



APPENDIX AVAILABLE ON WEB

Research Report 138

Health Effects of Real-World Exposure to Diesel Exhaust in Persons with Asthma

Appendix F. Intensive Characterization of Air Pollution in Oxford Street and Hyde Park

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Note: Appendices Available on the Web appear in a different order than in the original Investigators' Report. HEI has not changed these documents. Appendices were relettered as follows:

Appendix E was originally Appendix B
Appendix F was originally Appendix C
Appendix G was originally Appendix D
Appendix H was originally Appendix E

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APPENDIX C: INTENSIVE CHARACTERIZATION OF AIR POLLUTION IN OXFORD STREET AND HYDE PARK

Introduction and Methods

To better understand air pollution related to diesel exhaust, we conducted an intensive air pollution characterization campaign in each of the two study winters. The first campaign was carried out from January 7 to 21, 2004 and the second campaign was from January 11 to 25, 2005. On each day during the campaign, concurrent measurements of air pollutants were made or attempted at a site in Oxford Street and a site in Hyde Park, with approval and assistance of the London City officials. The Oxford Street site was a curbside spot, several meters away from the nearest bus stop, located in the center section of Oxford Street and within the defined walking path for the study. The Hyde Park site was an open and paved spot within the defined walking path. On days when exposure sessions (with subjects) concurred, we used the moving pushcart instead of the fixed sampling site on either Oxford Street or in Hyde Park.

Measurements were made over 12 successful (non-raining) days in each winter. On each day, the measurements lasted for 2 to 3 hours, between 10:00 am and 2:00 pm. The inlets of all the samplers/monitors were 1.5-1.7 meters above the ground (*i.e.* close to adults' breathing zone). The samplers/monitors were sheltered from rain and direct sunlight. A field staff member was at the sampling site throughout each experiment.

In addition to the three pollutants measured during each session, PM_{2.5}, ultrafine particles (UFP), and NO₂ (see Methods Section of the main text), PM₁₀ mass

concentrations, polycyclic aromatic hydrocarbons (PAHs), and carbonyl compounds were measured during the intensive characterization campaigns.

PM₁₀ and PAHs. Integrated PAH samples were collected over 2 -3 hours on each sampling day during the first winter campaign and for the first five days during Jan 11 – Jan 15, 2005. From Jan 17 to Jan 25, 2005, a cumulative sampling collection approach was used to collect over three consecutive days to increase the PAHs mass collected on the sampling media. In this case, the sampling inlet was sealed at the end of the first sampling day, reopened at the start of the second day, sealed again at the end of the second day, reopened again at the start of the third day, and finally sealed at the end of the third day, so the total duration of the three-day sampling was 3 times 2 to 3 hours.

Both particle-phase and gas-phase PAHs were measured. Particle-phase PAHs were collected on a 37 mm quartz fiber filter, backed by a stainless steel screen, and loaded in a personal “lollipop-type” impactor sampling head (Air Diagnostics & Engineering Inc., Harrison, ME) designed to collect particles with a 10 µm cutpoint at a sampling flow rate of 4 l/min. After having passed through the quartz fiber filter, the sampling air stream went through a polyurethane foam (PUF), with a density of 0.02g/cm³, that was used to collect gas-phase PAHs. The PUF was cleaned before sampling by refluxing with acetone followed by petroleum ether in a Soxhlet apparatus. All collected filter and PUF samples were stored separately in amber glass jars in complete darkness at - 4°C, minimizing PAHs degradation, prior to sample extraction and analysis.

The filter was used first for the determination of PM₁₀ mass concentration, using the same gravimetric procedure as for PM_{2.5} described above, and then used for the

determination of particle-phase PAHs. The extraction method for filter and PUF samples was identical, following the EPA-TO13A method. The samples were individually placed in a Soxhlet extraction apparatus and extracted for 16 hours with 120 mL of HPLC-grade dichloromethane at 70°C. After the dichloromethane extract had been cooled at room temperature, it was concentrated to 2 ml using a rotary evaporator at a reduced pressure. The concentrated dichloromethane extract was transferred into a 5 ml PYREX glass centrifuge tube where the extract, along with 1 to 2 ml of dichloromethane used for rinsing, was evaporated slowly to 0.1 ml under a stream of oxygen-free nitrogen, and finally diluted (re-dissolved) with acetonitrile (ACN) to 1 ml final volume. Solid phase extraction cartridges, Waters Sep-Pak silica cartridges (Waters Division, Millipore Corporation, Milford, MA), were used for sample cleaning. The final aliquot was transferred into 2ml amber glass vial with a cap for PAH analysis with an HPLC system.

The HPLC system and conditions used in our analysis were as follows. The system was a Waters 600E model equipped with a programmable fluorescence detector (Waters 470 Fluorescence Detector, MA). We used a Supelco PAH column (2.5x5x250mm) and its guard column and the following gradient elution program: Solution A = 50 % acetonitrile in water, Solution B = 100 % acetonitrile; 100% A for 20 minutes, followed by a linear gradient from 100% A to 100% B in 20 minutes, followed by 100% B for 15 minutes, followed by 100% B to 100% A for 10 min, and followed by 100% A 5 min. The fluorescence wavelength program was set at: 0-32.8 min (270/350 nm); 32.8-47 min (250/400 nm); 47-70 min (280/425 nm). A mixture of PAH standards (Supelco, Inc) was used as external standards to quantify the following 14 PAHs:

acenaphthene, anthracene, benz(a)anthracene, chrysene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, benzo(k)fluoranthene, dibenz(a,h)anthracene, fluoranthene, fluorine, naphthalene, phenanthrene, and pyrene.

Carbonyl Compounds. We used US EPA TO-11A method to measure carbonyls. In this method, a 2,3-dinitrophenylhydrazine-coated (DNPH) Sep-Pak cartridge (Waters Corp.) was used to form DNPH-carbonyl derivatives that were retained on the sampling medium (DNPH coated silica gels). We used a SKC personal sampling pump at a flow rate of 1 l/min to collect carbonyls for ~ 2 hours on each sampling day. The samples were sealed individually and stored in a refrigerator or a freezer until analysis.

