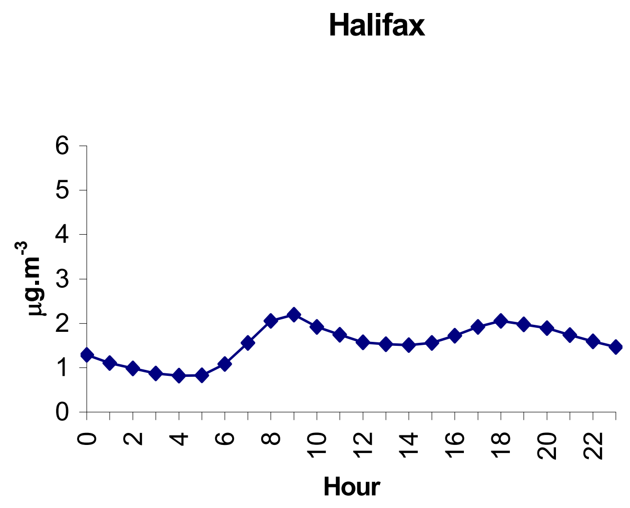

South Kirkby
µg.m-3
0
1
2
3
4
5
6
0 2 4 6 8 10 12 14 16 18 20 22
Hour

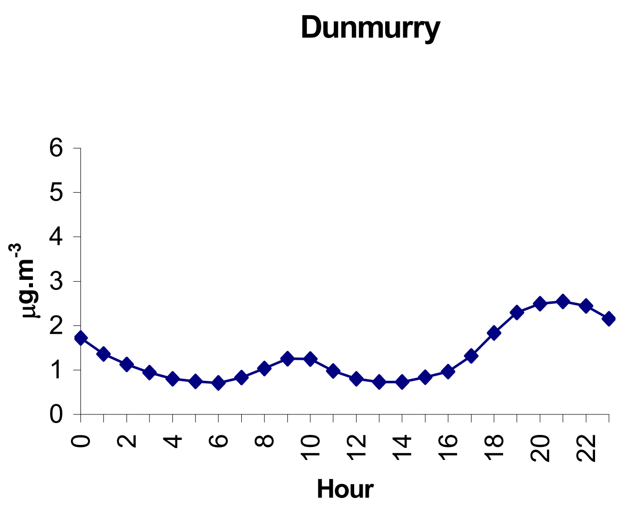

Birmingham Tyburn
µg.m-3
0
1
2
3
4
5
6
0 2 4 6 8 10 12 14 16 18 20 22
Hour

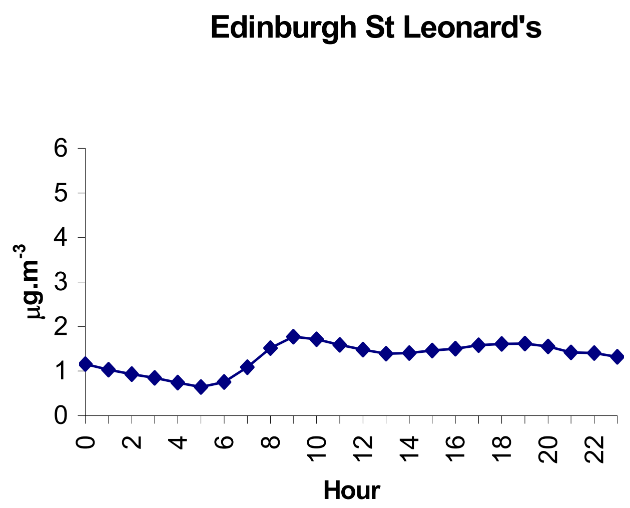

North Kensington
µg.m-3
0
1
2
3
4
5
6
0 2 4 6 8 10 12 14 16 18 20 22
Hour

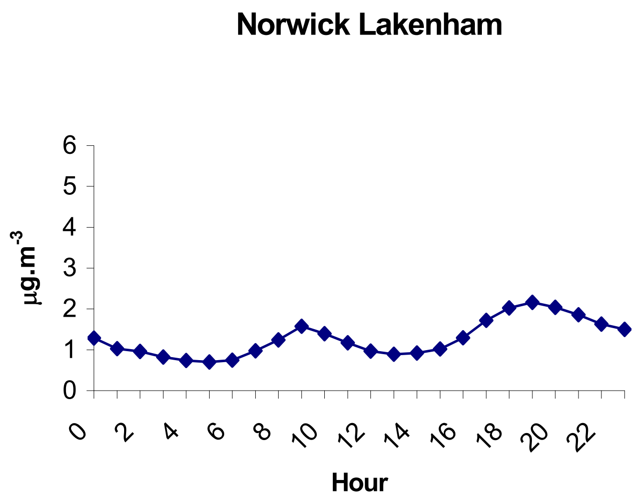

Cardiff
µg.m-3
0
1
2
3
4
5
6
0 2 4 6 8 10 12 14 16 18 20 22
Hour

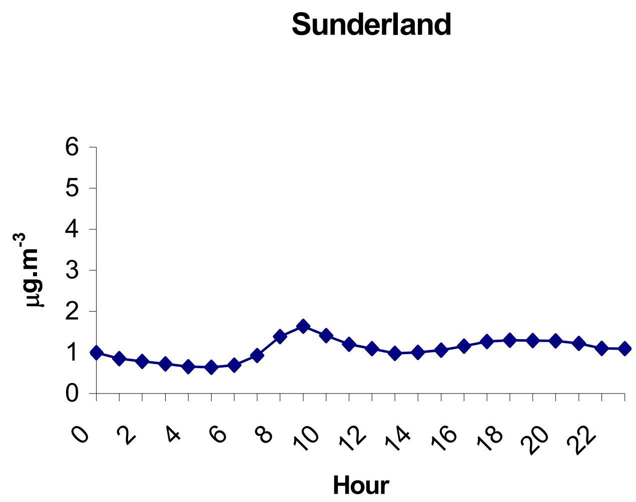

Strabane
µg.m-3
Hour


Halifax
µg.m-3
Hour


Dunmurry
µg.m-3
Hour


Edinburgh St Leonard's
µg.m-3
Hour





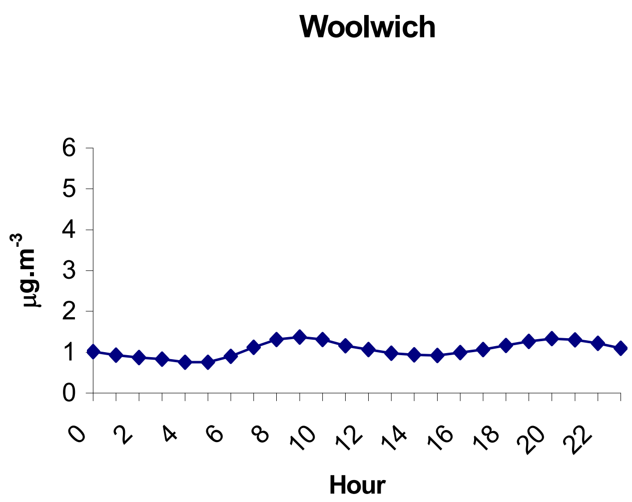


Figure 12 Urban Background Locations

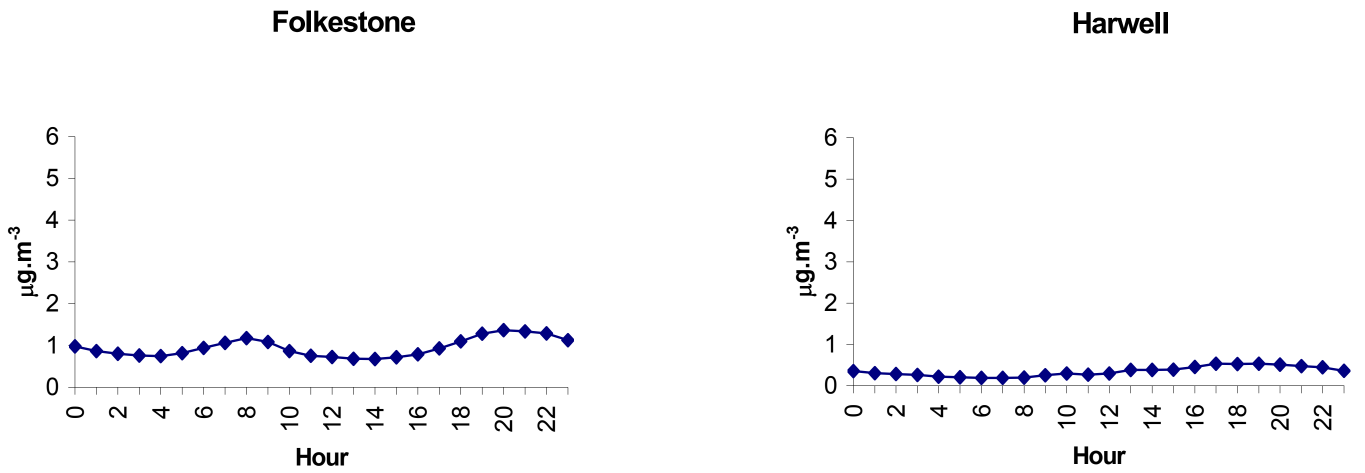


Figure 13 Suburban and Rural Locations

It can be seen that the black carbon concentrations at the roadside sites follow the expected profile for traffic movements through the day, with raised concentrations in the morning and evening rush hours. The city centre sites also show an increase in concentration coinciding with the morning rush hour, but the concentrations remain raised for longer into the evening than the roadside sites. The urban background sites are affected by the morning rush hour to a lesser extent but do show some increase in concentration. These sites also show an increase in concentration in the evening, which is probably due to local domestic heating. The Dunmurry and Strabane site concentrations are dominated by evening fuel use, probably due to the use of oil and solid fuel burning as a domestic fuel. The suburban and rural sites concentrations are lower than the other site classifications as expected.

5.1.4 Weekly Periodicity

Plots of the average concentrations on each day of the week for Roadside, Urban Centre, Urban Background, Suburban and Rural site classifications respectively can be seen in Figures 14 to 17. Table 10 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	10.9	6.8	1.59
Bath 6	2.7	1.8	1.51
Urban Centre			
Glasgow Centre	3.3	1.7	1.88
Bradford Town Hall	2.6	1.5	1.66
Belfast Centre	2.2	1.7	1.33
Manchester Piccadilly	2.2	1.4	1.57
Stoke Centre	2.2	1.4	1.55
Nottingham Centre	2.0	1.3	1.55
Dudley Central	1.8	1.0	1.78
Urban Background			
South Kirkby 1	2.6	1.1	2.25
Birmingham Tyburn	2.2	1.3	1.71
North Kensington	2.1	1.4	1.53
Cardiff 12	1.7	1.1	1.52
Halifax 17	1.7	0.9	1.84
Strabane 2	1.6	1.4	1.11
Dunmurry 3	1.4	1.0	1.36
Edinburgh St Leonard's	1.4	0.9	1.65
Norwich Lakenham	1.4	0.9	1.62
Sunderland 8	1.2	0.6	1.89
Woolwich 9	1.1	0.7	1.53
Suburban			
Folkestone	1.0	0.7	1.35
Rural			
Harwell	0.4	0.2	2.59

Table 10 Average Monday to Friday and Sunday Concentrations of Black Carbon

It can be seen that concentrations on a Sunday are significantly lower than on Monday to Fridays.

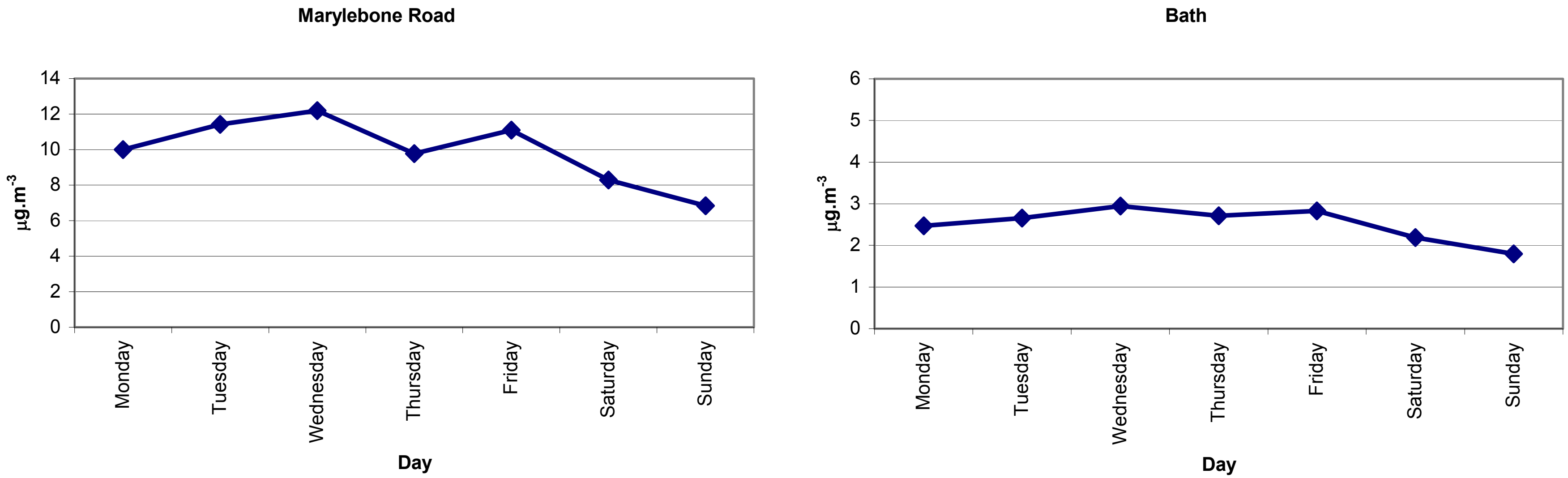
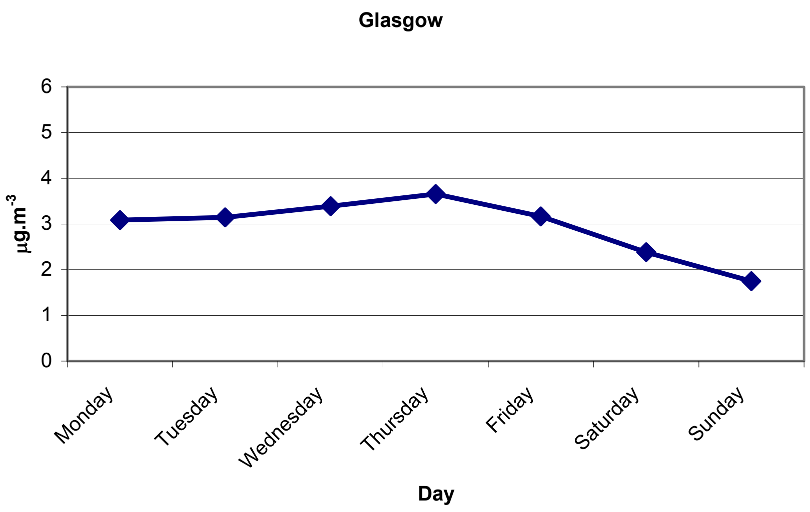
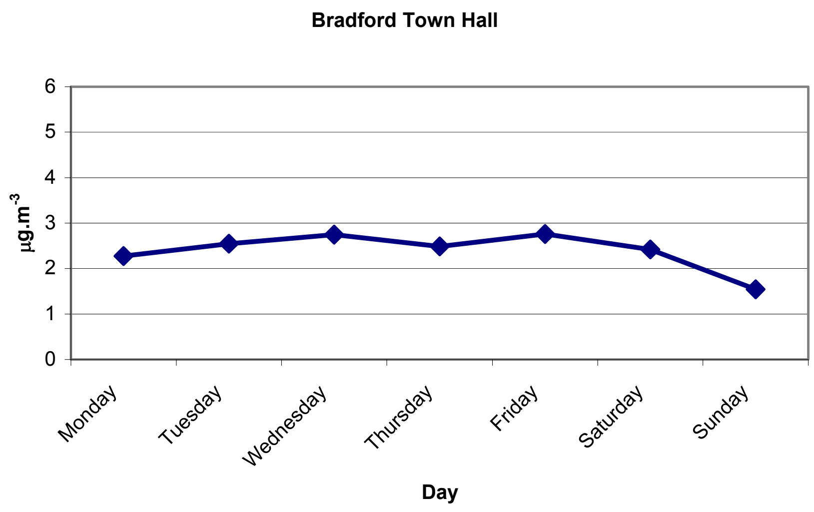
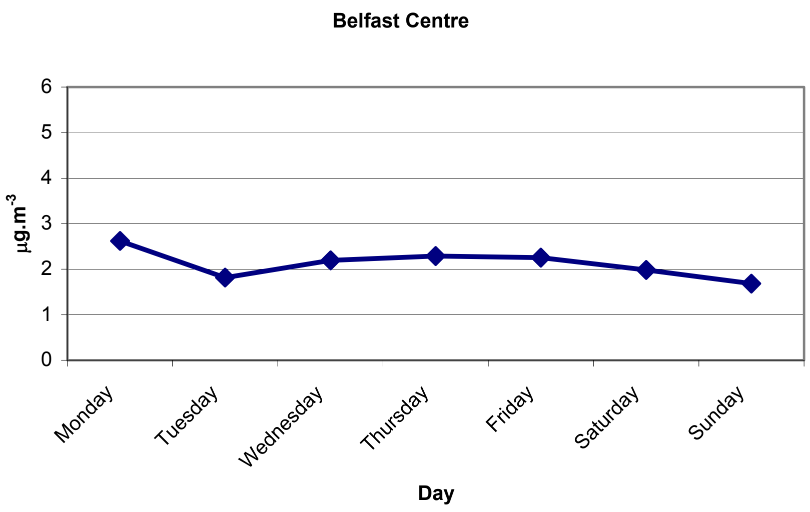
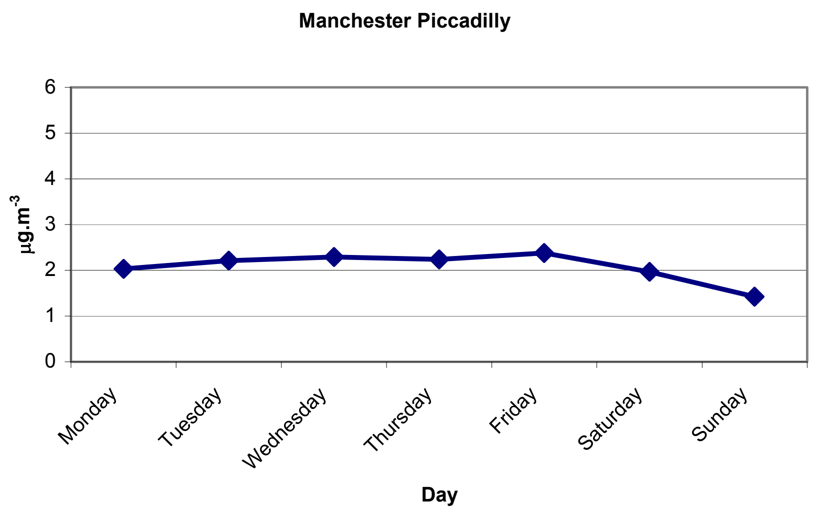


