Report

Investigation of Air Pollution from Transport Operations at Heathrow Airport

Report to British Airways

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Address for Correspondence

netcen
Culham Science Park
Abingdon
Oxfordshire
OX14 3ED
Telephone 01235 463179
Facsimile 01235 463011

ken.stevenson@aeat.co.uk

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	Name	Signature	Date
Author	Ken Stevenson Tony Clark		
Reviewed by	Brian Stacey		
Approved by	Ken Stevenson		

Executive Summary

British Airways has undertaken dispersion modelling of aircraft emissions at Heathrow Airport. In order to compare modelling results with measurements, netcen (part of AEA Technology) has been commissioned to undertake a preliminary study of air pollution concentrations on a transect across Heathrow Airport and extending into the residential areas to the north of the airport.

Diffusion tube samplers for nitrogen dioxide (NO_2) were deployed for one-week at each of the monitoring locations and, in addition, short-term and spot NO_2 measurements were made over approximately a 2 - 3min period at each monitoring location at the start and end of the diffusion tube monitoring period.

The results show that, over the one-week monitoring period, NO_2 concentrations were found to be generally higher at on-airport (airside) sites, compared to off-airport (landside) sites, even for the landside site close to the M4 motorway. The highest weekly average NO_2 concentrations on-airport were found at the monitoring sites close to Terminal 2.

Short-term monitoring showed much larger variations in NO_2 concentrations at different locations and on different days, especially at on-airport locations, with higher concentrations corresponding to increased aircraft or vehicle activity close to the monitoring site.

A long-term survey with diffusion tube samplers, for one year, will be undertaken as a follow up to this short study.

In this Issue 2 report, the diffusion tube results have been updated following the final annual data checking and full ratification of the automatic data from the Heathrow Airport LHR2 site. The results are presented on a base map of the airport to give a better visual realisation of the data and additional wind speed and wind direction analysis is presented.

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1 Introduction

British Airways has undertaken dispersion modelling of aircraft emissions at Heathrow Airport. In order to compare modelling results with measurements, netcen (part of AEA Technology) has been commissioned to undertake a preliminary study of air pollution concentrations on a transect across Heathrow Airport and extending into the residential areas to the north of the airport.

The study was undertaken over a one-week period in Aug/Sept 2002 at 15 monitoring locations across the airport. A combination of short-term samples and diffusion tube measurements was undertaken. A record was taken of general airport activity at each location to assist in the interpretation of the data.

This report presents the results of this study.

2 Survey Methodology

Diffusion tube samplers for nitrogen dioxide (NO_2) were deployed for one-week at each of the monitoring locations and, in addition, short-term and spot NO_2 measurements were made over approximately a 2 - 3min period at each monitoring location at the start and end of the diffusion tube monitoring period.

2.1 DIFFUSION TUBE MEASUREMENTS

Diffusion tubes are passive sampling devices which require no mains or battery power and hence are ideal for this type of survey at a number of locations. Some details of diffusion tube samplers for NO_2 are provided in Appendix 1. For this initial one-week survey, three tubes were deployed at each site in order to increase the reliability and accuracy of the data. Also, in line with general guidance on the use of diffusion tube samplers, one site was co-located with a continuous automatic monitor for NO_2 at the on-airport air quality monitoring site operated by netcen on behalf of BAA at LHR2. A scaling factor for diffusion tubes was calculated from the comparison of the diffusion tube measurements and the co-located automatic NO_2 measurements. All diffusion tube results have been scaled with this factor and hence, should provide reliable measurements closely aligned with data from the automatic reference method.

Diffusion tube samplers are generally referred to as an indicative method of measurement. In terms of the EC Directive for NO_2 concentrations, indicative methods of measurement should be accurate to $\pm$25%. The automatic monitoring of NO_2 at the LHR2 site is undertaken with a chemiluminescent analyser, which is defined as the EU reference method of monitoring. Under the Directive, this reference method is required to have an accuracy of $\pm$15%. In this study, the NO_2 diffusion tubes were scaled to agree with the automatic monitoring result at the co-located monitoring site at LHR2. Hence, it is anticipated that the NO_2 diffusion tube results in the report will have an uncertainty between $\pm$15% and $\pm$25% and, given that the tubes were exposed in triplicate we would expect the uncertainty to be towards the lower end of this range.