Each sample was extracted with 4 ml of acetonitrile. An aliquot of the extract was analyzed using an HPLC system equipped with a Nova-Pak C₁₈ column (Waters, 3.9 x 150 mm) and a UV detector set at 365 nm. The mobile phase program was as follows: after holding 100% of Solvent A (water/ACN/THF 60/30/10) for 5 minutes, the mobile phase was linearly changed to 100% Solvent B (ACN/water 60/40) in 20 minutes, then held at 100% B for 5 minutes, and then changed back to 100% A in 5 minutes. The flow rate of the mobile phase was constant at 1 ml/min. The sample injection volume was 20 µL (Herrington et al. 2005). The concentrations of carbonyls were determined through calibration curves prepared daily using standard solutions of DNPH-carbonyl derivatives purchased from Supelco Co. (Bellefonte, PA, USA). The following 15 carbonyls were targeted for analysis: acetaldehyde, acetone, acrolein, benzaldehyde, crotonaldehyde, 2,5-dimethylbenzaldehyde, butyraldehyde, formaldehyde, hexaldehyde, isovaleraldehyde, m-&p-tolualdehyde, o-tolualdehyde, propionaldehyde and

valeraldehyde, based on the commercial availability of a mixture containing the DNPH derivatives of these carbonyls.

Quality Control Measures

A number of quality control measures were in place to assess measurement reproducibility and between-instrument consistency. The results are shown in Table C1. When applicable, field blanks were prepared identically to sample substrates, transported to the field, and returned and analyzed with samples. Field blank distributions were used for determining blank corrections and method detection limits. Duplicate samples were collected from collocated samplers to determine method precision or reproducibility. When two units of a real-time monitor were used in the study, both units were collocated side by side; and a comparison between the two units was established. When samples were analyzed at two different laboratories, a subset of the samples was analyzed at both laboratories for the establishment of a correction factor.

During the first and second intensive air pollution characterization campaigns, a SidePak (TSI) was used, along with the DusTrak, to measure PM_{2.5} simultaneously. A SidePak monitor is a compact version of a DusTrak monitor, both from TSI Inc (St. Paul, MN). The monitors measure particles based on side light scattering, which is sensitive to refractive index and particle size changes and can measure to particle concentrations in the range of 0.01 to 10 mg/m³.

Due to constraints of instrument availability, two units of Langan CO monitors were only used in the first campaign and two units of condensation particle counter (CPC, TSI

Model 3007) were used in the second campaign. The paired monitors were used to make measurements in Oxford Street and Hyde Park concurrently.

A side-by-side comparison of the two CPCs is shown in Figure C1. The results show a very good regression coefficient ($R^2 = 0.99$). However, the secondary CPC measures particle number concentrations systematically higher, by approximately 20%, than the primary unit. Because the primary unit was used in all during-session measurements, we adjusted the results from the secondary CPC using the regression equation shown in Figure C1.

As shown in Figure C2, the SidePak monitor agrees reasonably well with the DustTrak, with a R^2 of 0.89 and a slope of 0.92. Since the DustTrak was used in all during-session measurements of real-time $PM_{2.5}$ mass concentrations, the results from the SidePak were adjusted using the regression equation shown in Figure C2.

The second unit of Langan monitor agreed poorly with the unit primarily used in the study ($R^2 = 0.3$). The second unit appeared to report CO concentrations 3 to 4 times higher than the primary unit. Upon an examination against standard CO span gas, we found that the second CO monitor was incorrectly reporting the data due to its electrochemical sensor malfunction. Unfortunately, the primary CO monitor, although manufactory calibrated, was no longer available for laboratory/field calibration at the time when this problem was identified. Due to all these problems, CO concentrations were not reported in this report.

Results

The time-series plots of the results from the characterization campaigns are shown in Figure C3. The plots were only shown for pollutants that had concurrent measurements at both sites. No plots are provided for PM_{10} for the 2004 winter, because we had uncorrectable filter weighing problems for PM_{10} measurements during the first winter of air pollution characterization campaign. In the first winter, we only had one unit of condensation particle counter (CPC); and thus ultrafine particles (UFP) were measured on alternative days between the two sites. The results indicate a relatively small difference in PM_{10} concentrations between the two sites. In fact, the difference in PM_{10} concentration was close to zero on three days (January 14, 20, and 24, 2005). In the same year (2005), $PM_{2.5}$ concentrations at the two sites overlapped on one day (January 22) and were almost the same on another day (January 24). In 2004, Hyde Park surpassed Oxford Street in $PM_{2.5}$ level on one day (January 19). No overlaps were found for UFP, EC, and NO_2 , with Oxford Street exhibiting higher levels consistently over the entire measurement periods.

Figure C3 also shows time-series plots of concurrently measured ambient temperature and relative humidity (RH). Interestingly and as expected, Oxford Street had consistently higher temperature but lower RH than Hyde Park.

Thanks to the real-time monitoring feature of the DustTrak, SidePak, and CPC, we were able to obtain more time-resolved plots for $PM_{2.5}$ mass concentrations and UFP number concentrations. Figure C4 provides examples of $PM_{2.5}$ concentrations and UFP concentrations, concurrently measured in Oxford Street and Hyde Park, within a 2-hr measurement session. In Figure C4, $PM_{2.5}$ concentrations determined by the DustTrak

and the SidePak were calibrated with the gravimetric measurement (see Quality Control Section of the main text). With a 5-minute measurement interval, both PM_{2.5} mass concentrations and UFP number concentrations exhibited a substantially larger temporal variation in Oxford Street than in Hyde Park.

Summary statistics are shown in Tables C2a-c, on concentrations of all measured pollutants as well as ambient temperature and relative humidity, by site and by year. Based on comparisons of mean values from the daily measurements (see Table C2a), Oxford Street had PM₁₀ concentration 1.6 times (in 2005), PM_{2.5} concentration 1.6 times (in 2004) and 1.9 times (in 2005), EC concentration 12 times (in 2004) and 5.5 times (in 2005), UFP concentration 3.8 times (in 2004) and 3.4 times (in 2005), NO₂ concentration 5.7 times (in 2004) and 6.5 times (in 2005), and CO concentration 1.2 times (in 2004) and 1.1 times (in 2005), the corresponding values in Hyde Park. It appears that the two sites had largest differences in EC, followed by NO₂, then UFP, and then PM_{2.5} mass.