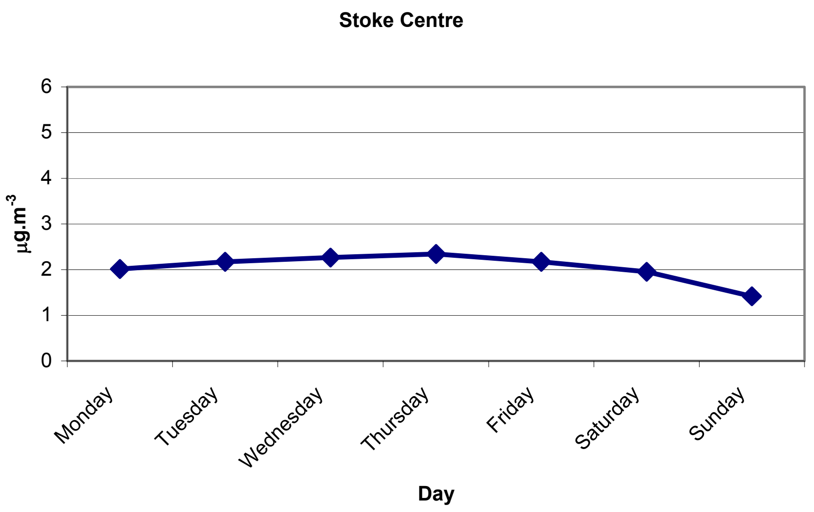
Figure 14 Roadside Locations

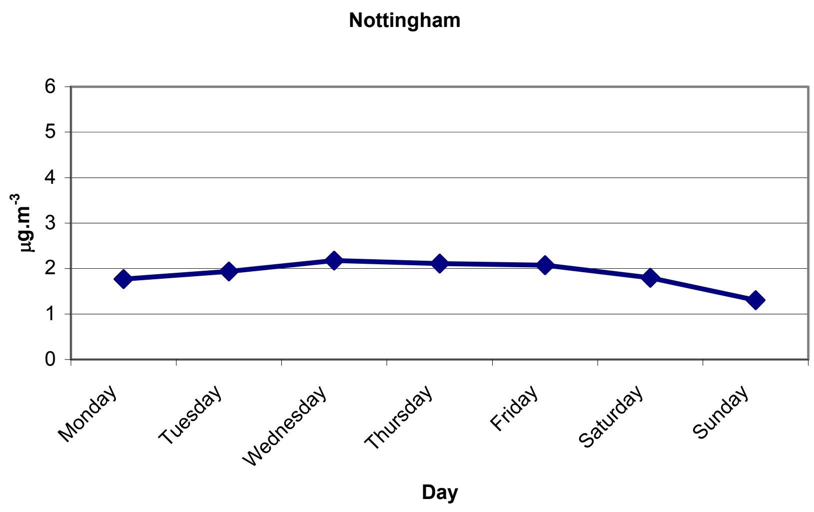

Glasgow
6
5
4
3
2
1
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Bradford Town Hall
6
5
4
3
2
1
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Belfast Centre
6
5
4
3
2
1
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Manchester Piccadilly
6
5
4
3
2
1
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day





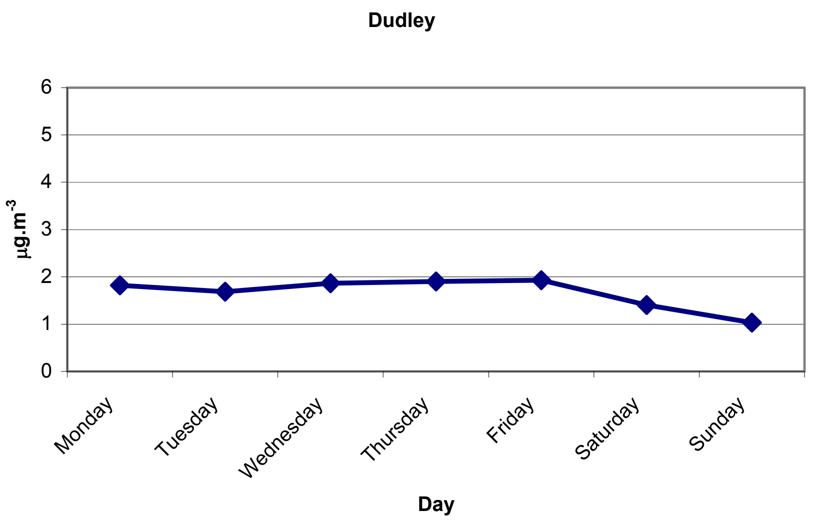
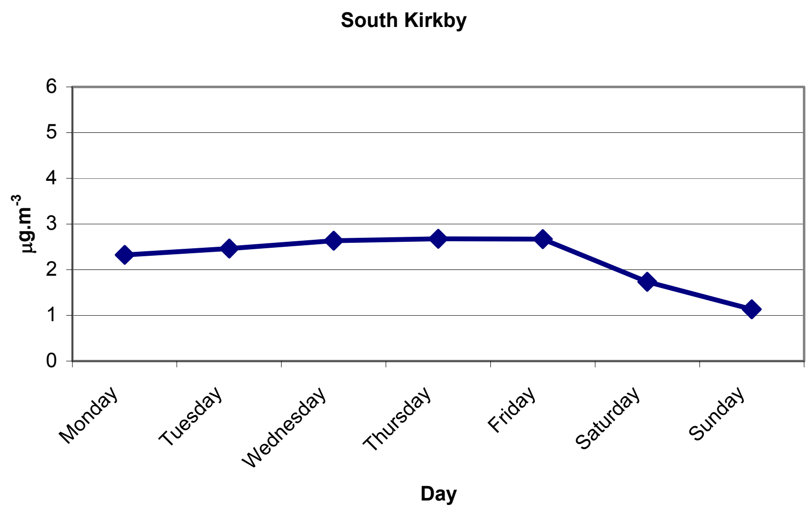
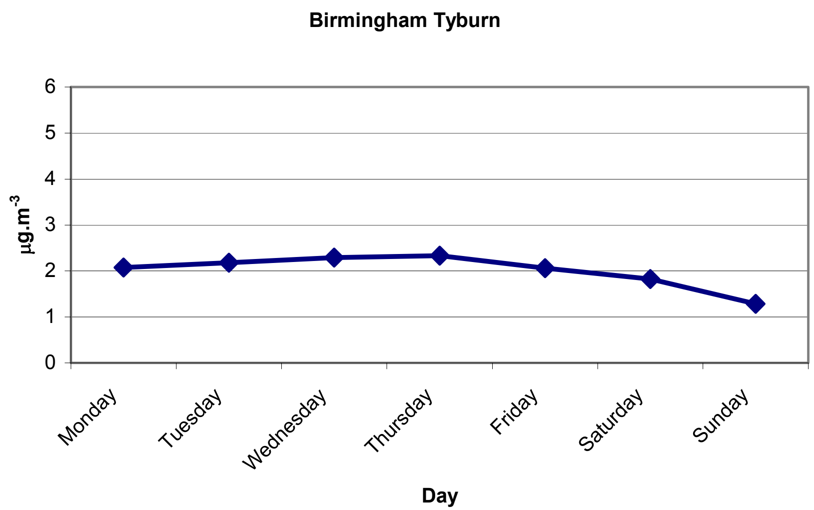
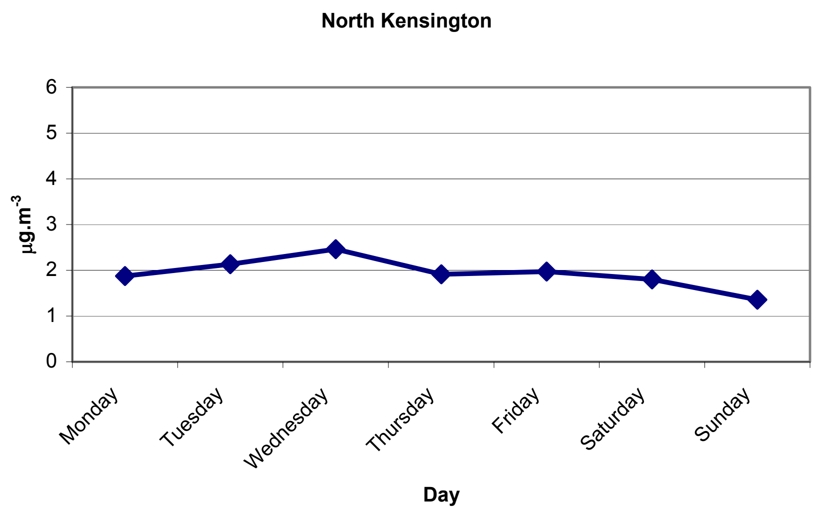
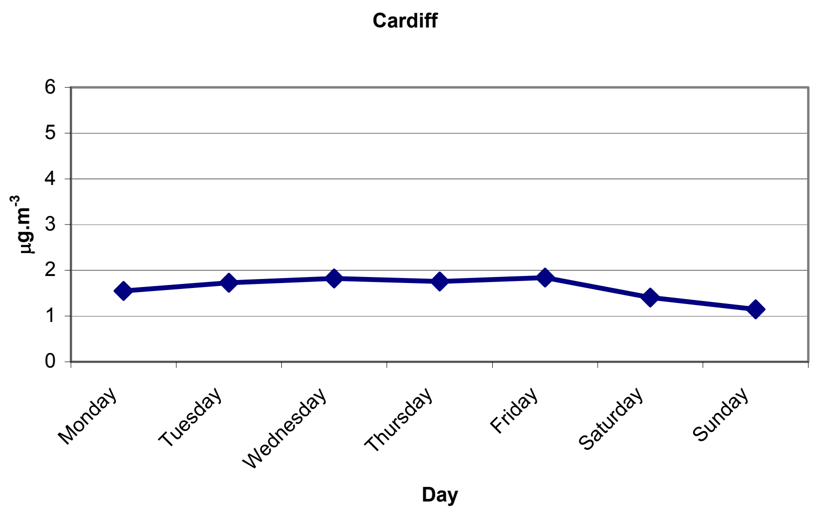


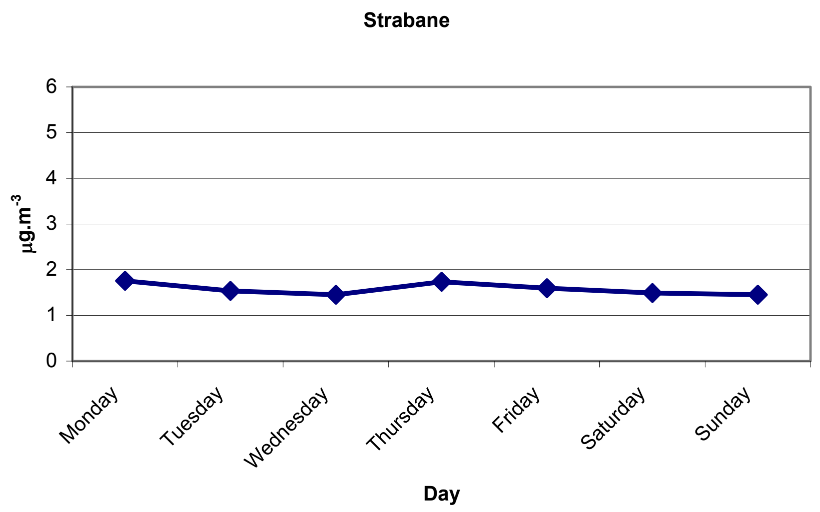
Figure 15 Urban Centre Locations

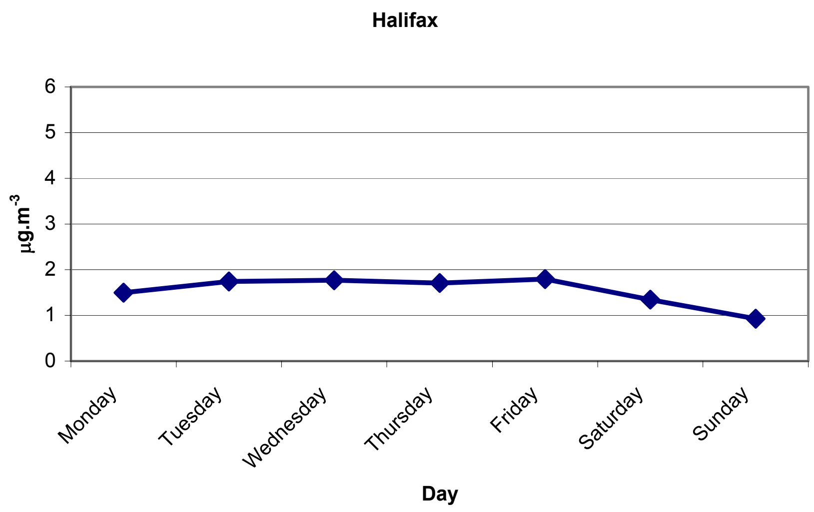

South Kirkby
µg.m-3
0
1
2
3
4
5
6
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