2.2 SHORT-TERM MEASUREMENT

During the deployment and collection of the diffusion tubes, real-time measurements of NO_2 were undertaken at each diffusion tube monitoring location for approximately 2 - 3 minutes. These measurements were undertaken with a TRI Odyssey 2001 gas monitor. This small portable analyser uses an electrochemical cell to determine NO_2 concentrations. The monitor was calibrated with certified NO_2 gas before and after the measurement campaign. As with all electrochemical cell analysers, the monitor inevitably suffers from some interference effects and, though these should be small in most circumstances, the data from this analyser carry a higher uncertainty of measurement than a chemiluminescent reference automatic analyser.

2.3 MONITORING LOCATIONS

A total of 15 monitoring locations were selected by British Airways. These are listed in Table 1 and shown in Figure 1. These follow a general transect of the airport from south west to north east, with 8 sites on the airport and 6 sites located outside of the airport to extend the transect to the residential areas to the north east of the airport. One further monitoring site was located at the BA Waterside offices.

Table 1. Monitoring Locations

Site	Easting	Northing	Comment
CP 17	506662	174508	
Royal Suite	507239	174891	
GA 16	507571	175025	
F 15	507767	175456	
E 9	507920	175548	
E 40	508017	175736	
C 32	508210	176198	
LHR 2	508382	176749	
Newall Road	508458	176846	
New Road	508402	177109	
West End Lane	508455	177383	
Imp. College 1	508270	177831	sports ground entrance
Imp. College 2	508327	178040	centre of sports ground
Shepiston Lane	508582	178453	close to M4
BA Waterside	505127	177559	

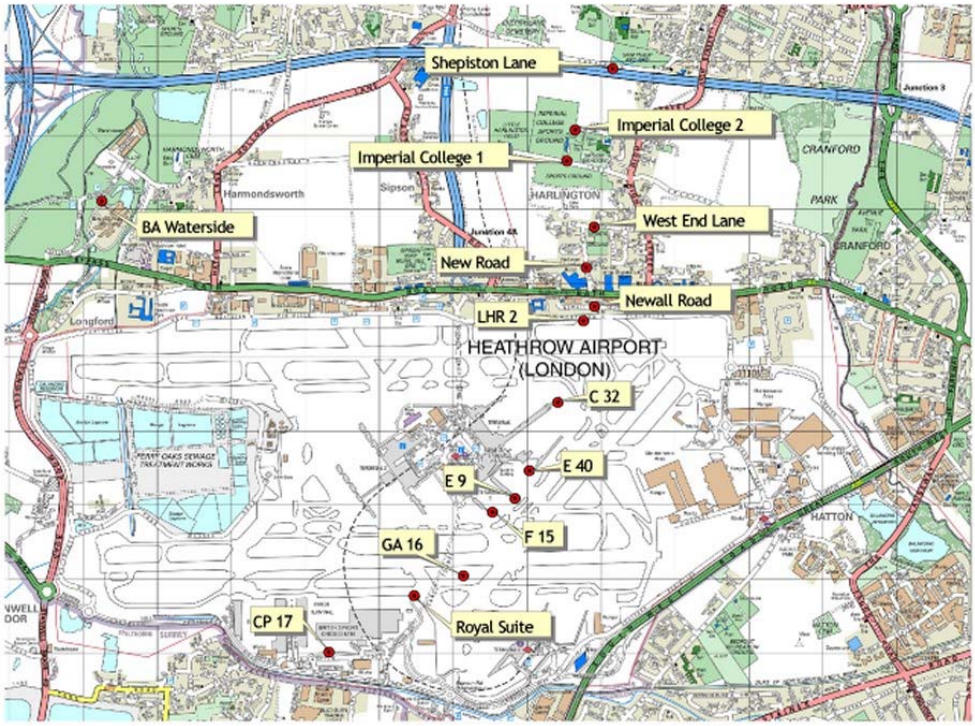

Figure 1. Location of NO_2 diffusion tube monitoring sites

3 Results

In this Chapter, the basic results from the diffusion tubes and the two short-term measurements on 29 August and 5 September 2002 are tabulated. These results are discussed in Chapter 4.