Table C2b summarizes the results for the 14 PAHs measured during the 2005 intensive characterization campaign. Only results from the cumulative samples (~9 hours of duration) are reported because daily measurements (~3 hours of duration) show most of the data below detection limit. For each PAH compound, reported here are the total of gas-phase and particle-phase concentrations. Based on the mean values, all but the following PAHs appeared to have higher concentrations in Oxford Street than in Hyde Park: fluoranthene, chrysene, and benzo[g,h,i]perylene. These three PAHs, among the 14 target PAHs, also appeared to have lowest concentrations. The sum of the 14 PAHs was about 2 times higher in Oxford Street than in Hyde Park.

Table C2c summarizes the results for the carbonyl compounds measured during the intensive air pollution characterization campaigns. Although we targeted 15 carbonyls, only 7 were reported in the table, because the method is known to have problems measuring unsaturated carbonyls (acrolein and crotonaldehyde) (Herrington et al. 2005), and because the remaining carbonyls (2,5-dimethylbenzaldehyde, hexaldehyde, isovaleraldehyde, m- & p-tolualdehyde, and o-tolualdehyde) on the list were rarely detected. Among the 7 carbonyls reported in Table C2c, only formaldehyde had concentrations consistently higher in Oxford Street in both years.

Discussion

Diesel exhaust (DE) is a complex mixture, composed of both particulate and gaseous species. It is difficult to precisely quantify exposures to diesel engine emissions because many species of their complex compositions are also emitted from other sources, such as gasoline emissions, wood smoke, tobacco smoke, manufacturing emissions, and production via atmospheric chemical reactions. Although diesel exhaust may not contain a single constituent to serve as a unique marker of exposure, a group of substances may be related to predominant diesel combustion emissions. These substances can be used as proxies to estimate the presence and levels of diesel exhaust. For example, elemental carbon (EC) is a major component of diesel exhaust and constitutes of 60-80% of diesel particles by weight (Amann and Sieglä 1982; Zaebst et al. 1991). Most of the atmospheric EC associated with vehicular traffic has been attributed to diesel exhaust; and the contribution from other sources (e.g., gasoline exhaust and tire debris) appears to be small (Hildemann et al. 1991; Zaebst et al. 1991;

Schauer et al. 1996). EC is chemically inert and is not depleted rapidly by dry deposition due to its small size (0.1 to 0.25 μm). Therefore, it has been suggested as an indicator of diesel exhaust or diesel exhaust particles (DEP) (Zaebst et al. 1991; Ligocki et al. 1993).

Previous measurements showed ambient EC concentrations of 0.1 $\mu\text{g}/\text{m}^3$ at a remote site, 2.6 $\mu\text{g}/\text{m}^3$ in a densely populated community in southern California, and 5.4 $\mu\text{g}/\text{m}^3$ as maximum daily concentration in Los Angeles (Chow et al. 1994). Kinney et al. (2000) reported that EC concentrations averaged 3.4 $\mu\text{g}/\text{m}^3$ (ranging from 1.5 to 6 $\mu\text{g}/\text{m}^3$) on street sidewalks in Harlem, New York City, an urban district impacted by local diesel traffic. In Budapest, Hungary, Salma et al. (2001) found curbside daytime EC concentrations ranging from 1.8 to 11 $\mu\text{g}/\text{m}^3$ and a median of 3.4 $\mu\text{g}/\text{m}^3$ and near-city background EC concentrations ranging from 0.19 and 0.64 $\mu\text{g}/\text{m}^3$ with a median of 0.33 $\mu\text{g}/\text{m}^3$. A recent study showed slightly higher urban background EC in comparison with Hyde Park at 20 residences in Riverside County, California (mean EC = 2.5 $\mu\text{g}/\text{m}^3$) (Na and Cocker 2005). In Mexico City, a daily EC average of 4.0 $\mu\text{g}/\text{m}^3$ was reported for a downtown monitoring site and that of 2.9 $\mu\text{g}/\text{m}^3$ for a suburban site. At the high end, black smoke (similar to EC) concentration of 14.9 $\mu\text{g}/\text{m}^3$ was measured near a freeway in Delft, the Netherlands (van Vliet et al. 1997). Based on the measurements made during the intensive air pollution characterization campaigns, EC concentrations ranged from 2.0 to 24.2 $\mu\text{g}/\text{m}^3$ in Oxford Street and from 0.5 to 2.8 $\mu\text{g}/\text{m}^3$ in Hyde Park (Table C2a). Therefore, the EC concentrations measured at the Hyde Park site were comparable to typical urban/suburban background levels, whereas the EC

concentrations in Oxford Street were similar to, on some days, or higher than the levels reported for urban roadsides and roadways with heavily traveled diesel vehicles.

Concurrent measurements show that EC levels consistently higher on all the days in Oxford Street than in Hyde Park (Figure C3). The EC content in PM_{2.5}, on average, was 25% in 2004 and 33% in 2005 in Oxford Street. In contrast, the EC content in PM_{2.5}, on average, was 3% in 2004 and 10% in 2005 in Hyde Park.

While EC concentrations in Oxford Street were over ~ 5 times those in Hyde Park, mean PM_{2.5} levels in Oxford Street were < 2 times those in Hyde Park. PM_{2.5} concentrations measured in Oxford Street were similar to pedestrian exposure concentrations of PM_{2.5} (37.7±16.4 µg/m³) measured in a previous study (Kaur et al. 2005a) at Marylebone Road, a dual carriageway in Central London. Gulliver and Briggs (2004) found the PM_{2.5} pedestrian exposure concentrations (15.06 ±16.15 µg/m³) in Northampton, UK, to be lower than those found in Oxford Street, but only slightly higher than those found in Hyde Park. Some of the difference can be attributed to dissimilarity in traffic density, urban design and meteorological conditions. A number of other studies examining PM_{2.5} concentrations at static points on streets have found concentrations to be 42.9±23.0 µg/m³ in Arnhem, Netherlands (Janssen et al. 1997), 37 – 47 µg/m³ on sidewalks in Harlem, New York City (Kinney et al. 2000), 18.2 - 29.9 µg/m³ at intersections in Hunts Point, New York City (Lena et al. 2002) and 12 - 86 µg/m³ at nine roadside sites in Boston, Massachusetts (Levy et al. 2002). Therefore, PM_{2.5} concentrations measured in Oxford Street, although filled with diesel-powered vehicles, were not atypical compared to other urban streets or sites elsewhere.