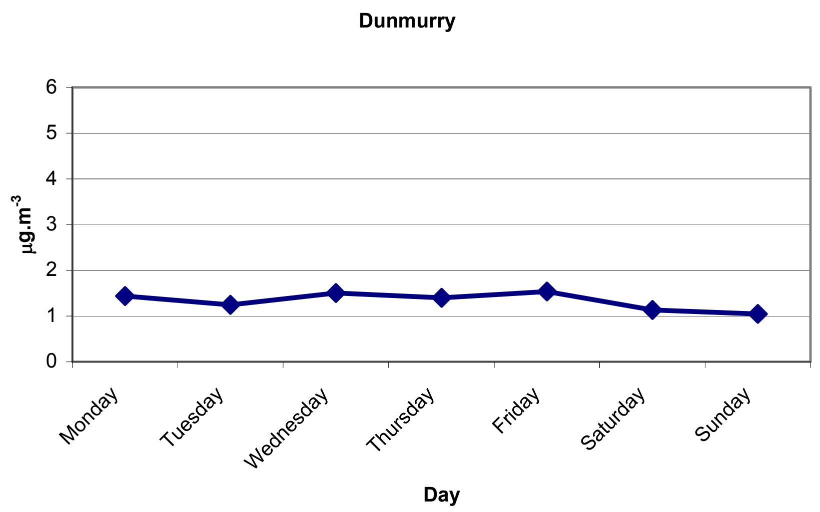

Birmingham Tyburn
µg.m-3
0
1
2
3
4
5
6
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

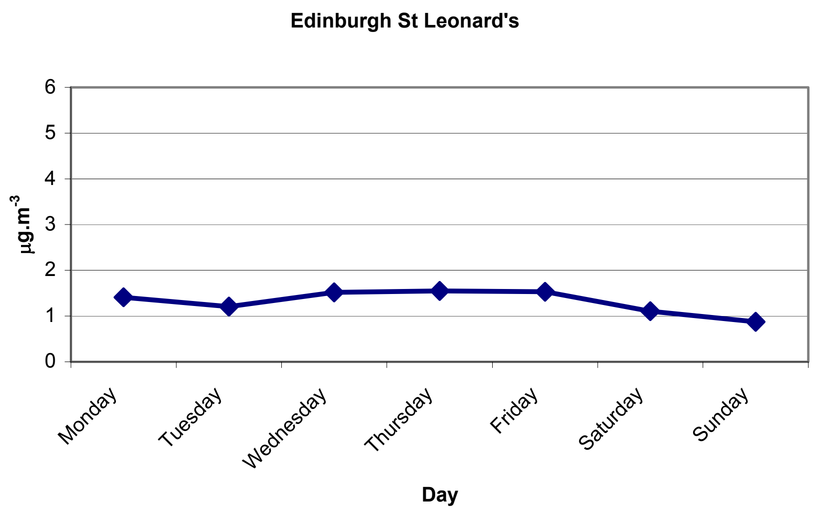

North Kensington
µg.m-3
0
1
2
3
4
5
6
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

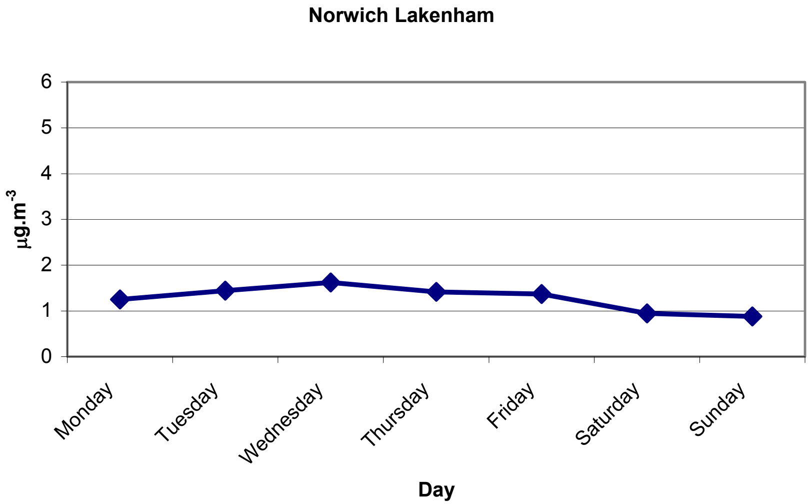

Cardiff
µg.m-3
0
1
2
3
4
5
6
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

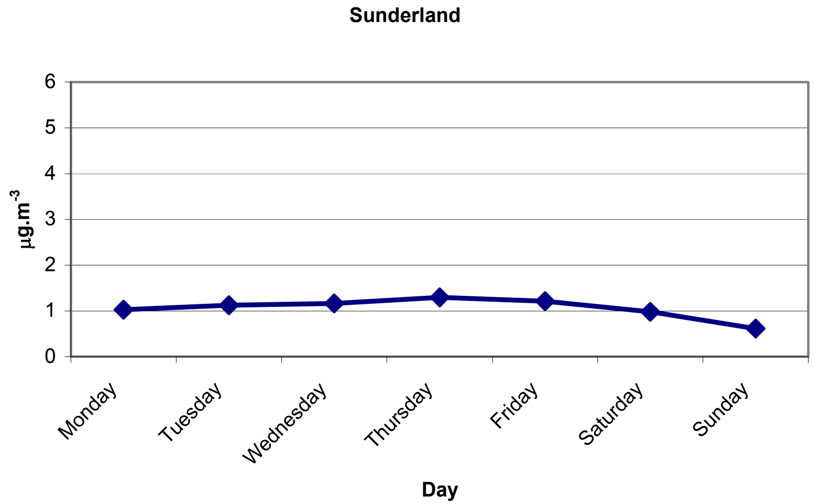

Strabane
µg.m-3
6
5
4
3
2
1
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Halifax
µg.m-3
6
5
4
3
2
1
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Dunmurry
µg.m-3
6
5
4
3
2
1
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Edinburgh St Leonard's
µg.m-3
6
5
4
3
2
1
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day





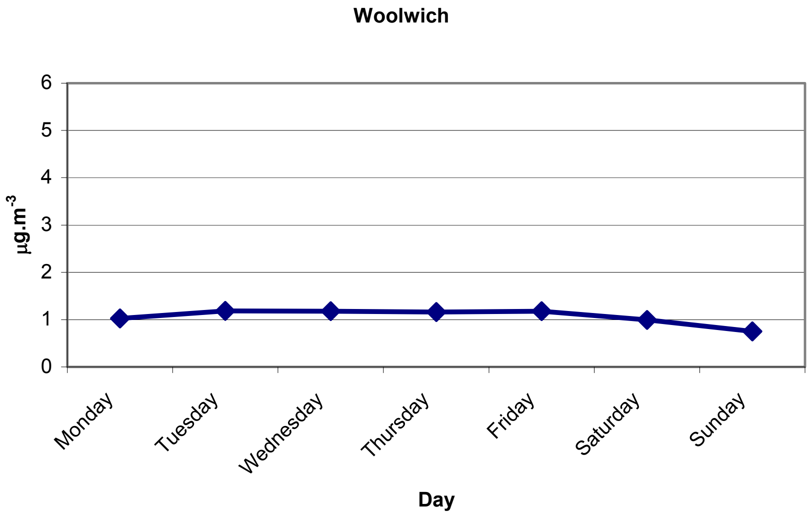
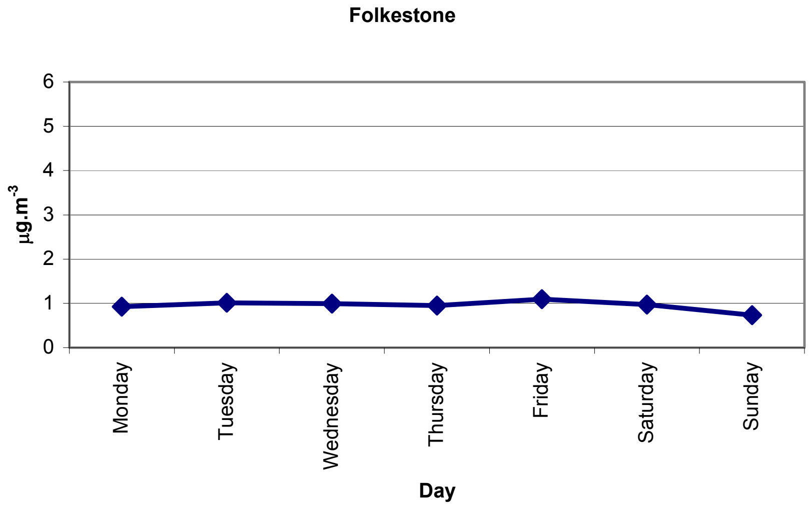


Figure 16 Urban Background Locations



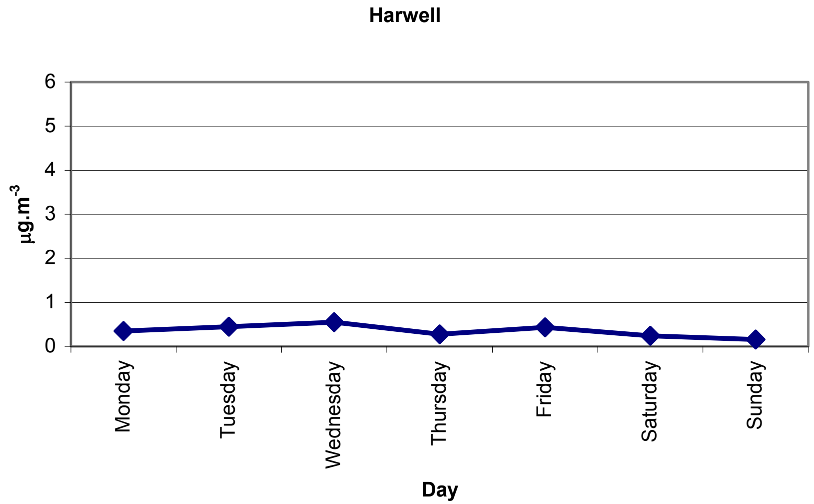


Figure 17 Suburban and Rural Locations

5.1.5 Comparisons With Other Pollutants

Elemental Carbon

Daily Elemental Carbon (EC) measurements are made at the North Kensington, Marylebone Road and Harwell sites by the Particle Number and Speciation Network[5]. Aethalometer concentrations (BC) at these sites have been averaged into daily measurements and plotted as scatter plots against the elemental carbon results in Figures 18 to 20.