3.1 DIFFUSION TUBE RESULTS

All individual diffusion tube results are given in Appendix 2. The mean, standard deviation and coefficient of variation (CoV) for each set of 3 tubes has been calculated. The coefficients of variation are all below 10% except for the tubes at site E40 where the CoV was 13.4%. Hence, a simple mean of the triplicate results for all sites has been taken, except for site E40 where the result for the first tube has been disregarded and the mean of the remaining two tubes taken as the best measure of NO_2 at this location.

In addition, as explained in Section 2.1 and in line with standard guidance on the use of diffusion tubes, all measurement data have been scaled by the ratio of the co-located measurements at the LHR2 site:

For the period 29 August 2002 to 5 September 2002
NO_2 concentration at LHR2 by diffusion tube samplers = 100μgm^{-3}
NO_2 concentration measured by the automatic analyser at LHR2 (midday – midday) = 50μgm^{-3}

Hence diffusion tube correction factor = 0.5

All diffusion tube results have been corrected by this factor.

Following this processing of data, the best measure of NO_2 concentrations from the diffusion tubes is as shown in Table 2.

Table 2. Average corrected NO_2 diffusion tube results (μgm^{-3})

Site	Average corrected NO_2 Concentration from diffusion tube samplers μgm^{-3}
CP 17	46
Royal Suite	56
GA 16	51
F 15	60
E 9	56
E 40	64
C 32	48
LHR 2	50
Newall Road	56
New Road	tubes stolen
West End Lane	33
Imp. College 1	36
Imp College 2	36
Shepiston Lane	46
BA Waterside	30

For comparison, average NO_2 concentrations at a range of automatic air quality monitoring stations in London are given in Table 3 below.

Table 3. Average NO_2 concentrations at Automatic Monitoring Stations 29 Aug – 5 Sept 2002

Monitoring site:	Location:	Average NO_2 concentration ($\mu g\ m^{-3}$) 29 Aug – 5 Sept 2002
Heathrow LHR2	North perimeter of Heathrow Airport	50
London Hillingdon	A suburban site approximately 30m from the M4 in Hillingdon	42
London Bloomsbury	Urban Centre site in Russell Square, Central London	44
London Marylebone Rd	Kerbside of Marylebone Road - a 6-lane urban highway	76

3.2 SHORT-TERM MEASUREMENT RESULTS

Short-term measurements were undertaken with the portable NO_2 monitor when the diffusion tubes were installed (29/08/02) and when they were retrieved (05/09/02). A manual average result over the 2 – 3 minutes of monitoring was recorded, along with the highest spot reading. Results have been scaled from the calibrations of the analyser undertaken with standard calibration gas at Culham. Details of the airport activity at the monitoring location were recorded on the day, and wind speed and wind direction data have been added from the meteorological sensors located at one of the Terminal 5 air quality monitoring sites located to the west of Heathrow Airport. A summary of the results for 29 August and 5 September 2002 is shown in Tables 4 and 5 respectively.

As a check of the data from the portable analyser, monitoring was undertaken for a full 15min period at the LHR2 site on 5 September. The average from the chemiluminescent analyser at LHR2 for that period was $44\mu gm^{-3}$, whereas the average from the portable analyser was $48\mu gm^{-3}$. This level of agreement is considered reasonable, given the limitations on the uncertainty of the portable analyser.

3.3 METEOROLOGICAL SITUATION

On both of the days of short-term measurements, the wind was from the generally prevailing direction of south west and the average wind speed was ranged from about 1.5 – 2.6m/s. Under these conditions, the wind would tend to carry pollutants emitted on the airport into areas to the north east of the airport.

During the whole monitoring period, 29 August to 5 September, when the diffusion tubes were exposed, the wind moved from the south west to northerly then easterly during the period up to 1 September. The wind remained generally easterly during the period 1 – 3 September before moving back to south westerly on 5 September. Wind speed varied from 1-2m/s on 29 August and from 1.5-2.6m/s on 5 September.

Figure 2 shows the wind speed, wind direction and NO_2 pollution rose for the period 29 Aug – 5 Sept 2002. (The direction is plotted as %*5 and the wind speed as m/s *40 to make the scales more equal for the plot presentation.)