Interestingly, Figure C3 shows PM_{2.5} levels were substantially higher in 2004 than in 2005. We suspect this was due to the fact that the city of London has made an effort to reduce bus emissions by installing particle traps on the exhaust pipes. The effort is expected to gradually improve the air quality with increasing number of buses retrofitted over the years. This speculation seems to be further supported by our pilot study data showing PM concentrations higher in November 2001 than in January 2004 (see Appendix B).

In terms of number, the vast majority of airborne particles (> 80%) are in the ultra fine range (particle diameter $\leq 0.1 \mu\text{m}$) in urban areas where motor vehicle emissions are a dominant pollution source. However, these particles do not have much mass due to their extremely small particle size. Thus, using particle number concentrations (counts) are more appropriate to quantify these particles. During the concurrent measurements in Oxford Street and Hyde Park, we observed UFP number concentrations consistently higher in Oxford Street than in Hyde Park, while there were overlaps for PM_{2.5} and PM₁₀ (see Figure C3).

UFP number concentrations in Oxford Street were similar to the levels (mean = $65 \times 10^3/\text{cm}^3$) measured at Marylebone Road in London by Kaur et al (2005b). A number of studies have reported varying UFP number concentrations in the urban environment, e.g., $5,690 \pm 2,200/\text{cm}^3 - 19,300 \pm 8,580/\text{cm}^3$ for particles with size range of 0.018-0.421 μm at three sites in Basel (Junker et al. 2000); 180,000 – 350,000 / cm^3 for particles of 0.06 to 0.22 μm at a site 17 meter away from a freeway in Los Angeles (Zhu et al. 2002) and 18,000 / cm^3 for particles of 0.01 - 2.5 μm in Erfurt, Germany (Cyrus et al. 2003). Hitchins et al. (2000) observed a clear decline in UFP concentrations as

distance from the road increased, suggesting that the particles were related to vehicle exhaust emission. This was similarly observed by Levy et al. (2002) and Weijers et al. (2004). In another study, Zhu et al. (2002) found an exponential decay in black carbon (proxy to EC) and particle numbers with distance from a freeway. Therefore, larger difference in UFP number concentration than in PM_{2.5} mass concentration is expected between Oxford Street and Hyde Park. Zhu et al. (2002) also found a large impact of wind speed and direction on UFP concentration, suggesting that day-to-day variations in meteorological condition were largely responsible for day-to-day variations in UFP concentrations observed for Oxford Street and Hyde Park.

Oxides of nitrogen including NO₂ are formed through high-temperature combustion. NO₂ levels are highest close to busy roads and in large urban areas. NO₂ values found by other studies are more difficult to contrast as they are habitually expressed as annual or daily average values, while our NO₂ concentrations were measured for 2 hours around mid-day. Lewne et al. (2004) found annual average values for NO₂ for different sampling sites were between 15.9 µg/m³ and 50.6 µg/m³ (mean 28.8 µg/m³) in Germany, between 12.1 µg/m³ and 50.8 µg/m³ (mean 28.9 µg/m³) in the Netherlands and between 6.1 µg/m³ and 44.7 µg/m³ (mean 18.5 µg/m³) in Sweden. Day-time 2-hr averaged NO₂ concentrations measured in our study in Oxford Street were considerably higher than these longer-term averages. However, our 2-hr-averaged NO₂ levels measured in Hyde Park were comparable to the levels reported, for urban background sites, by Lewne et al. (2004).

The present study shows that the diesel-powered traffic contributed to higher concentrations of several PAHs and formaldehyde measured in Oxford Street compared

to those in Hyde Park (see Tables C2b and C2c). Previous studies have shown that different PAH compositions result from combustion of different fuels and that there is a general consistency of compound ratios for diesel and gasoline particles (Li and Kamens 1993; Rogge et al. 1993; Schauer et al. 1996; Morawska and Zhang 2001). It has been reported that more aldehydes species at higher concentrations were emitted by diesel engines than those by gasoline engines with catalyst (Lipari and Swarin 1982). Therefore, data on relationships among EC, PAHs, and aldehydes may provide useful information for assessing DE-specific exposure. Due to insufficient sampling volume to detect many of the targeted PAHs and carbonyls, however, our measurements of these compounds failed to generate data sufficient for this kind of source maker analysis.

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Table C1. Method detection limits (MDLs) and measurement precision

	MDLs ^a		Precision(%) ^b	N ^b
	2-hr sampling	9-hr sampling		
PAHs (ng/m ³)				
Naphthalene	31.65	10.56	12.06	6
Acenaphthylene	18.15	6.06	2.78	6
Fluorene	37.90	12.65	27.15	6
Phenanthrene	76.24	25.45	48.50	6
Anthracene	7.03	2.35	40.44	6
Fluoranthene	0.20	0.07	36.96	6
Pyrene	6.86	2.29	40.13	6
Benz[a]anthracene	9.21	3.08	28.75	6
Chrysene	0.18	0.06	20.98	6
Benzo[b]fluoranthene	0.03	0.01	36.06	6
Benzo[k]fluoranthene	0.46	0.15	22.16	6
Benzo[a]pyrene	0.25	0.08	24.79	6
Dibenzo[a,h]anthracene	0.07	0.02	ND	6
Benzo[g,h,i]perylene	0.76	0.25	23.14	6
Indeno[1,2,3-cd]pyrene	0.07	0.02	ND	6
Carbonyls (µg/m ³)				
Formaldehyde	38.95		12.7	3
Acetaldehyde	16.64		6.4	3
Acetone	9.35		ND	3
Propionaldehyde	35.97		15.6	3
Butyaldehyde	24.98		43.4	3
Benzaldehyde	32.21		ND	3
Valeraldehyde	44.37		52.5	3
Hexaldehyde	29.45		87.9	3

^a Detection limits were estimated as 3xSD of the field or laboratory blanks.

^b Values are expressed as the pooled CVs of pairs of collocated field measurements expressed as percentage. The total number of pairs is given.

ND indicates that CVs were not determined because more than half the values were below detection.