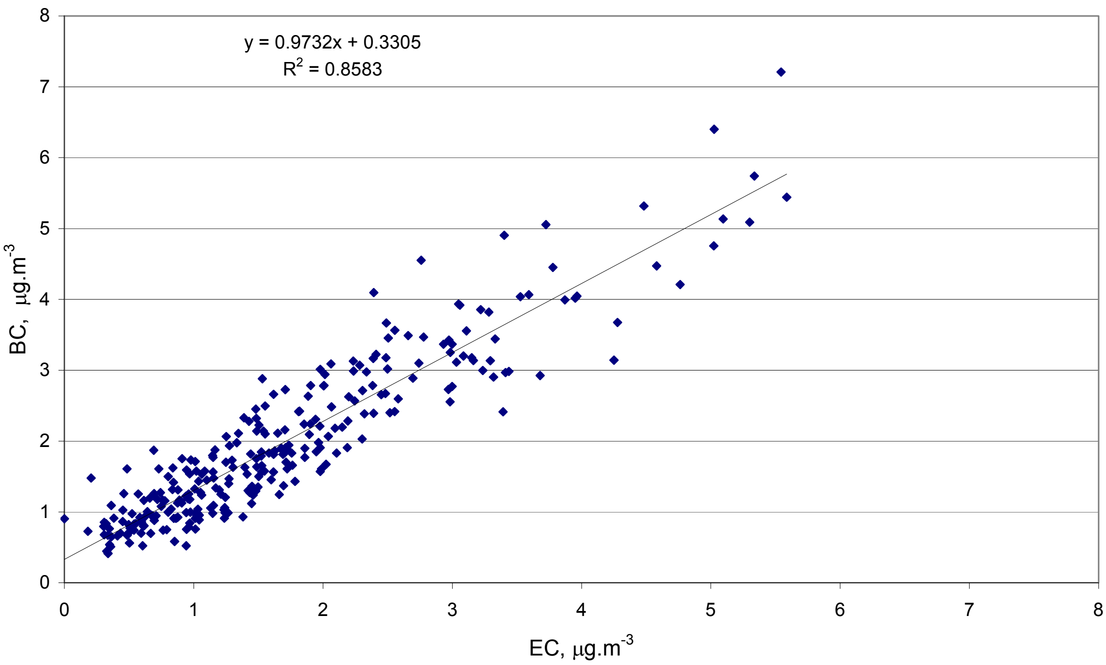


Figure 18 2009 EC and BC Measurements at North Kensington

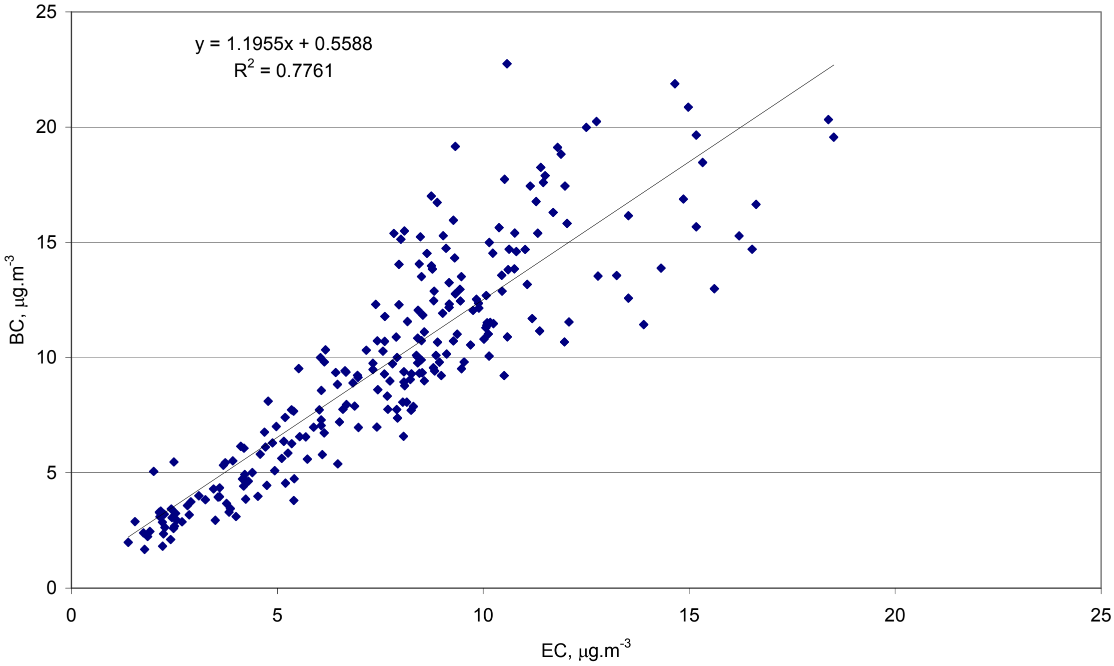


Figure 19 2009 EC and BC Measurements at Marylebone Road

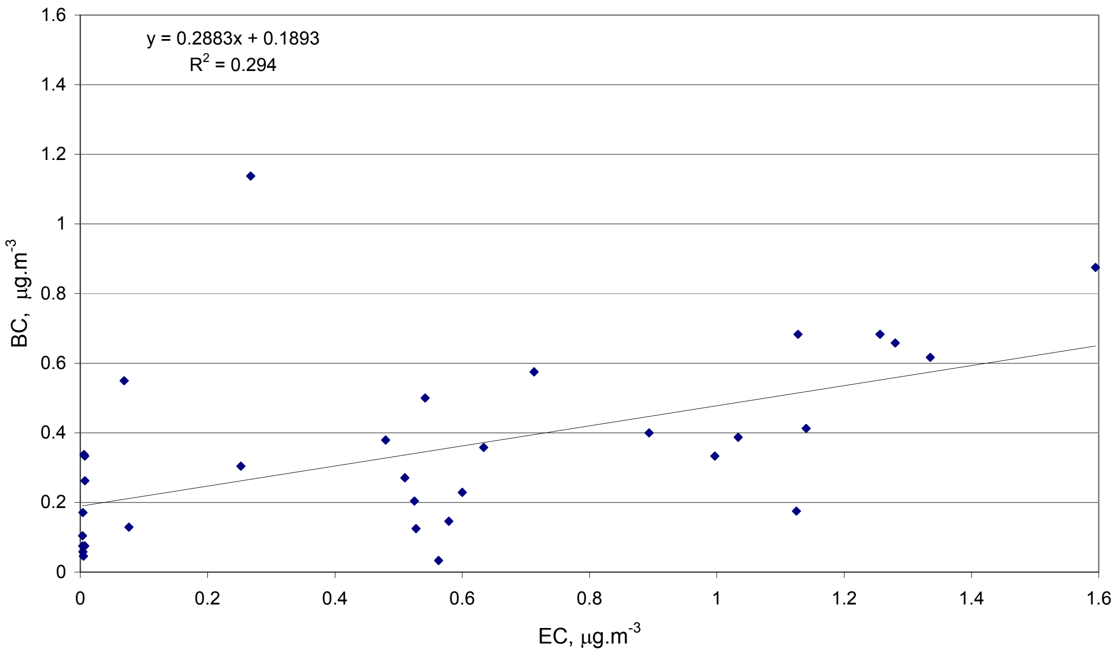


Figure 20 2009 EC and BC Measurements at Harwell

It can be seen that there is a good relationship between the EC and BC concentrations measured at North Kensington and Marylebone Road. There were not enough BC data collected at Harwell to make a significant comparison. The lack of agreement is likely to be due to measurement method issues at low concentrations, as described by P Quincey[6].

5.2 UV Component

The following sections present the UV component concentrations measured in 2009.

5.2.1 Time Series

The following charts show the UV component concentrations measured by the UK Black Carbon Network for 2009. The time resolution of the measurements is hourly. Data has been split into regions of the UK for presentation purposes.

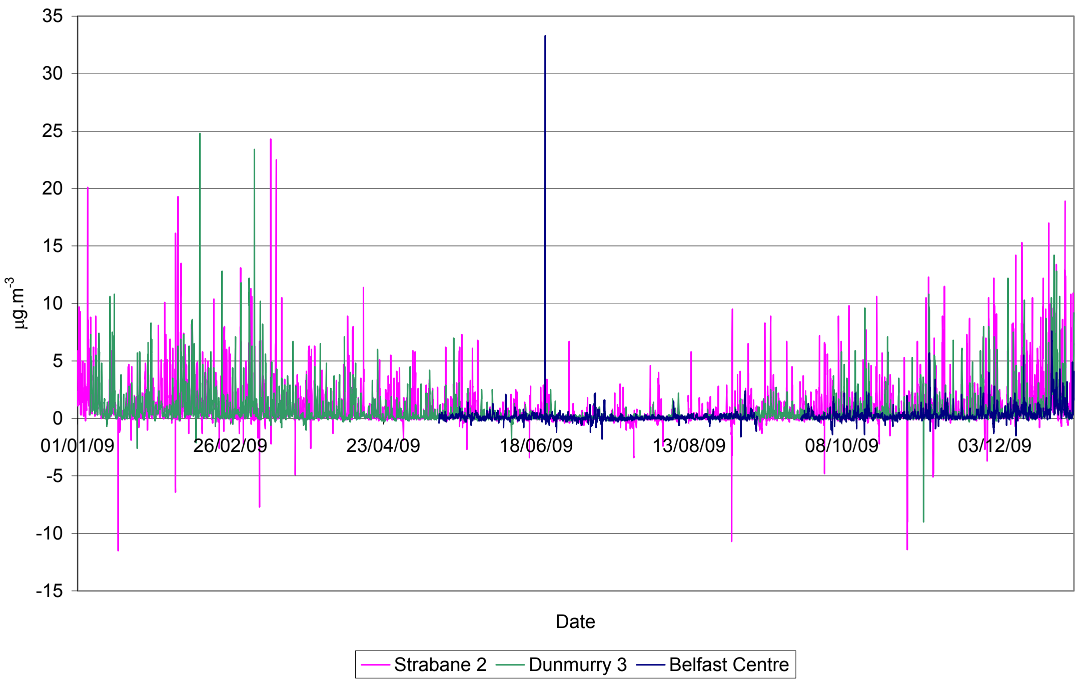
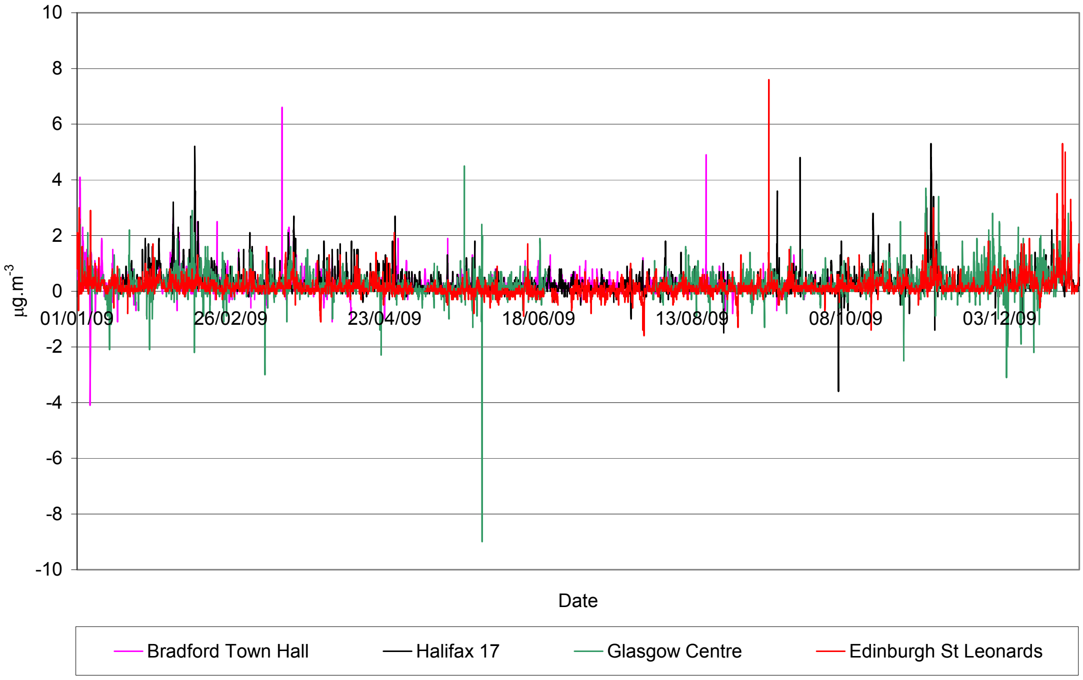


Figure 21 UV component concentrations during 2009 in Northern Ireland



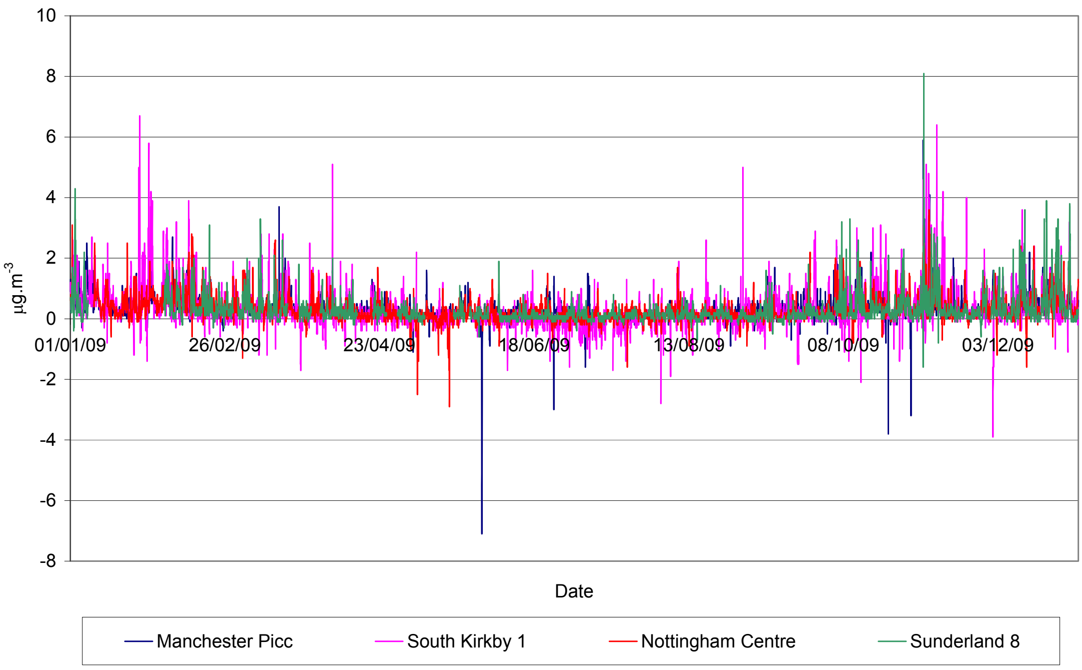
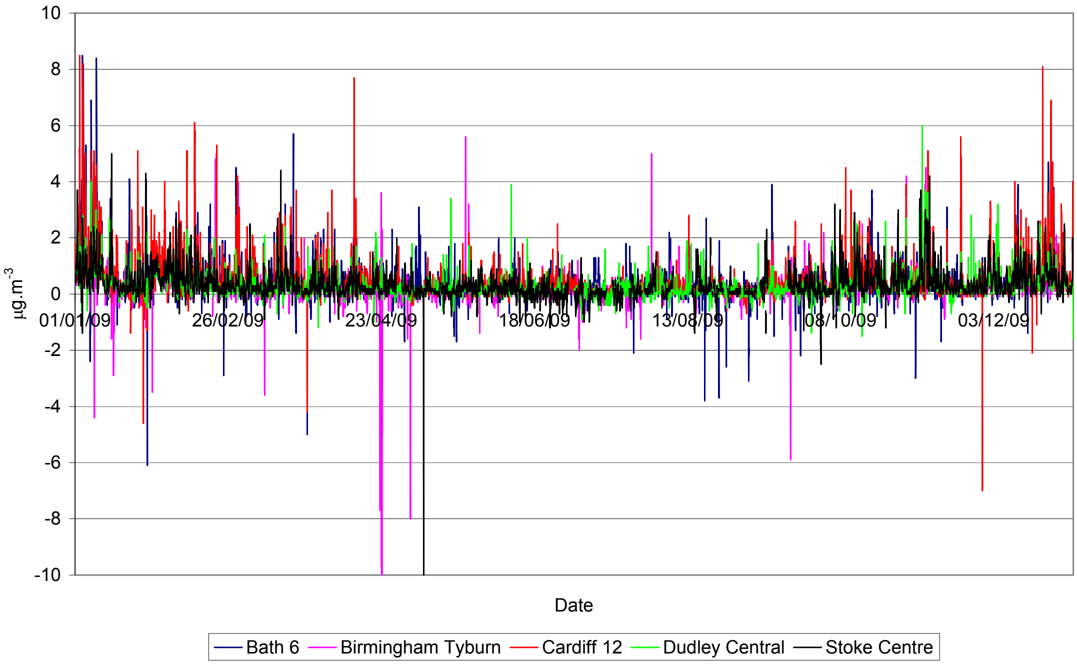


Figure 22 + 23 **UV component concentrations during 2009 in Scotland and Northern England**



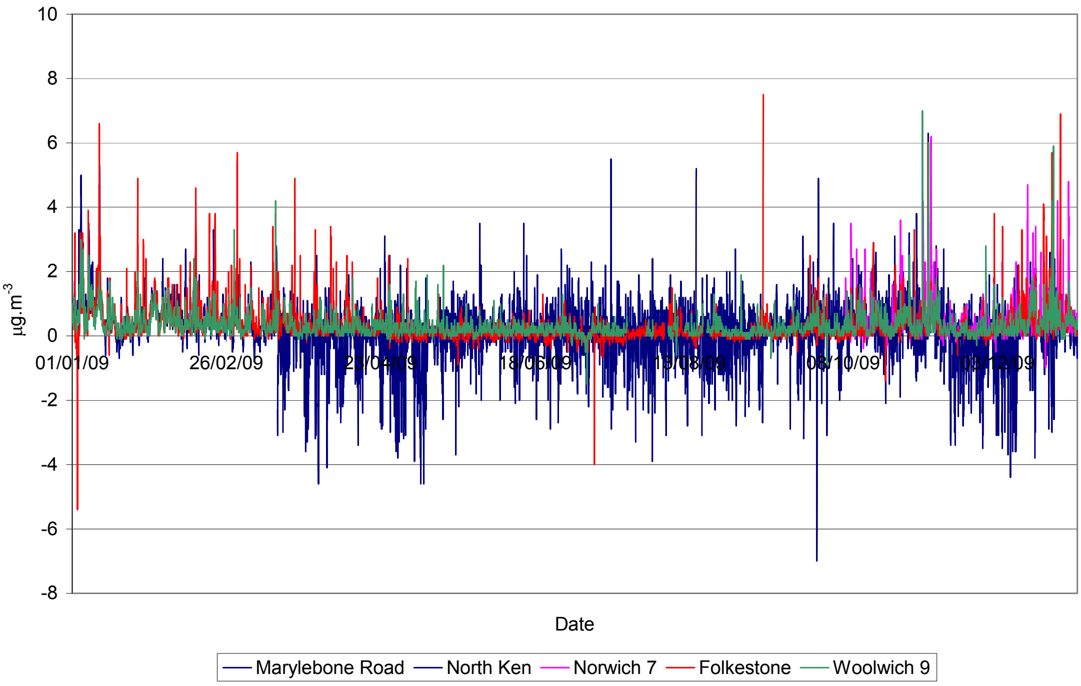


Figure 24 + 25 UV component concentrations during 2009 in Southern England and Wales

Most of the negative concentration spikes occur at roadside or near roadside sites and are probably an artefact due the particle size of exhaust emissions being close to the wavelength of light used to measure the UV component.