Wind speed and wind direction data from one of the Terminal 5 air quality monitoring stations located to the west of Heathrow Airport has been used for this assessment of the meteorological conditions during the monitoring period.

The wind speed rose indicates average wind speed for wind directions recorded in each of 16 sectors of 22.5^{o} each, and the wind direction rose indicates the percentage of time wind was recorded from each particular direction. Pollution rose plots relate air pollution measurements to wind direction and show the average pollutant concentrations during periods when the wind was recorded in each of the 16 direction sectors. Due to the difficulty of defining a wind direction when wind speeds are very low, the pollution rose plots do not include data for which the recorded wind speed was less than 0.1 ms^{-1}

Figure 2 shows that the highest NO_2 concentrations were associated with winds from the north and south east. However, these were the directions the lowest percentage of wind and the lowest wind speeds. This indicates that care must be taken in interpreting wind rose analysis over such a short duration of monitoring.

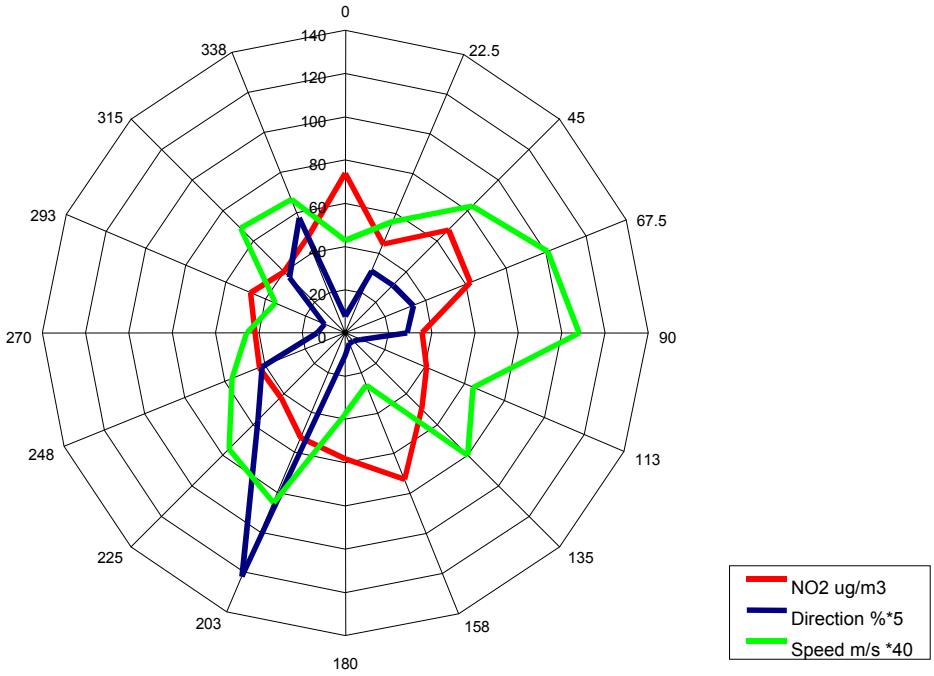

Figure 2 NO_2 (ugm^{-3}), wind direction (%*5) and wind speed (m/s *40) rose for Heathrow, 29 Aug - 5 Sept 2002

Table 4. Results of the short-term monitoring, 29 August 2002

Site	Wind speed m/s	Wind direction	Weather summary	Airport Activity	Start time	End time	mean NO_2 ugm^{-3}	peak NO_2 ugm^{-3}
CP 17 – airside	1.3	WSW	cloudy	Lorries queuing to CP	09:13	09:15	87	131
Royal Suite – airside	1.3	WSW	cloudy	No traffic, air or road	09:37	09:39	61	73
GA 16 – airside	1.7	SW	cloudy	Occasional aircraft	13:39	13:41	26	35
F 15 – airside	1.5	WSW	cloudy	No aircraft manoeuvring	09:59	10:01	65	74
E 9 – airside	1.5	WSW	cloudy	Busy junction nr. aircraft	10:18	10:20	96	187
E 40 – airside	1.5	WSW	cloudy	Fairly busy junction	10:31	10:33	no result	
C 32 – airside	1.7	SW	cloudy	No vehicles or aircraft	13:15	13:17	55	63
LHR 2 – airside	1.5	WSW	cloudy	AQ monitor trailer site	11:17	11:20	48	104
Newall Road	1.9	SW	sunny	Approach Rd to Vis Cen	14:07	14:09	35	52
New Road	1.9	SW	cloudy	Light traffic	14:28	14:30	30	39
West End Lane	1.9	SW	cloudy	Light Traffic	14:41	14:43	22	28
Imperial College 1	2.0	SW	sunny	Medium traffic	15:15	15:17	26	61
Imperial College 2	2.0	SW	sunny	Centre of sports ground	15:30	15:32	35	39
Shepiston Lane	2.0	SW	cloudy	Dual Roadside/by M4	15:51	15:53	87	96
BA Waterside	2.0	SW	sunny	Semi-rural office locn.	16:38	16:40	26	39