Table C2a. Summary results for pollutants and parameters measured during the intensive characterization campaigns. The pollutants and parameters shown in this table were also measured during each exposure/control session

Yr	Pollutant/ parameter	Oxford Street						Hyde Park					
		N	Min	Max	Median	Mean	SD	N	Min	Max	Median	Mean	SD
2005	PM _{2.5} (µg/m ³)	8	23.3	128	50.7	63.5	41.5	9	3.0	96.1	34.8	39.0	35.5
	EC (µg/m ³)	9	9.03	24.2	16.5	15.6	4.95	9	0.67	2.22	1.25	1.29	0.47
	UFP (/cm ³)*10 ³	6	60.0	80.0	69.0	69.1	8.52	4	16.0	21.0	18.0	18.2	2.26
	NO ₂ (µg/m ³)	11	41.7	99.3	75.0	74.8	16.7	8	6.72	19.1	13.0	13.2	4.56
	Temp (°C)	9	7.01	12.8	11.2	10.7	1.70	8	6.76	12.2	8.81	8.81	1.80
	RH (%)	9	57.0	86.2	71.3	70.0	10.3	8	62.0	84.1	72.0	72.7	9.38
2005	PM _{2.5} (µg/m ³)	13	10.2	33.0	17.0	18.4	7.03	13	2.39	22.5	8.91	9.64	5.63
	EC (µg/m ³)	13	2.00	9.11	6.35	6.09	2.01	13	0.52	2.82	0.96	1.12	0.59
	PM ₁₀ (µg/m ³)	8	61.6	161	125	119	42.7	6	59.5	100	72.0	74.7	15.6
	UFP (/cm ³)*10 ³	13	52.0	112	80.0	77.4	20.8	13	15.0	41.0	22.0	22.6	6.60
	NO ₂ (µg/m ³)	13	33.3	149	62.2	73.3	35.8	13	2.41	27.8	9.22	11.3	7.36
	Temp (°C)	13	7.67	13.6	10.4	10.5	2.00	13	4.16	12.1	8.04	8.15	2.60
RH (%)	13	36.9	76.9	57.2	58.2	12.8	13	57.9	80.3	67.1	69.5	8.04	

* All the samples had concentrations above detection limits.

Table C2b. Summary results for polycyclic aromatic hydrocarbon (PAHs), concentration in ng/m³, measured during the 2005 intensive characterization campaign, n=3.

PAH	Oxford Street						Hyde Park					
	% detected	Min	Max	Median	Mean*	SD*	% detected	Min	Max	Median	Mean*	SD*
Naphthalene	100	12.6	31.6	31.6	25.3	11.0	100	1.04	35.6	8.08	14.9	18.3
Acenaphthene	100	3.75	9.32	4.87	5.98	2.94	100	1.9	4.71	2.05	2.89	1.58
Fluorene	100	12.0	21.2	12.1	15.1	5.3	100	3.82	12.1	7.22	7.71	4.16
Phenanthrene	100	19.8	47.9	23.3	30.3	15.4	100	5.70	17.1	8.36	10.4	5.97
Anthracene	100	1.31	1.90	1.39	1.53	0.32	100	0.29	0.68	0.67	0.55	0.22
Fluoranthene	33	<0.03	0.94	<0.03	ND	ND	0	<0.03	<0.03	<0.03	ND	ND
Pyrene	100	3.10	12.4	7.49	7.67	4.67	100	0.28	8.46	6.33	5.03	4.24
Benzo[a]anthracene	100	1.75	9.28	7.05	6.02	3.87	100	1.07	10.1	4.37	5.19	4.58
Chrysene	33	<0.03	0.24	<0.03	ND	ND	0	<0.03	<0.03	<0.03	ND	ND
Benzo[b]fluoranthene	100	0.05	0.10	0.07	0.08	0.02	0	<0.01	<0.01	<0.01	ND	ND
Benzo[k]fluoranthene	100	0.02	0.10	0.04	0.05	0.04	100	0.01	0.06	0.02	0.03	0.02
Benzo[a]pyrene	100	0.12	2.87	0.94	1.31	1.41	33	<0.04	1.61	<0.04	ND	ND
Dibenzo[a,h]anthracene	67	0.01	0.71	0.13	0.28	0.37	67	0.01	0.12	0.07	0.07	0.06
Benzo[g,h,i]perylene	100	0.06	0.98	0.36	0.47	0.47	100	0.06	0.94	0.58	0.53	0.44
Sum of 14 PAH	100	78.1	121	84.6	94.5	23.0	100	16	81.7	45.8	47.8	32.9

Table C2c. Summary results for carbonyl compounds, concentration in $\mu\text{g}/\text{m}^3$, measured during the intensive characterization campaigns

Yr	Carbonyl compound	Oxford Street						Hyde Park							
		n	% detected	Min	Max	Median	Mean*	SD*	n	% detected	Min	Max	Median	Mean*	SD*
2004	Formaldehyde	12	100	25.9	90.0	42.3	43.8	16.9	11	100	22.7	44.5	36.4	35.7	6.90
	Acetaldehyde		58	<0.35	46.5	5.14	13.3	16.5		45	<0.35	25.4	<0.35	ND	ND
	Acetone		100	6.13	219	12.3	29.8	59.9		91	<0.35	28.5	10.9	13.4	8.19
	Propionaldehyde		83	<0.33	5.22	1.89	1.99	1.32		82	<0.33	2.80	1.59	1.51	0.85
	Butyraldehyde		75	<0.36	3.43	0.91	1.22	1.04		55	<0.36	2.48	0.49	0.83	0.85
	Benzaldehyde		25	<0.57	7.91	<0.57	ND	ND		18	<0.57	58.6	<0.57	ND	ND
2005	Valeraldehyde		33	<0.45	4.77	<0.45	ND	ND		36	<0.45	20.9	<0.45	ND	ND
	Formaldehyde		100	10.2	43.6	23.6	23.8	9.06		100	4.03	19.0	12.2	11.4	4.84
	Acetaldehyde		100	5.42	17.7	10.9	11.2	3.26		100	6.94	18.6	11.9	12.0	3.81
	Acetone		36	<0.35	2.90	<0.35	ND	ND		50	<0.35	6.39	0.42	1.19	1.72
	Propionaldehyde		14	86	<0.33	9.32	6.21	5.48	3.02	14	<0.33	22.1	7.30	7.88	5.47
	Butyraldehyde		57	<0.36	4.97	1.15	2.00	1.96		93	<0.36	9.12	5.20	4.91	2.70
2005	Benzaldehyde		29	<0.57	9.03	<0.57	ND	ND		71	<0.57	6.21	1.33	2.21	2.09
	Valeraldehyde		100	5.42	9.95	6.77	7.03	1.37		93	<0.45	13.5	7.32	7.33	3.68

* Half of detection limit was assigned to an undetected sample for calculating mean and SD. When >50% of samples were below detection limit, mean and SD were not determined (ND).