5.2.2 Averages and Data Capture

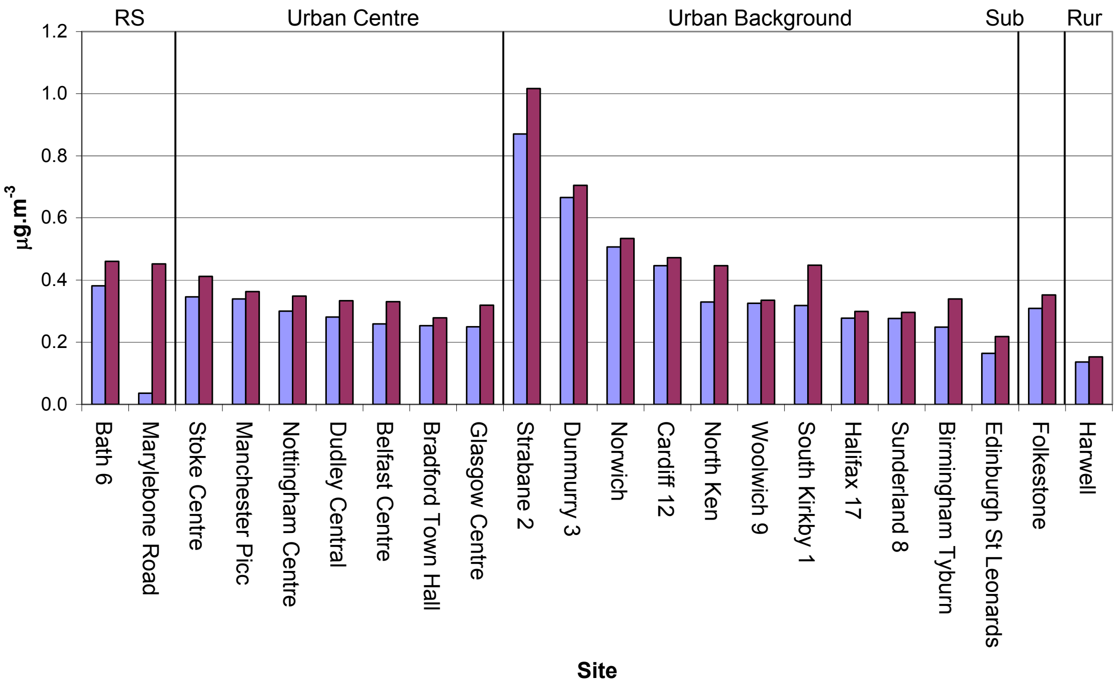
Site	Mean concentration, (all measurements included) $\mu g.m^{-3}$	Mean concentration, (negative measurements excluded) $\mu g.m^{-3}$
Bath 6	0.38	0.46
Belfast Centre	0.26	0.33
Birmingham Tyburn	0.25	0.34
Bradford Town Hall*	0.25	0.28
Cardiff 12	0.45	0.47
Dunmurry 3	0.67	0.70
Edinburgh St Leonard’s	0.16	0.22
Folkestone	0.31	0.35
Glasgow Centre	0.25	0.32
Dudley Central	0.28	0.33
Halifax 17	0.28	0.30
Manchester Piccadilly	0.34	0.36
Marylebone Road	0.04	0.45
North Kensington	0.33	0.45
Norwich Lakenham*	0.51	0.53
Nottingham Centre	0.30	0.35
South Kirkby 1	0.32	0.45
Stoke Centre	0.35	0.41
Strabane 2	0.87	1.02
Sunderland 8	0.28	0.30
Woolwich 9	0.33	0.33
Harwell*	0.14	0.15

Table 11 Annual Mean UV Component Concentration for 2009, all data included

It can be seen that by excluding all the negative UV component concentrations, the Marylebone Road mean becomes comparable to other sites.

The annual mean concentrations are presented as a bar graph (Figure 26) to aid the comparison of sites:

The concentrations of the UV component measured at the suburban site in Folkestone, the urban background sites in London (North Kensington and Woolwich) and the Marylebone Road site in Central London are comparable with no obvious urban or roadside increment.

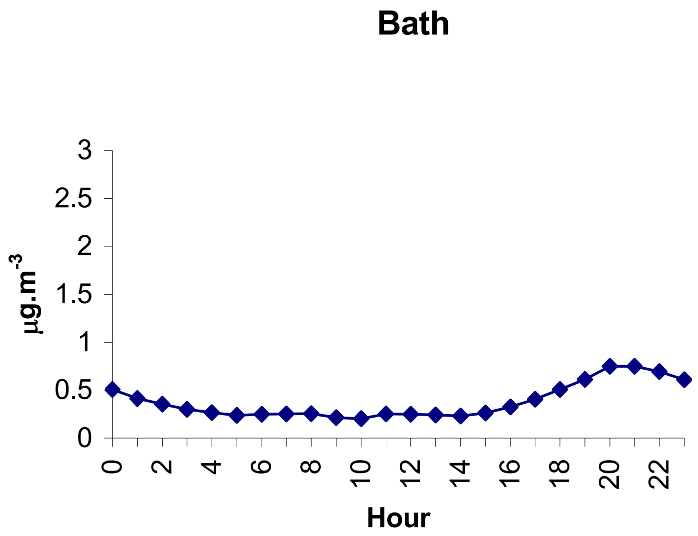


Key:
Mean of all data
Mean of all negative concentrations excluded

Figure 26 Annual Mean UV component concentration for 2009

5.2.3 Diurnal Periodicity

Plots of the average concentrations on each hour of the day for Roadside, Urban Centre, Urban Background, Suburban and Rural site classifications respectively can be seen in Figures 27 to 30. The results are averages of all measurements, including negative values.



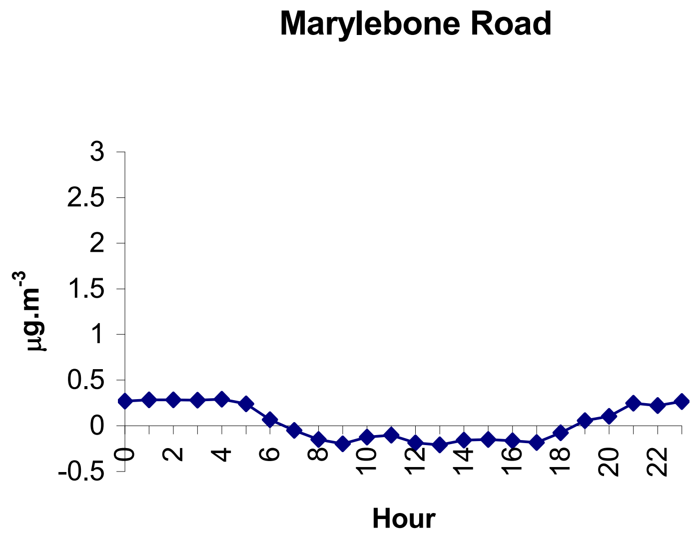
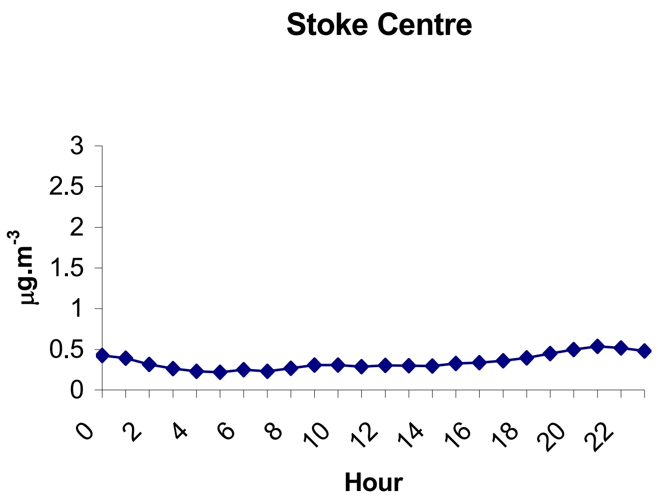
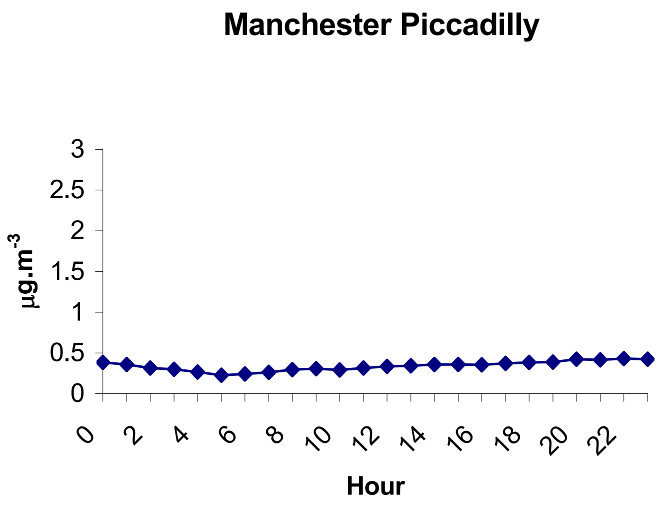
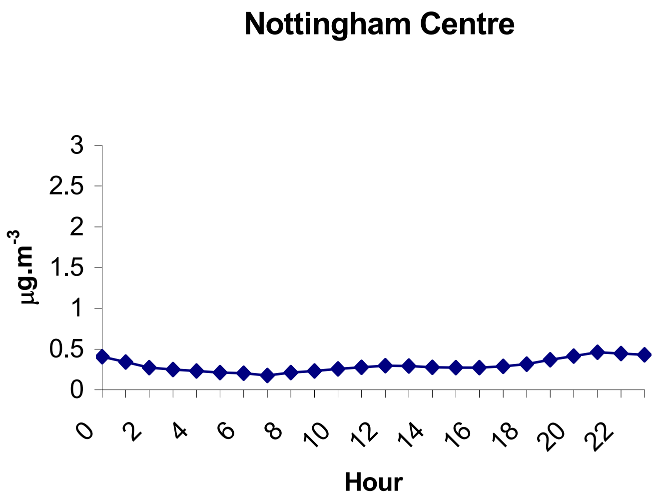
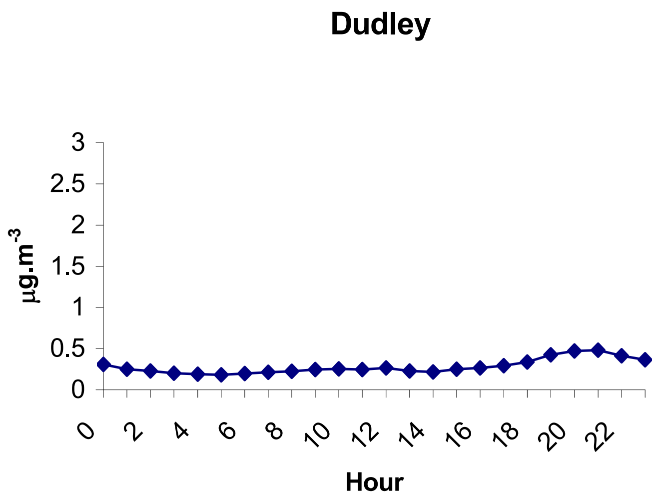


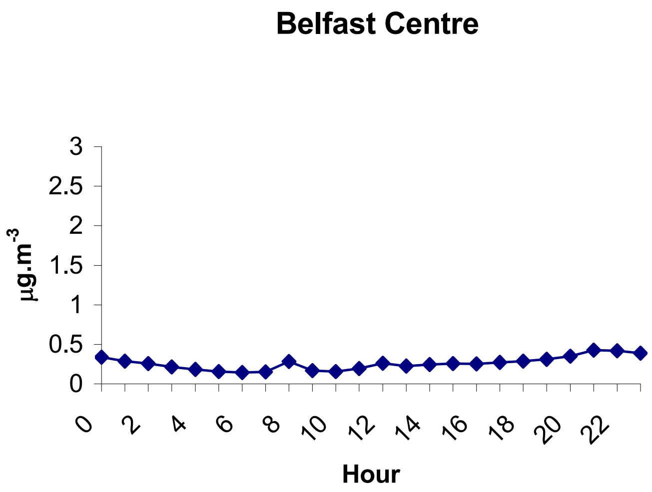
Figure 27 Roadside Locations

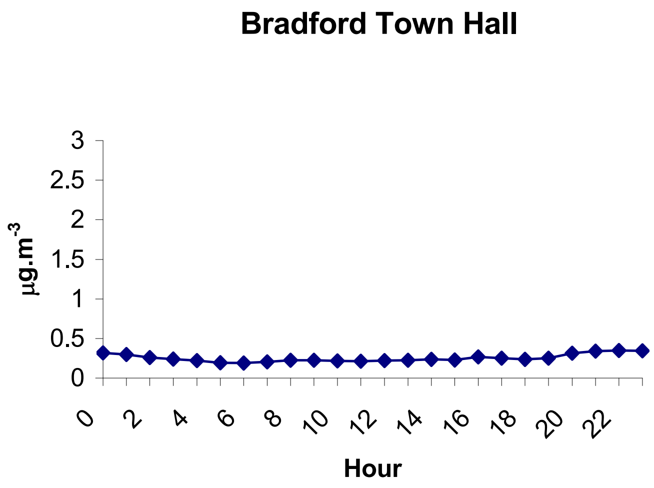

Stoke Centre
3
2.5
2
1.5
1
0.5
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Manchester Piccadilly
3
2.5
2
1.5
1
0.5
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Nottingham Centre
3
2.5
2
1.5
1
0.5
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Dudley
3
2.5
2
1.5
1
0.5
0
µg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour





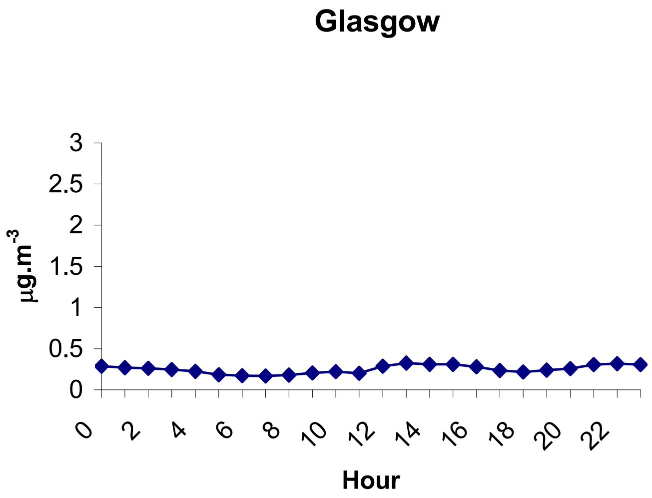
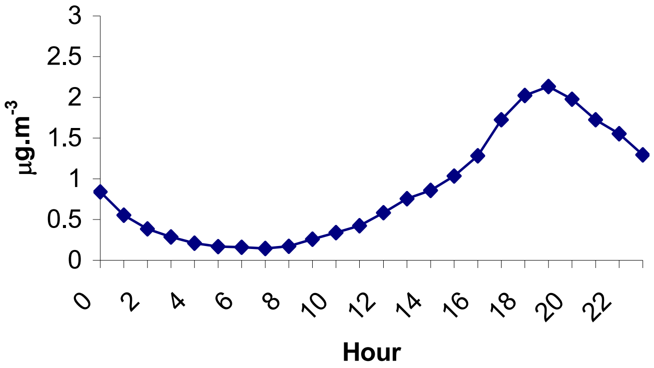
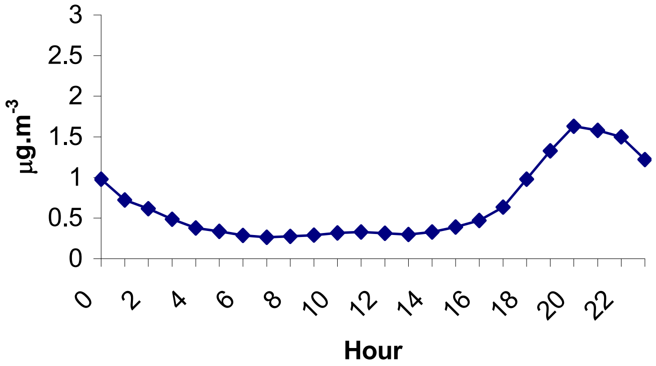