Table 5. Results of the short-term monitoring, 5 September 2002

	Wind speed m/s	Wind direction	Weather summary	Airport Activity	Start time	End time	mean NO_2 ugm^{-3}	peak NO_2 ugm^{-3}
CP 17 – airside	1.5	SW	sunny	Some vehicles	08:56	08:58	104	148
Royal Suite – airside	1.5	SW	sunny	No aircraft/no vehicles	09:06	09:08	78	96
GA 16 – airside	2.1	SW	cloudy	Aircraft taxiing nearby	13:28	13:30	139	322
F 15 – airside	1.5	SW	sunny	No aircraft close by	09:29	09:31	91	174
E 9 – airside	1.5	SW	sunny	Vehicles & idling plane	09:52	09:54	83	261
E 40 – airside	1.6	SW	sunny		10:04	10:06	113	165
C 32 – airside	1.6	SW	sunny	No vehicles/plane idling	10:13	10:15	109	117
LHR 2 – airside	1.9	WSW	sunny		11:00	11:15	48	70
Newall Road	2.1	SW	cloudy/windy	Light traffic	13:52	13:54	104	139
New Road	2.6	SW	cloudy/windy	No traffic	14:12	14:14	70	83
West End Lane	2.6	SW	cloudy/windy	Little traffic	14:22	14:24	30	35
Imperial College 1	2.6	SW	cloudy/windy	Light traffic	14:29	14:31	24	35
Imperial College 2	2.6	SW	cloudy/windy	Centre of sports ground	14:36	14:38	44	52
Shepiston Lane	2.6	WSW	sunny spells	Next to M4 hardshoulder	14:55	14:57	78	100
BA Waterside	2.6	WSW	sunny spells	No traffic	15:26	15:28	17	26

4 Discussion

Figure 3 shows a plot of the diffusion tube and mean short-term measurements along the transect from the south to the north of the airport. The site at Waterside is not located on the transect and hence has not been included on the diagram.