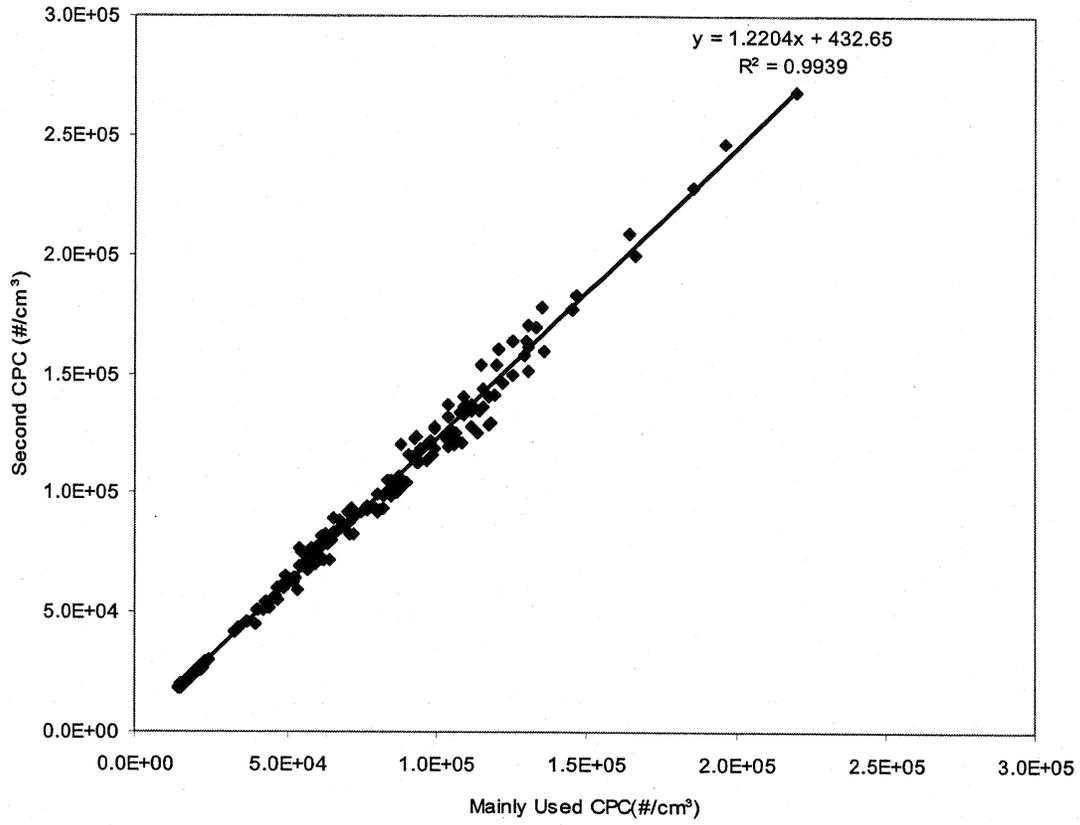


Figure C1. Comparison of two condensation particle counters (CPCs) used in the study

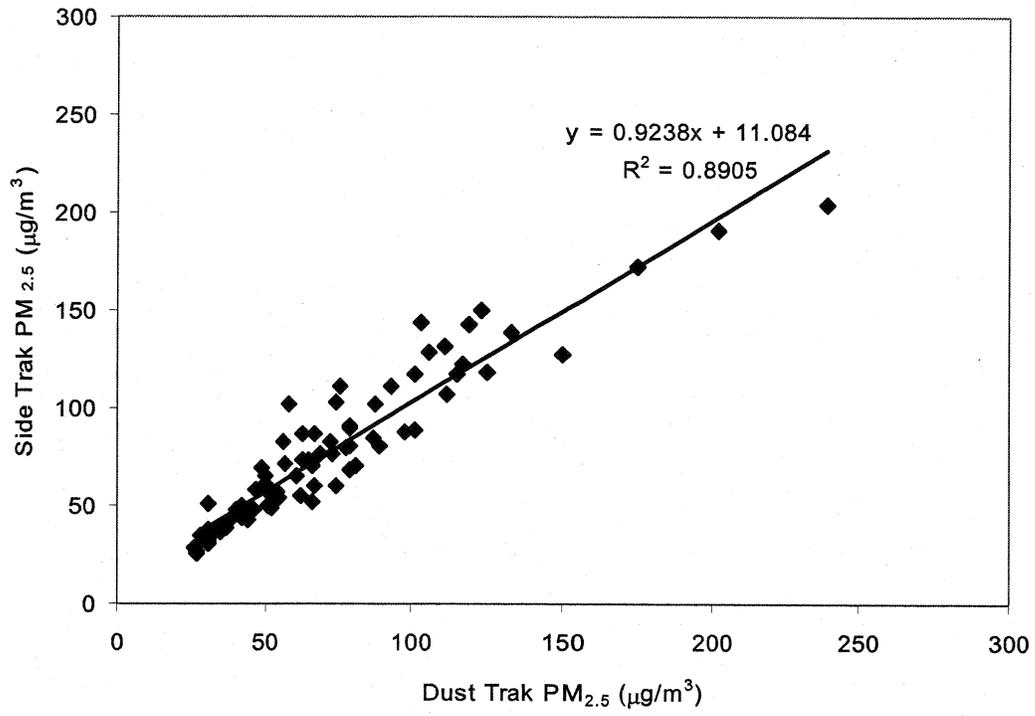


Figure C2. Comparison of the DustTrak and the SidePak PM_{2.5} monitors used in the study