Figure 28 Urban Centre Locations

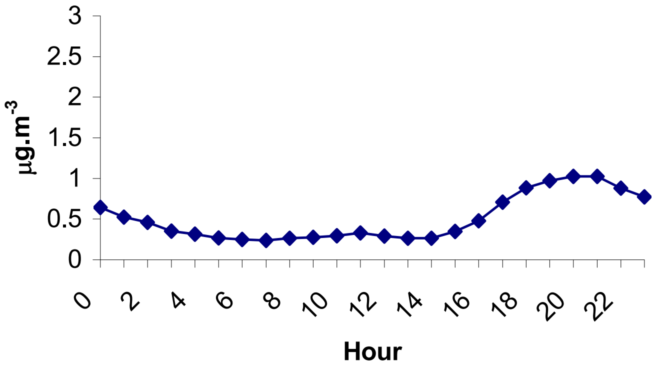
Strabane



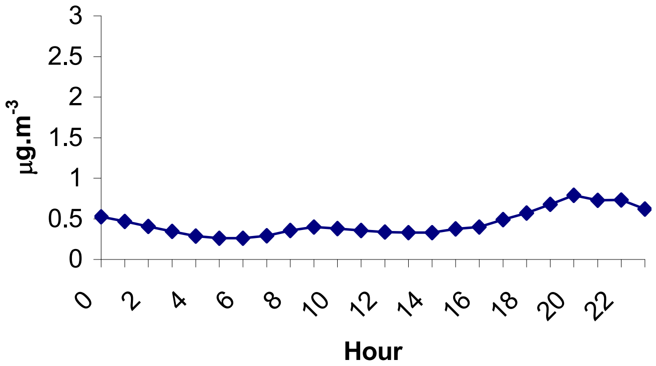
Dunmurry

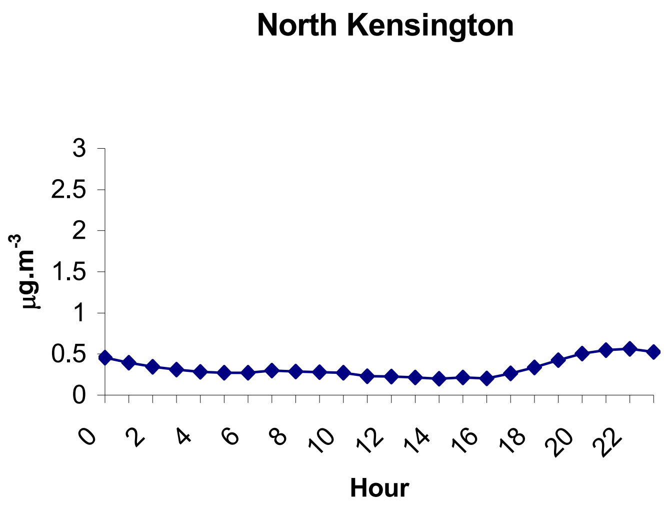


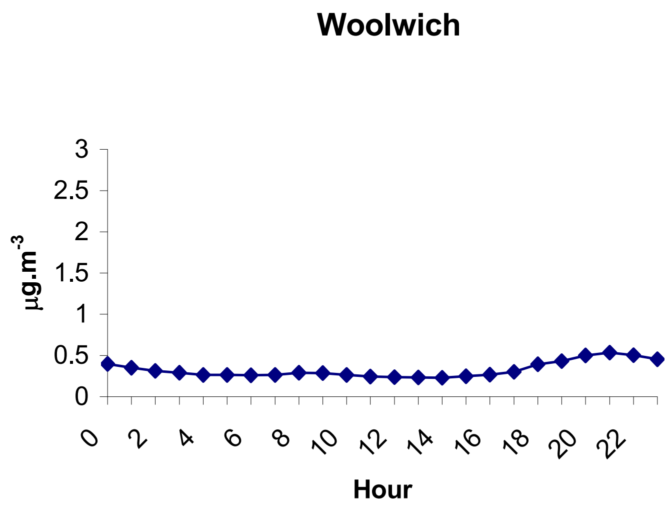
Norwich Lakenham

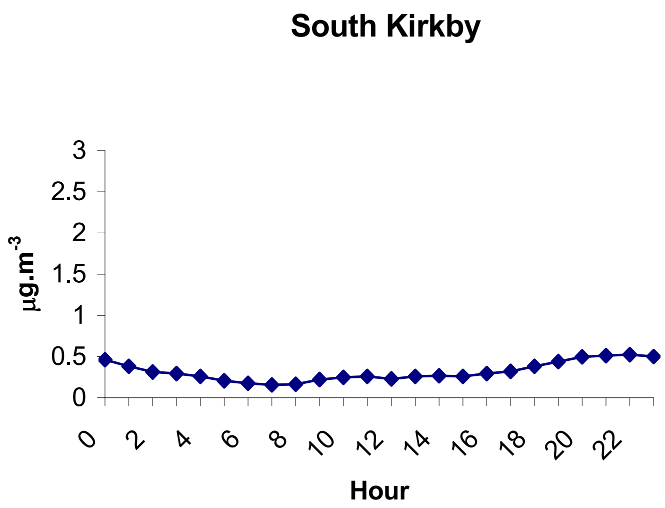


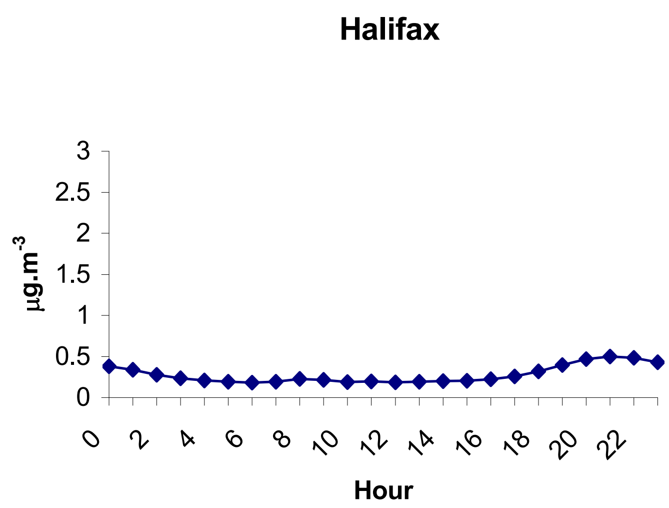
Cardiff

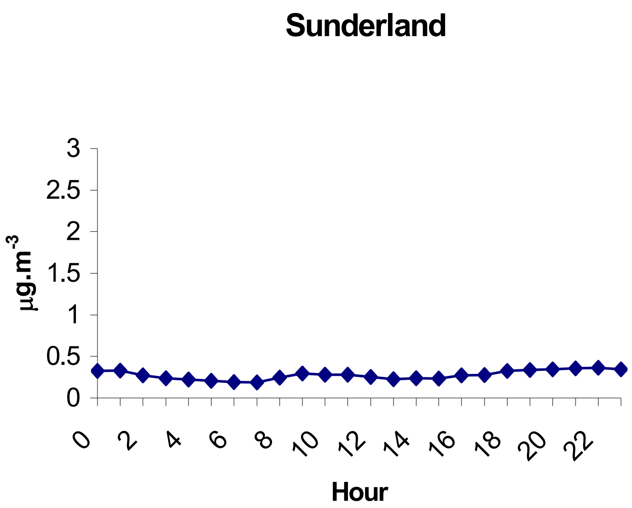


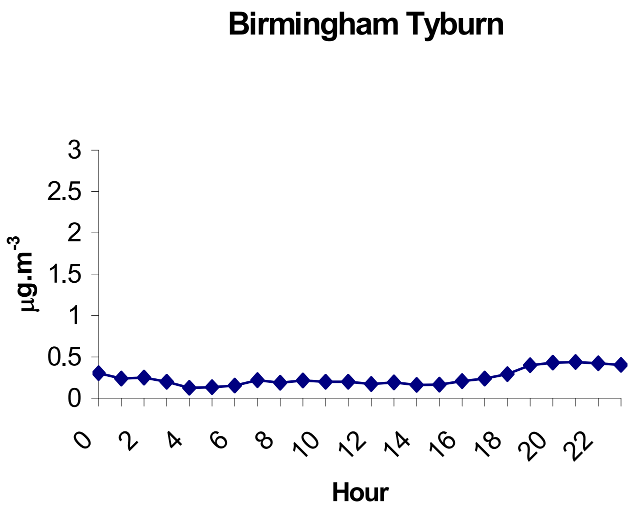

North Kensington
3
2.5
2
1.5
1
0.5
0
μg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Woolwich
3
2.5
2
1.5
1
0.5
0
μg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


South Kirkby
3
2.5
2
1.5
1
0.5
0
μg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour


Halifax
3
2.5
2
1.5
1
0.5
0
μg.m-3
0 2 4 6 8 10 12 14 16 18 20 22
Hour





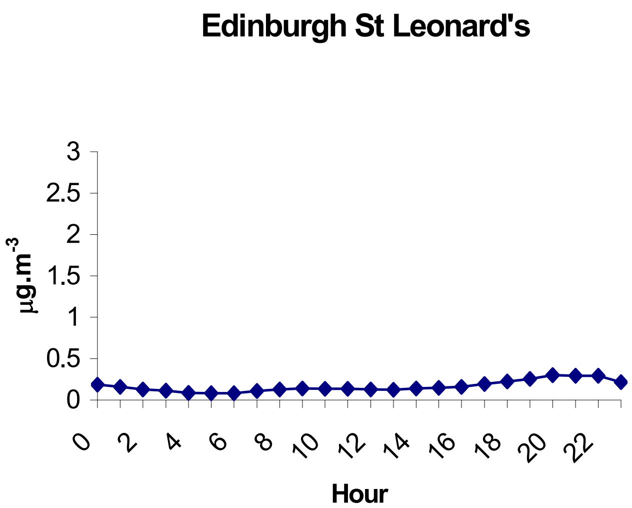
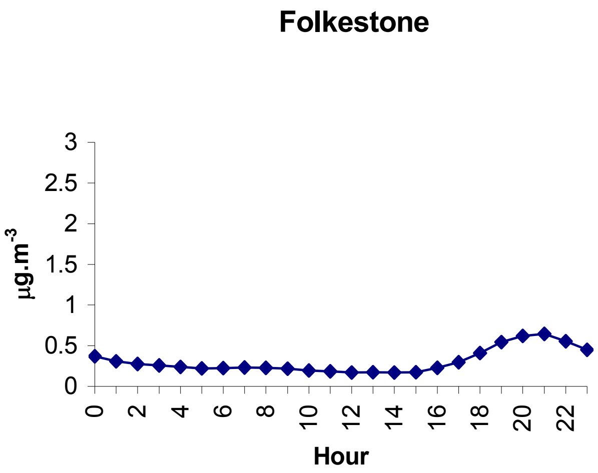


Figure 29 Urban Background Locations



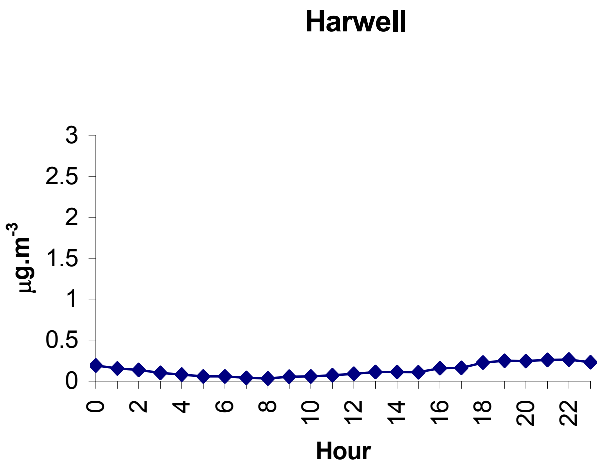


Figure 30 Suburban and Rural Locations

It can be seen that at the roadside sites the negative concentrations depress the hourly average 'UV' concentrations between the morning and evening rush hours. This is especially apparent at the Marylebone Road site, where the average 'UV' concentration during this period is actually negative. The urban centre concentrations show very little time dependence during the day, with slight rises in concentration during the evening. The small 09:00 hrs increment at Belfast Centre may be due to lorries parking next to the site while they unload goods to the local shops; there are a significant number of lorry movements past the site at this time. Concentrations at the urban background sites show a significant increase in concentrations during the evening period, especially at the Strabane, Dunmurry and Norwich sites. This is due to the use of oil and solid fuel burning in the local domestic heating. This effect of local heating can also be seen in the concentrations at the Folkestone suburban site.

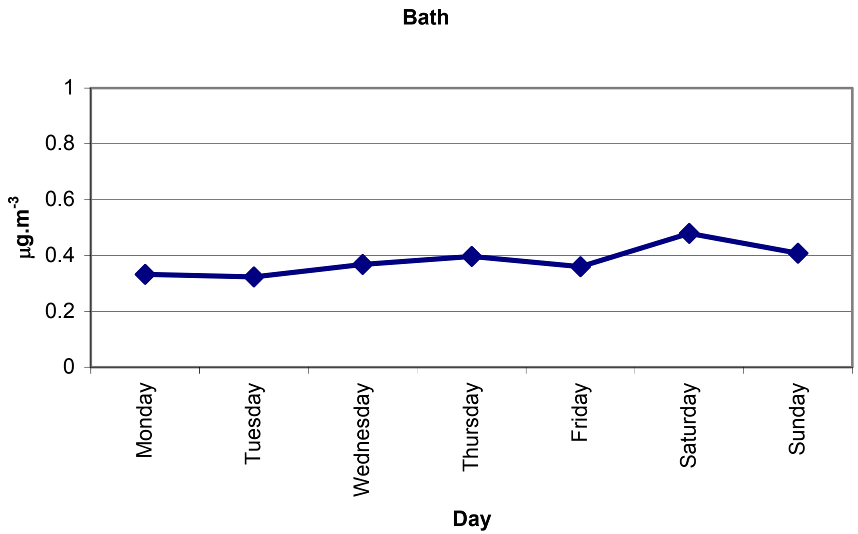
5.2.4 Weekly Periodicity

Plots of the average concentrations on each day of the week for Roadside, Urban Centre, Urban Background, Suburban and Rural site classifications respectively can be seen in Figures 31 to 34. Table 12 shows the difference between the Monday to Friday average concentration and the Sunday average concentration for all data. The sites have been sorted into site classification and are in descending order of annual average in each site classification. The results are averages of all measurements, including negative values.