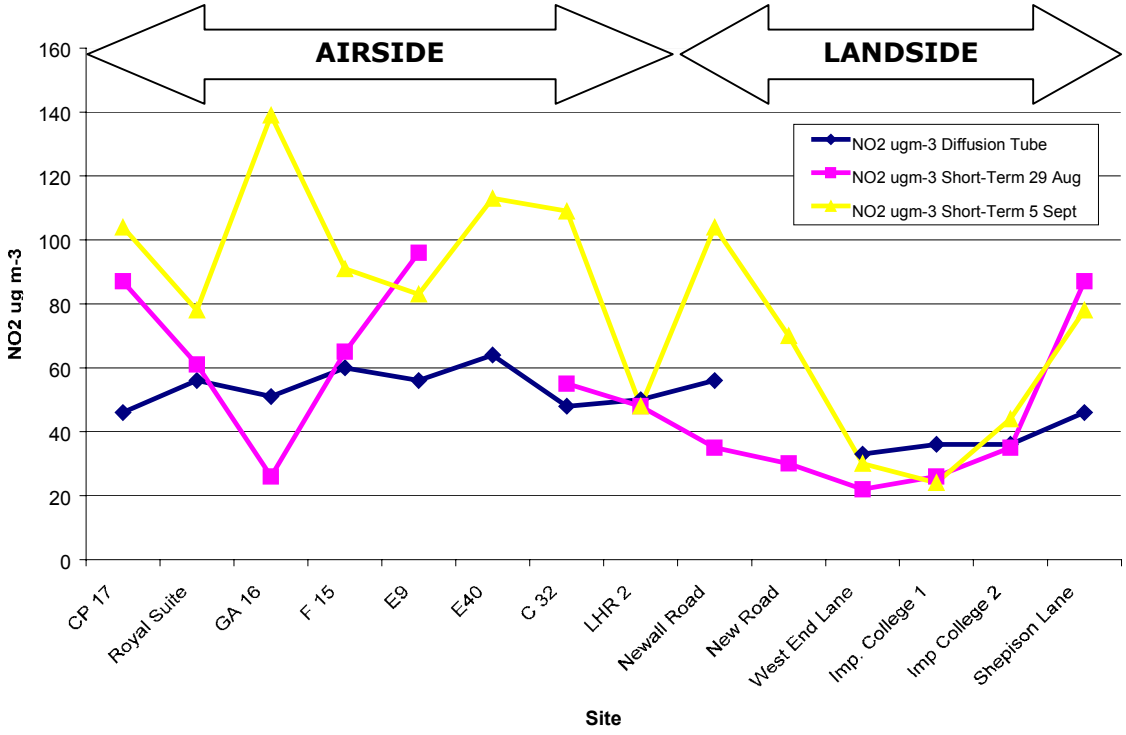

Figure 3. NO_2 Concentrations ($\mu g\ m^{-3}$) on south – north transect across Heathrow Airport

The diffusion tube results show that concentrations were generally higher on-airport (airside) compared to off-airport (landside). Weekly average concentrations were highest close to the Terminal 2 monitoring sites (F15, E9 and E40) with the highest weekly average ($64 \mu g\ m^{-3}$) being recorded at site E40.

Concentrations at sites closer to the southern and northern perimeters (CP17, Royal Suite, GA6 and LHR2) were generally lower. Though site C32 was located on one of the Terminal 1 piers, it was quite distant from the central terminal area and, perhaps, this explains why concentrations at this site were closer to the perimeter sites rather than the other Terminal sites.

Concentrations at Newall Road, just outside the airport perimeter boundary, were similar to those inside the airport. However, all other off-airport sites showed lower concentrations than the on-airport sites – even the site at Shepiston Lane, which was close to the busy M4 motorway.

As might be expected, the short-term measurements show a much greater variation both between locations and between the 2 days of monitoring. A particular example is GA16 which had the lowest concentration on 29 August and the highest concentration on 5

September. This is explained by the notes on airport activity which for 29 August describe "occasional traffic" and for 5 September indicate "aircraft taxiing nearby".

Concentrations at most on-airport sites were higher on 5 September, compared to 29 August, though there is no clear explanation for this – wind conditions were similar on both days, with slightly higher wind speeds on 5 September.

As with the diffusion tubes, generally, the short-term concentrations were lower at off-airport compared to on-airport sites. The exception is Shepiston Lane, close to the busy M4 motorway. At this site, concentrations were much higher than at most other off-airport sites. It is interesting to note that the concentrations measured at Shepiston Lane were almost identical on both days. This indicates the fairly constant nature of the emissions from the M4 at roughly the same time and on the same day of the week. In comparison, airport sites show much more variation because the emission locations and magnitude are much more variable.

Peak spot readings are also provided for each site in Tables 4 and 5. These peak values tend to correspond to specific activities noted close to the site of measurement. For example, on 29 August, peaks at CP17 corresponded to lorry activity and the peak at LHR2 corresponded to a Concorde take-off on the adjacent runway. On 5 September, peaks at E9 were due to local vehicle activity, in addition to aircraft idling nearby. Similarly, the peak at GA 16 reflects aircraft taxiing close to the measurement point.

The results of the diffusion tube monitoring are shown on a basemap of the airport in Figure 4.