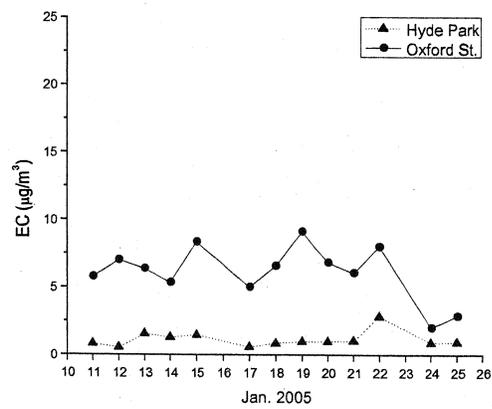
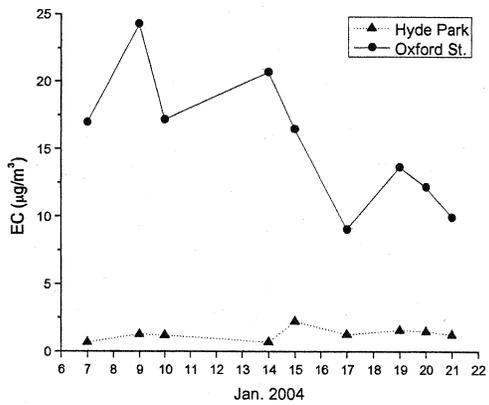
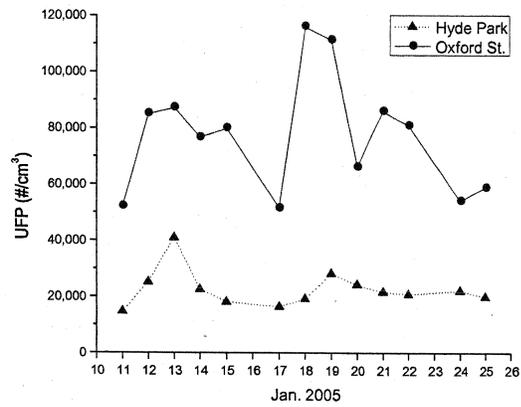
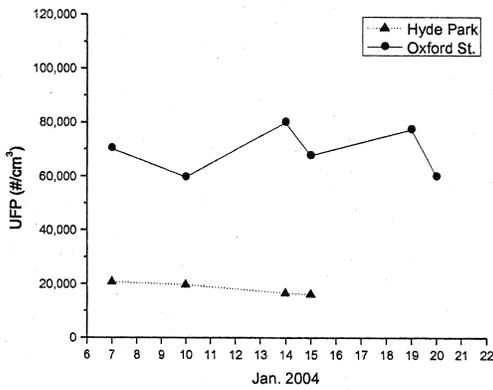
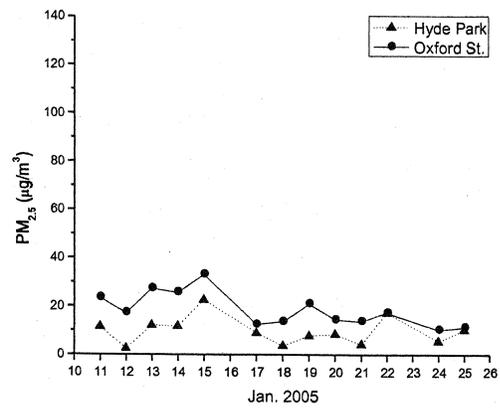
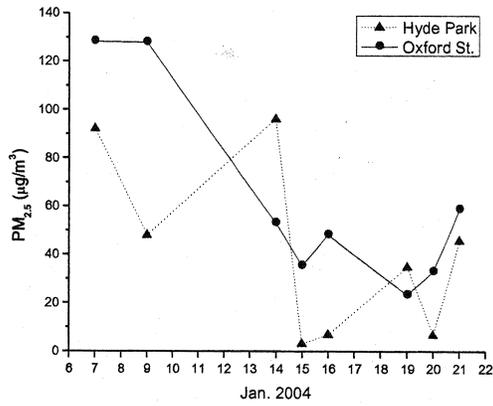


Figure C3. Daily time-series plots of air pollutants, ambient temperature, and relative humidity, concurrently measured in Oxford Street and Hyde Park

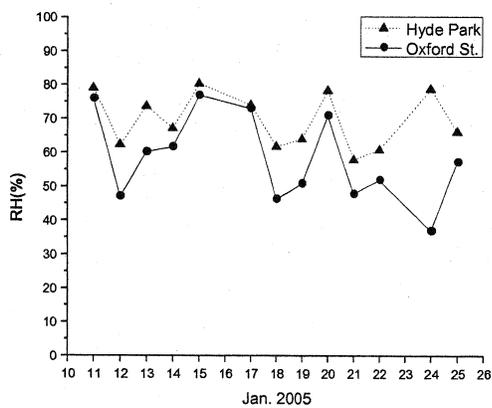
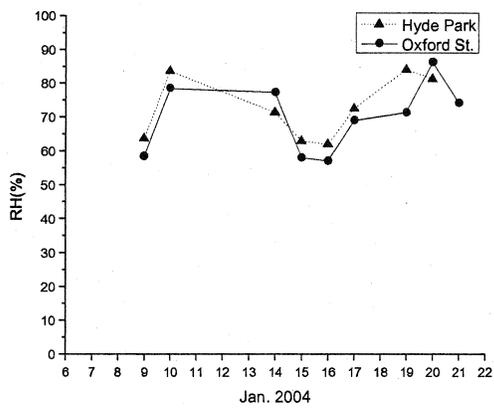
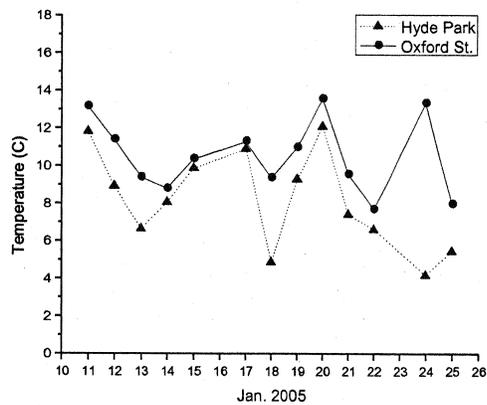
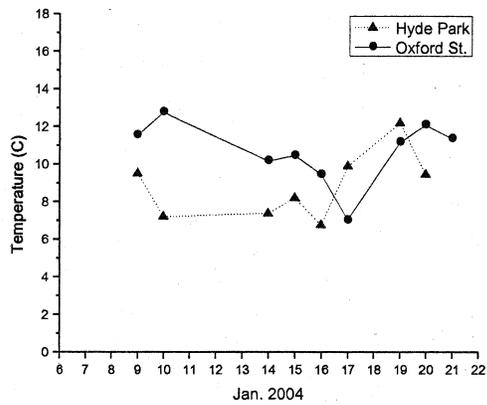
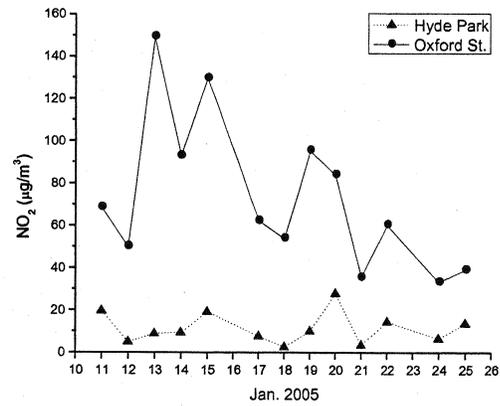
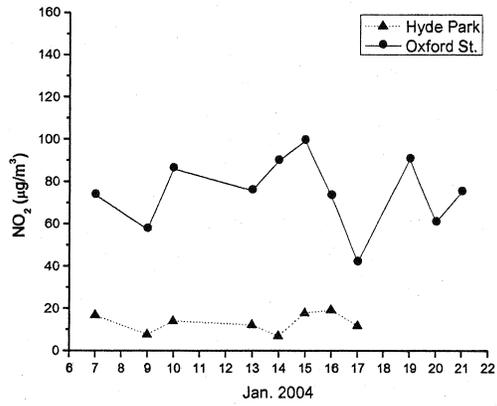