Site	Monday - Friday	Sunday	Ratio
Roadside			
Marylebone Road	0.0	0.2	-0.17
Bath 6	0.4	0.4	0.87
Urban Centre			
Glasgow Centre	0.3	0.2	1.20
Bradford Town Hall	0.2	0.2	1.02
Belfast Centre	0.3	0.3	0.93
Manchester Piccadilly	0.3	0.3	1.06
Stoke Centre	0.4	0.3	1.15
Nottingham Centre	0.3	0.3	1.13
Dudley Central	0.3	0.3	1.09
Urban Background			
South Kirkby 1	0.3	0.3	1.14
Birmingham Tyburn	0.2	0.3	0.93
North Kensington	0.3	0.3	0.91
Cardiff 12	0.4	0.5	0.95
Halifax 17	0.3	0.3	0.95
Strabane 2	0.9	0.9	0.95
Dunmurry 3	0.7	0.7	0.97
Edinburgh St Leonard’s	0.2	0.2	1.04
Norwich Lakenham	0.5	0.5	0.98
Sunderland 8	0.3	0.2	1.45
Woolwich 9	0.3	0.3	0.95
Suburban			
Folkestone	0.3	0.3	0.82
Rural			
Harwell	0.2	0.1	2.01

Table 12 Average Monday to Friday and Sunday Concentrations of the UV Component, all data included

It can be seen that the negative concentrations at Marylebone Road are dominant in the Monday to Friday period, suggesting that this effect is dominated by vehicle exhaust, probably from commercial vehicles rather than the private fleet. Concentrations at urban centre and background sites are generally constant over the week, while concentrations at the suburban site are significantly higher at the weekend than in the week.



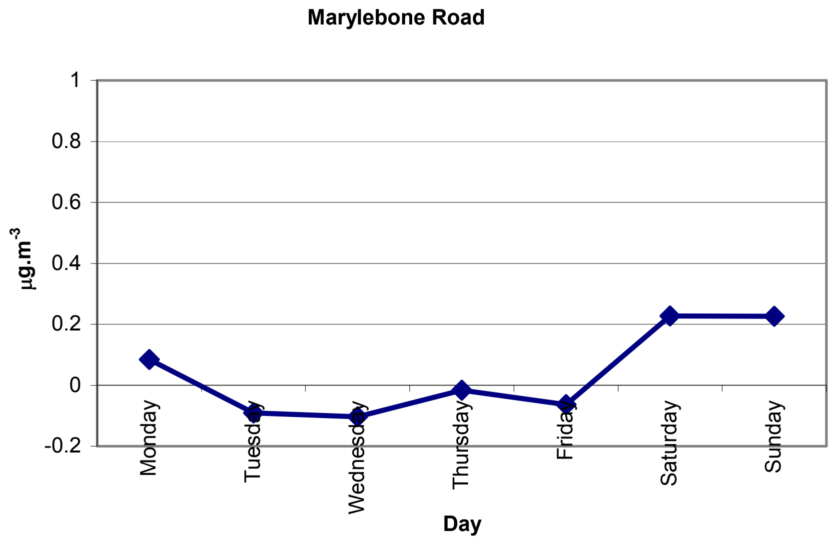
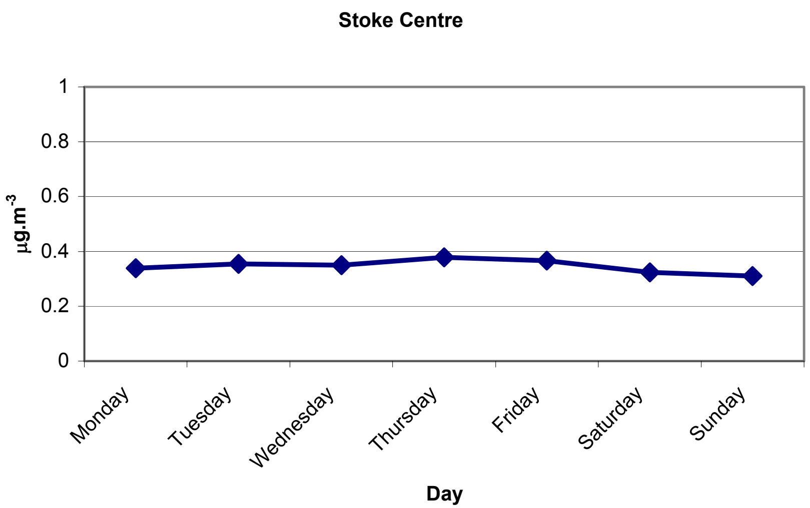
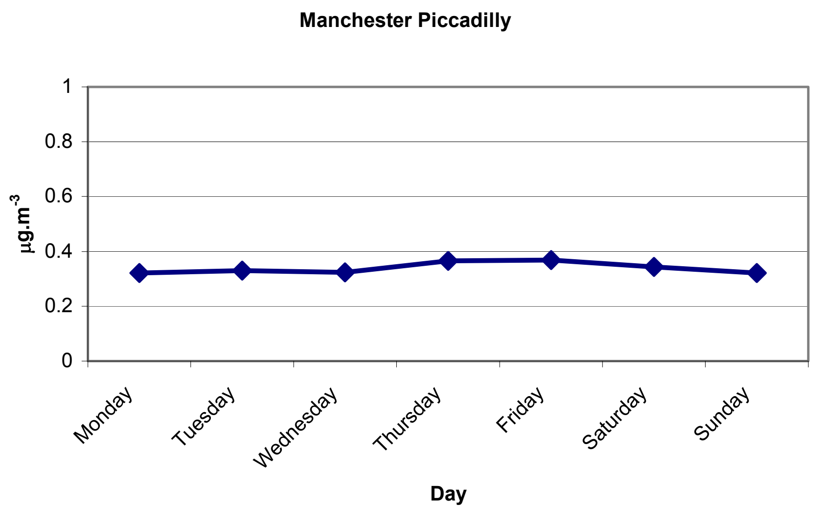
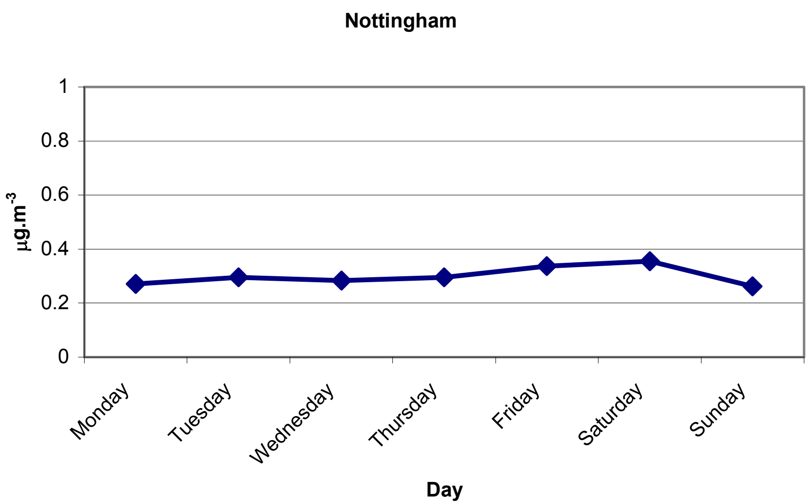
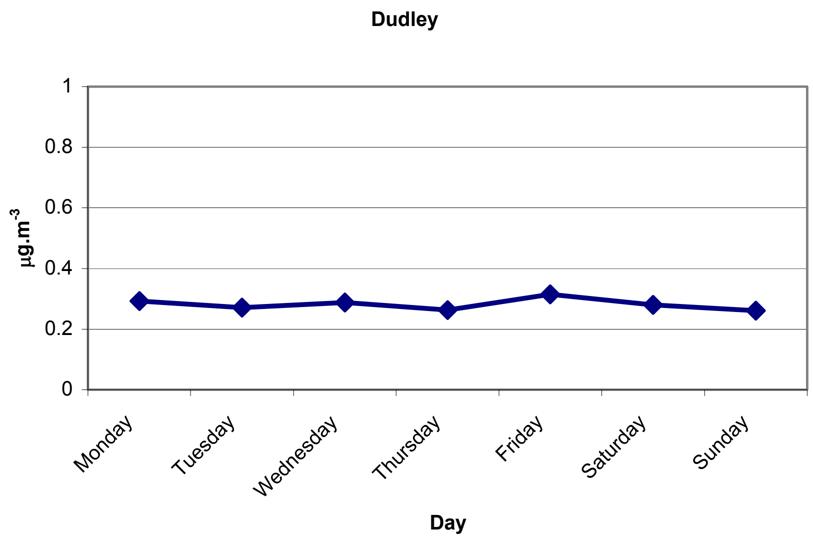


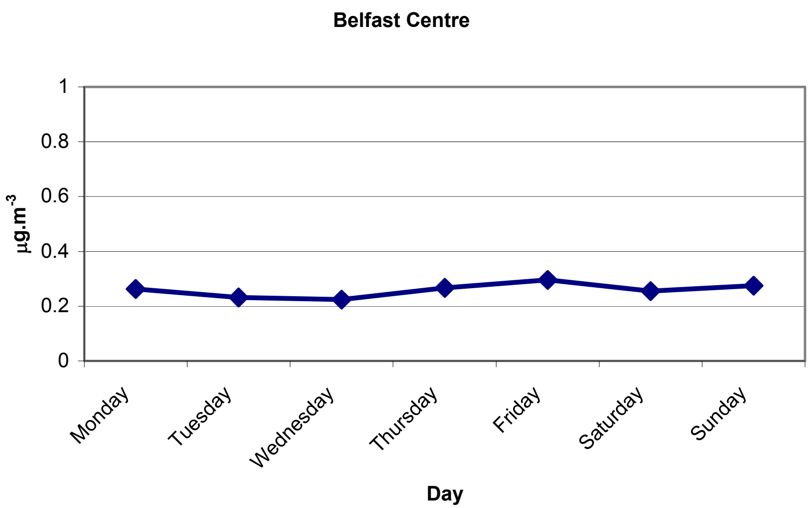
Figure 31 Roadside Locations

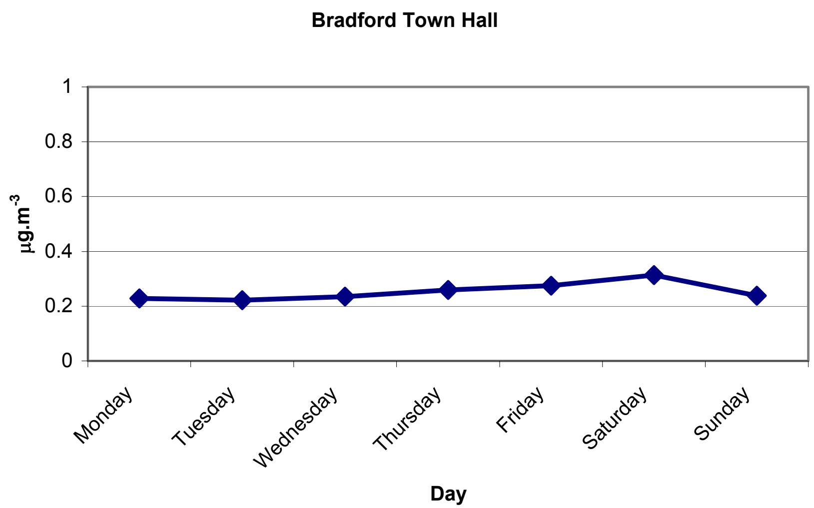

Stoke Centre
1
0.8
0.6
0.4
0.2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Manchester Piccadilly
1
0.8
0.6
0.4
0.2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Nottingham
1
0.8
0.6
0.4
0.2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Dudley
1
0.8
0.6
0.4
0.2
0
µg.m-3
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day





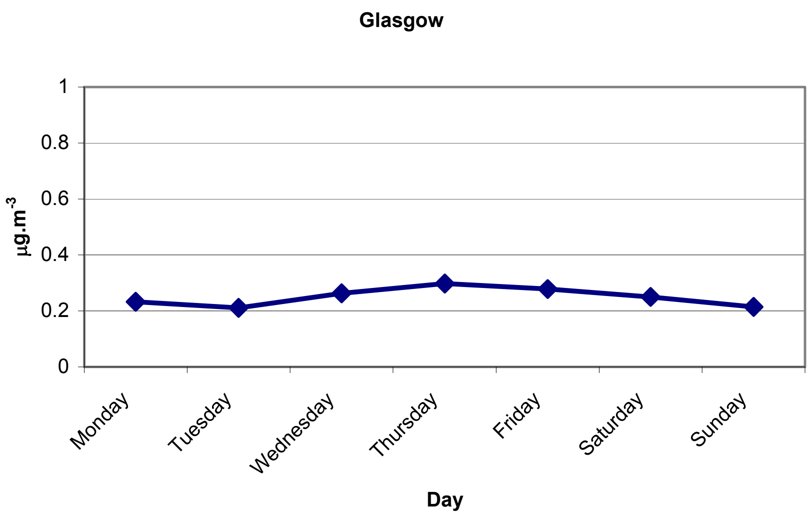
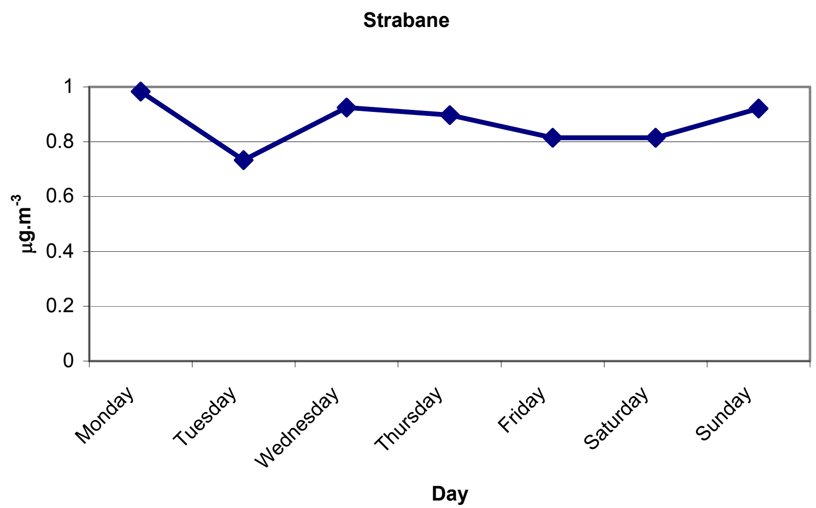
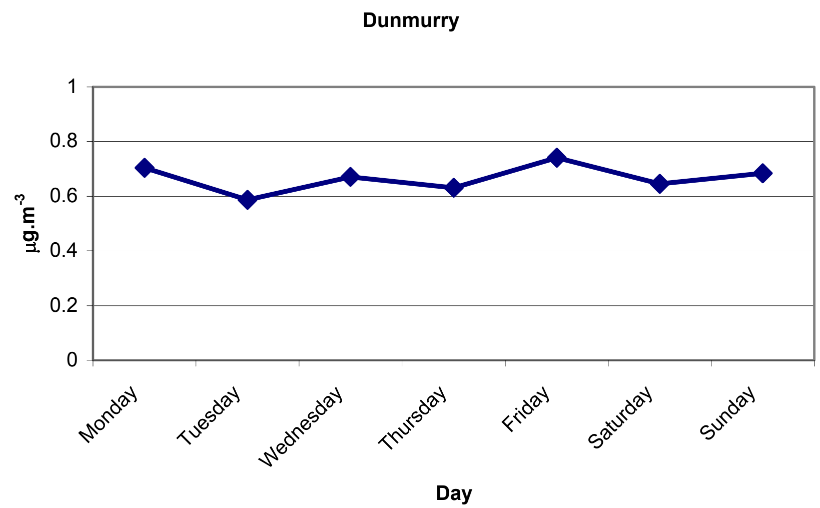
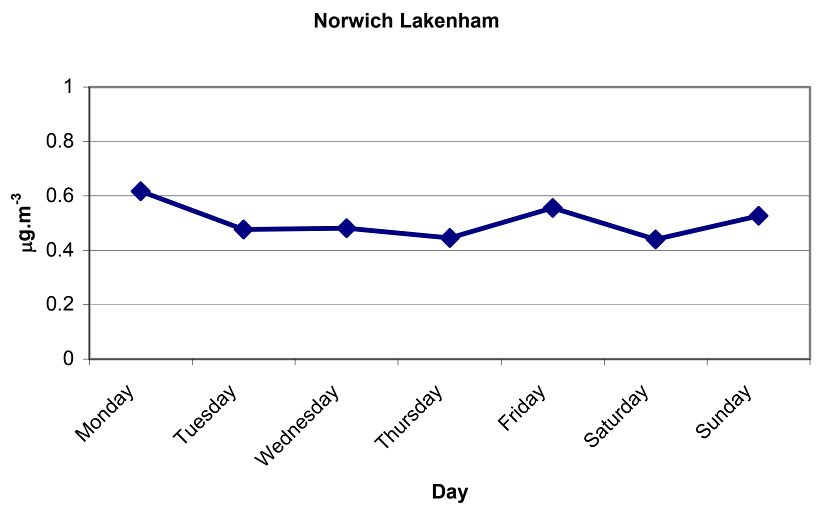
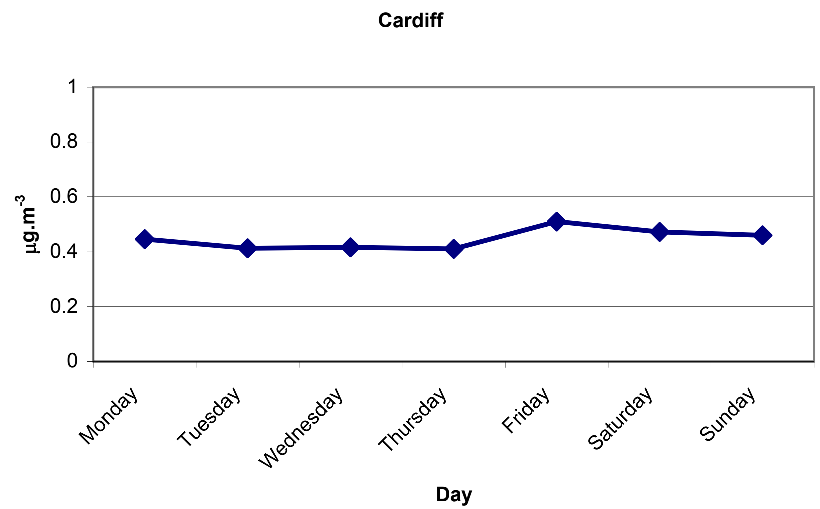