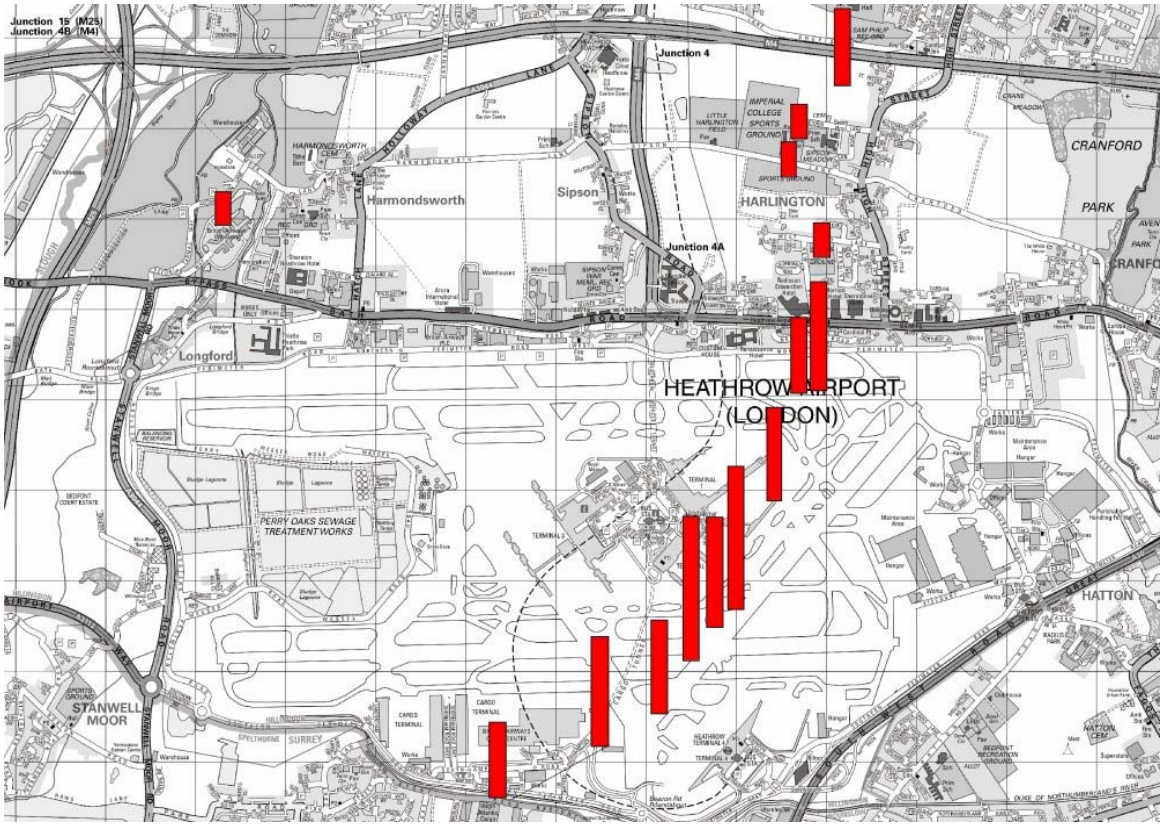

Figure 4. Geographic representation of NO_2 concentrations at the diffusion tube monitoring sites on the transect of the airport

5 Conclusions

A short study of NO_2 concentrations at 15 sites forming a transect across Heathrow Airport has been undertaken with diffusion tube samplers and a portable NO_2 monitoring instrument.

From the results presented in this report, the following conclusions can be drawn:

- Over the one week monitoring period, NO_2 concentrations were found to be generally higher at on-airport (airside) sites, compared to off-airport (landside) sites, even the landside site close to the M4 motorway
- The highest weekly average NO_2 concentrations on-airport were found at the monitoring sites close to Terminal 2
- Short-term monitoring showed much larger variations in NO_2 concentrations at different locations and on different days, especially at on-airport locations
- Short-term concentrations were high at on-airport locations when the activity (aircraft and/or vehicles) was recorded as generally high and low when there was little activity close to the monitoring location
- In contrast, at the off-airport monitoring site close to the M4, the concentrations were remarkably similar at roughly the same time on the same day of the week. This indicates the fairly constant nature of traffic emissions on a busy motorway, from day to day
- Peak spot values at on-airport sites corresponded to specific events such as nearby aircraft take-off or vehicle activity.

Appendices

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Appendix 1
NO_2 Diffusion Tubes

NO_2 Diffusion Tube Samplers

Passive sampling involves the collection of air pollutants using an absorbing material without the use of pumps; hence, no power supply is required. This makes these samplers very easy to deploy and flexible in terms of siting.