Figure C3 (Cont'd). Daily time-series plots of air pollutants, ambient temperature, and relative humidity, concurrently measured in Oxford Street and Hyde Park

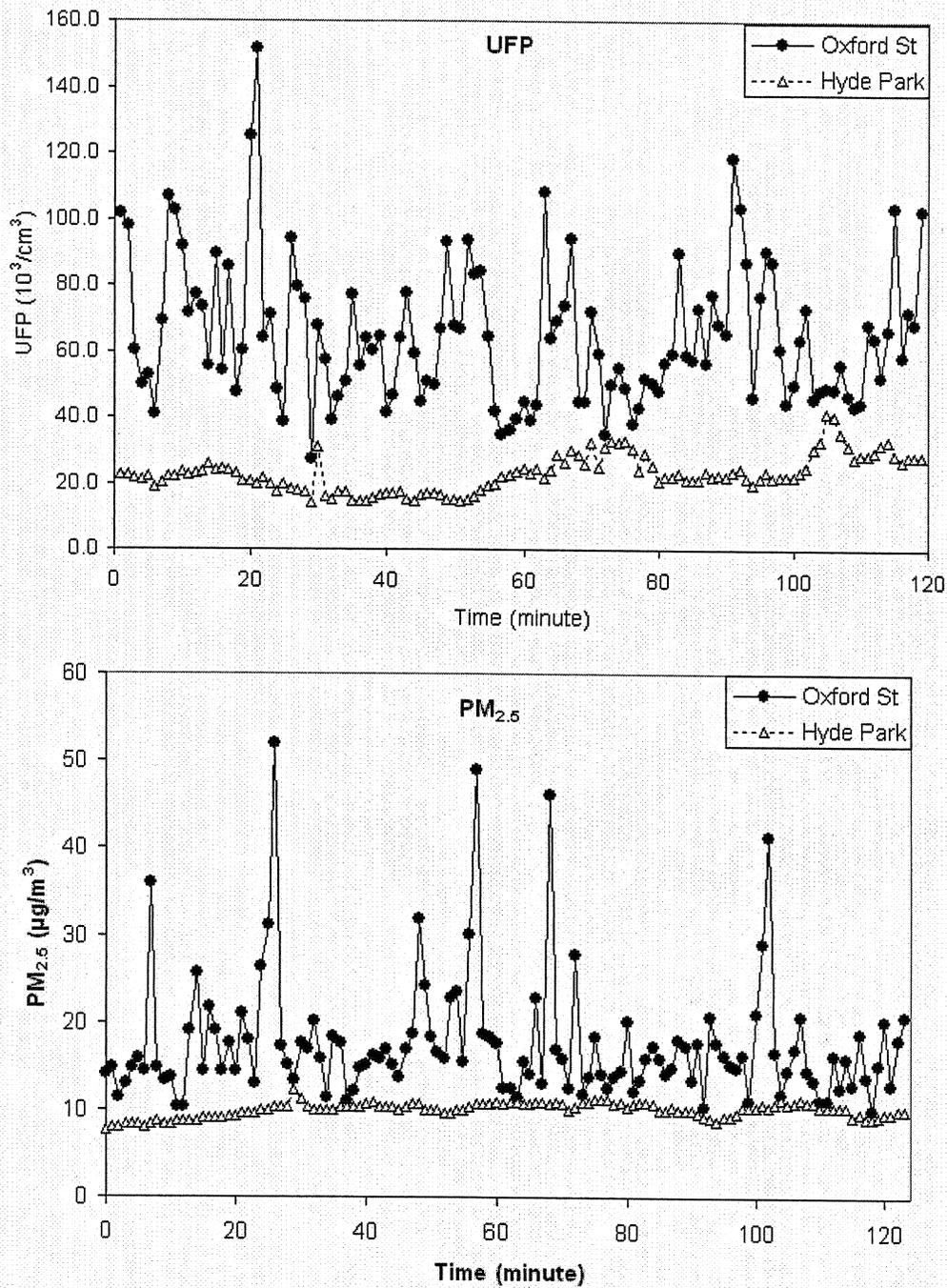


Figure C4. Minute-by-minute concentrations of PM_{2.5} and ultrafine particles (UFP) measured within a 2-hr measurement sessions and concurrently in Oxford Street and Hyde Park