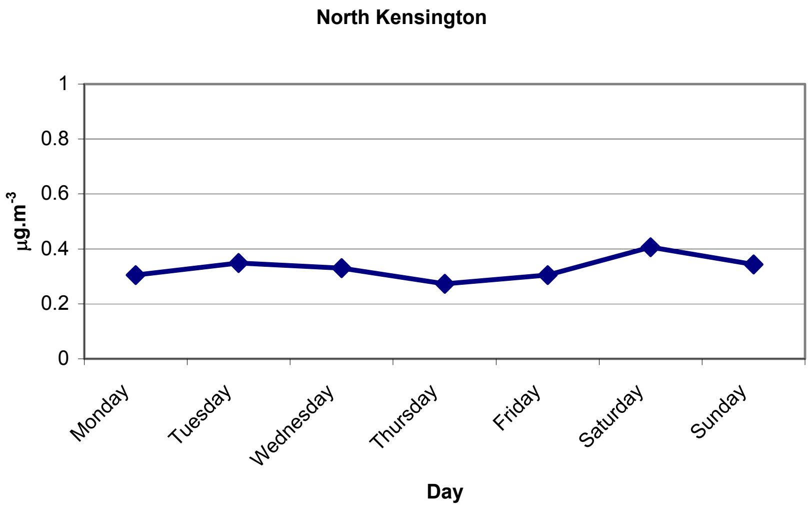
Figure 32 Urban Centre Locations

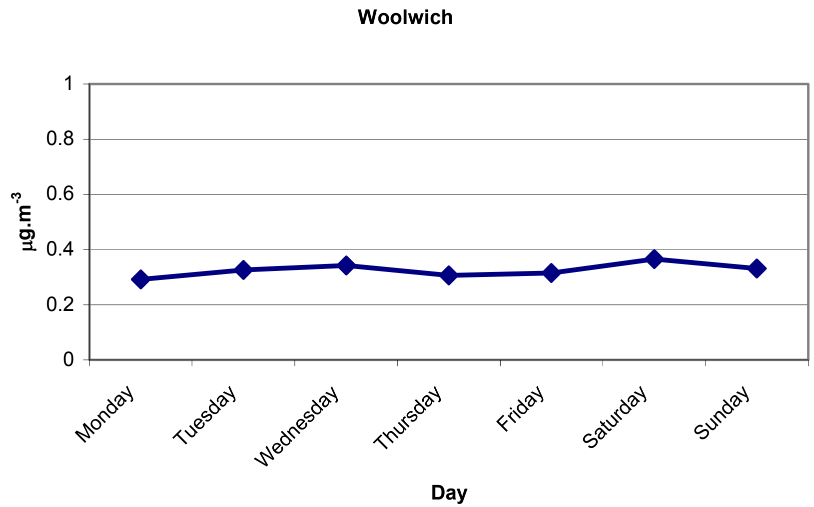

Strabane
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

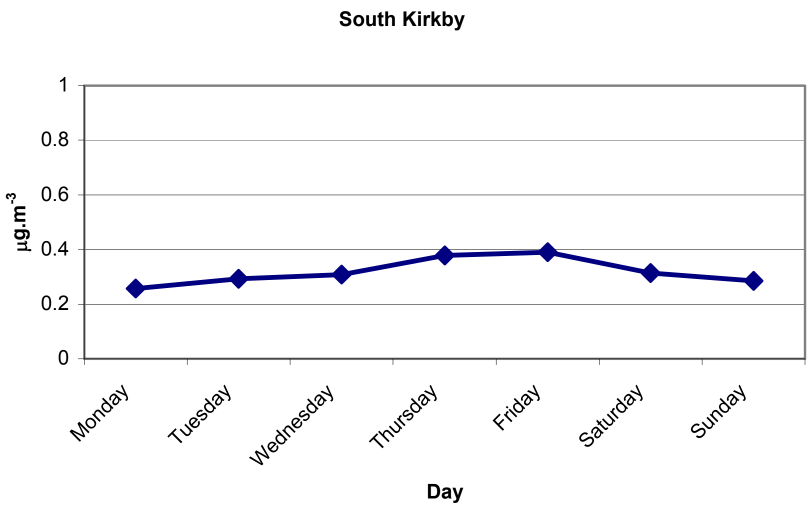

Dunmurry
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

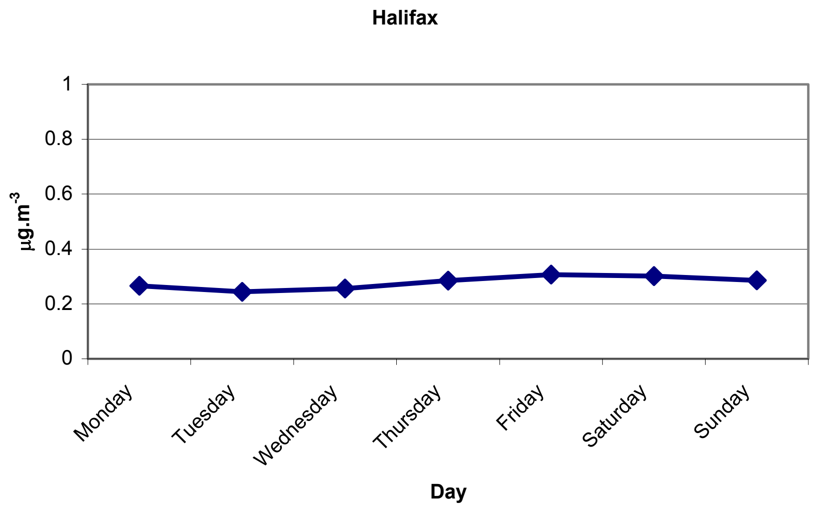

Norwich Lakenham
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

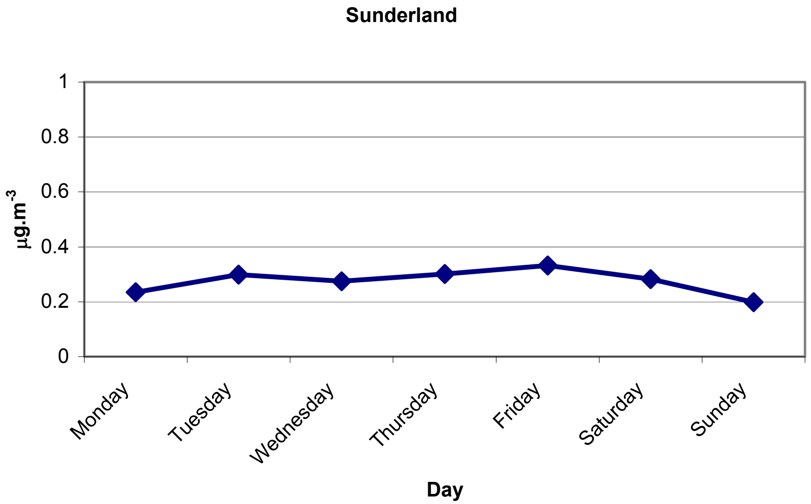

Cardiff
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day

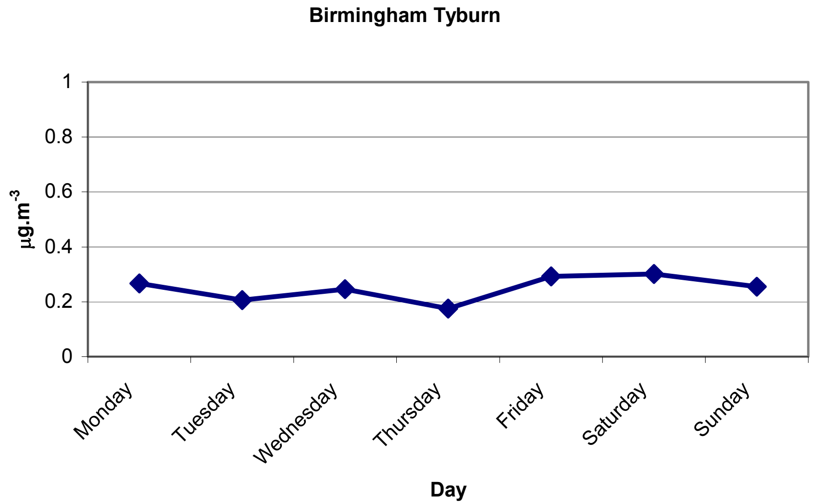

North Kensington
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Woolwich
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


South Kirkby
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day


Halifax
µg.m-3
1
0.8
0.6
0.4
0.2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Day





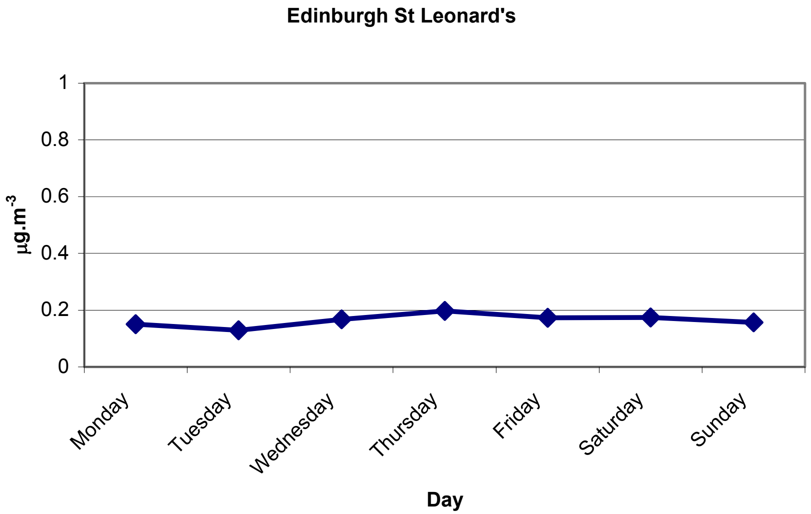
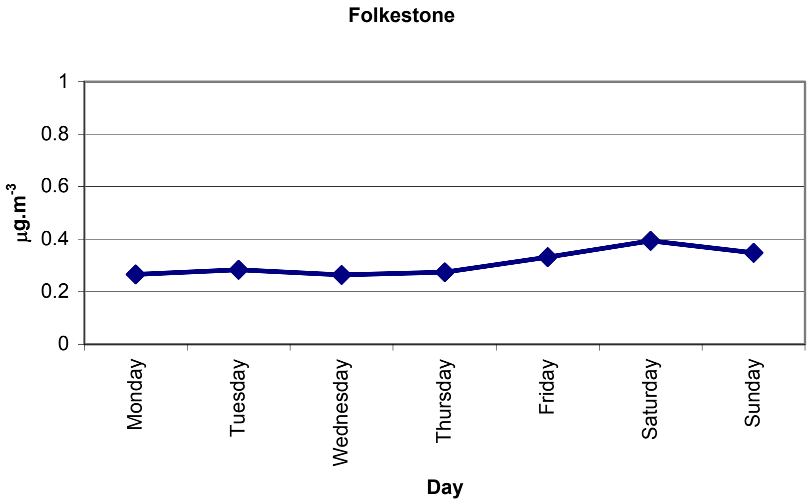


Figure 33 Urban Background Locations



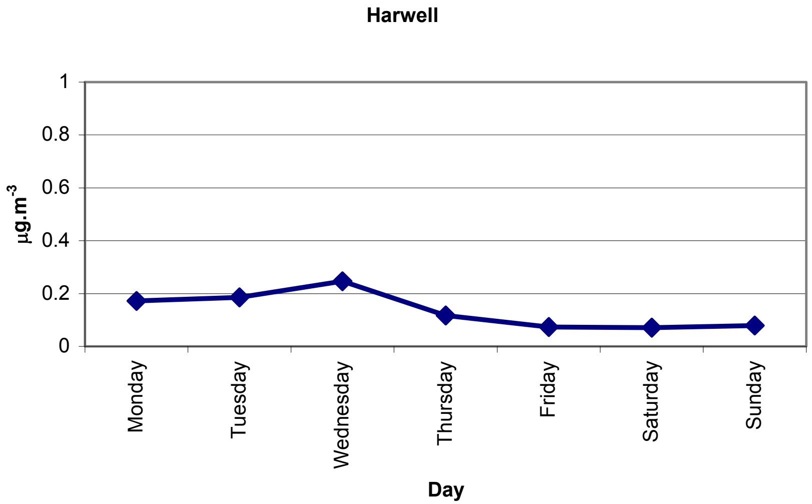


Figure 34 Suburban and Rural Locations

References

1 D Butterfield and P Quincey, NPL REPORT AS 39, Summary Of Measurements Of Black Smoke, Black Carbon And Elemental Carbon Performed By Defra Networks, August 2009.

2 P Quincey, A relationship between Black Smoke Index and Black Carbon concentration, Atmospheric Environment 41 (2007) 7964–7968.

3 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.

4 D Butterfield et al, NPL REPORT AS 37, 2008 Annual Report for the UK Black Smoke Network, August 2009.

5 S Beccaceci et al, NPL REPORT, 2009 Annual Report for Airborne Particulate Concentrations and Numbers in the United Kingdom (phase 2), April 2010.

6 P Quincey, D Butterfield, D Green, M Coyle, N Cape, An evaluation of measurement methods for organic, elemental and black carbon in ambient air monitoring sites, Atmospheric Environment 43 (2009) 5085–5091