A passive sampler for gaseous species is defined as a device which is capable of sampling gas or vapour pollutants from the atmosphere, at a rate controlled by a physical process such as diffusion through a static layer or permeation through a membrane, but which does not involve the active movement of air through the sampler

Samplers are available for a wide range of pollutant species. The NO_2, SO_2, NH_3 and O_3 diffusion tubes supplied by AEA Technology are based on the work of Palmes, and consist of a cylindrical plastic tube, approximately 71 mm long and 11 mm in diameter. During sampling, one end is open and the other end holds an absorbent for the gaseous species to be monitored.

The basic principle on which diffusion tube samplers operate is that of molecular diffusion, with molecules of a gas diffusing from a region of high concentration (open end of the sampler) to a region of low concentration (absorber end of the sampler). The movement of molecules of gas (1) through gas (2) is governed by Fick's law, which states that the flux is proportional to the concentration gradient:

$$J = - D_{12} \frac{dc}{dz} \qquad (1)$$

Where:

J = the flux of gas (1) through gas (2) across unit area in the Z direction ($\mu g/m^2/s$)
c = the concentration of gas (1) in gas (2) ($\mu g/m^3$)
z = the length of the diffusion path (m)
D_{12} = the molecular diffusion coefficient of gas (1) in gas (2) (m^2/s)

For a cylinder of cross-sectional area **a** (m^2) and length **l** (m), then **Q** (μg) the quantity of gas transferred along the tube in **t** seconds (taken as the quantity of gas absorbed during **t**) is given by

$$Q = \frac{D_{12}(C_1 - C_o)at}{l} \qquad (2)$$

Where C_o and C_1 are the gas concentrations at either end of the tube.

In a diffusion tube, the concentration of gas (1) is maintained at zero by an efficient absorber at one end of the tube (i.e. C_o = zero) and the concentration C_1 is the average concentration of the gas (1) at the open end of the tube over the period of exposure.

Hence:

$$C = \frac{Ql}{D_{12}at} \qquad (3)$$

The diffusion coefficient for the gas to be monitored must be determined, or obtained from the literature. A best estimate of the area and length of a typical tube must be determined by measurement using Vernier callipers. Nominal tube dimensions are set at 11mm (diameter) and 71mm (length). The gas concentration C, can be readily derived from the quantity of gas absorbed Q, (assessed by desorption & chemical analysis of the tube), and the exposure time t.

Appendix 2 Diffusion Tube Individual Results

HEATHROW TRANSECT AIR QUALITY MONITORING, 29 AUG - 5 SEPT 2002.

Location	NO_2 TUBE 1 (ug/m3)	NO_2 TUBE 2 (ug/m3)	NO_2 TUBE 3 (ug/m3)	Mean of all 3 results	Standard Deviation	Coefficient of Variation	Mean Result Used	Corrected Mean Result (ug/m3)
CP 17	93.2	100.6	82.4	92	9.2	9.9%	92	46
Royal Suite	103.7	123.3	110.6	112	9.9	8.9%	112	56
F 15	114.8	125.6	118.4	120	5.5	4.6%	120	60
E 9	120.9	113.4	103.3	112	8.8	7.9%	112	56
E 40	100.5	124.2	130.6	118	15.9	13.4%	127*	64
LHR 2	98.7	92.7	109.3	100	8.4	8.4%	100	50
C 32	99.5	97.3	92.4	96	3.6	3.8%	96	48
GA 16	94.7	110.6	100.1	102	8.1	7.9%	102	51
Newall Road	108.8	121.4	103.8	111	9.1	8.2%	111	56
New Road	Tubes Stolen							
West End Lane	66.4	62.3	66.2	65	2.3	3.6%	65	33
Imp.College 1	68.5	73.6	72.4	71	2.7	3.8%	71	36
Imp.College 2	69.1	71.2	72.8	71	1.9	2.6%	71	36
Shepiston Lane	85.5	95.6	90.7	91	5.1	5.6%	91	46
BA Waterside	53	61.7	61.6	59	5.0	8.5%	59	30

* E 40 -Tube 1 result ignored – mean used is mean of tubes 2 and 3