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PUBLIC ATTITUDES TO AIR POLLUTION FROM ROAD VEHICLES

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ACRONYMS AND ABBREVIATIONS

AEA	Atomic Energy Authority
AFR	Air/fuel ratio
ASCII	American Standard Code Information Interchange
BOC	British Oxygen Company
BRF	British Road Federation
BS	British Standards
CASE	Cooperative Awards in Science and Engineering
CBI	Confederation of British Industries
CFC	Chlorofluorocarbons
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COHb	Carboxyhaemoglobin
CONCAWE	The oil companies' European organisation for environmental and health protection
CRAC	Careers Advisory Council
DERV	Diesel Engined Road Vehicle
DoE	Department of the Environment
DoEnergy	Department of Energy
DNPH	Dinitrophenylhydrazone
DOAS	Differential Optical Absorption Spectrocopy
EC	European Community
EEC	European Economic Community
EPA	Environmental Protection Agency
EUN	Extra Urban Network
FoE	Friends of the Earth
GLC	Greater London Council
HC	Hydrocarbons
HGV	Heavy Goods Vehicle
HNO_2	Nitrous acid
HNO_3	Nitric acid
HPLC	High Performance Liquid Chromatography
IARC	International Agency for Research on Cancer
IAPSC	Investigation of Air Pollution Standing Conference
INRETS	Institut National de Recherche sur les Transports et leur Securite
IUAPPA	International Union of Air Pollution Prevention Associations
id	Internal diameter
LPG	Liquid Petroleum Gas
MU	Middlesex University
NILU	Norwegian Institute for Air Research
NMHC	Non-methane hydrocarbons
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_3	Nitrogen trioxide
NO_x	Nitrogen oxides
N_2O	Dinitrogen oxide
N_2O_3	Dinitrogen trioxide
N_2O_4	Dinitrogen tetroxide
N_2O_5	Dinitrogen pentoxide
NIST	National Institute of Standards and Technology

NRC	National Research Council
NSCA	National Society for Clean Air and Environmental Protection
NTNF	Royal Norwegian Council for Scientific and Industrial Research
OECD	Organisation for Economic Co-operation and Development
OH	Hydroxide
O_3	Ozone
OPSIS	Trade name for DOAS equipment
PAH	Polycyclic aromatic hydrocarbons
PAN	Peroxyacetyl nitrates
PAP	Photochemical air pollution
PEC	Particulate elemental carbon
PM_{10}	Particulate matter less than 10 μm in diameter
ppb	parts per billion (by volume)
ppm	parts per million (by volume)
QUARG	Quality of Urban Air Review Group
PTFE	Polytetrafluroethane
SCPR	Social and Community Planning research
SERC	Science and Engineering Research Council
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide
SO_x	Sulphur oxides
SPM	Suspended particulate matter
THC	Total hydrocarbons
TNO	Dutch Research Institute for Road Vehicles
TRL	Transport Research Laboratory, formerly TRRL, Transport and Road Research Laboratory
TSP	Total suspended particulates
UK	United Kingdom
US	United States
UN	United Nations
UV	Ultra-violet
VOC	Volatile organic compounds
WHO	World Health Organisation
WLAS	West London Assessment Scheme
WYTConsult	West Yorkshire Transportation Consultants

Site abbreviations

R	Residential
C	Commercial
B	Birmingham
C	Cardiff
Cov	Coventry
E	Ealing
Edin	Edinburgh
S	Sheffield
WG	Wood Green

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ABSTRACT

An assessment of the environmental effects of any new road scheme is currently recommended by the Department of Transport, but the existing appraisal does not include an evaluation of public nuisance from vehicle-derived air pollution. This research project has investigated the subjective nuisance effects of air pollution from road traffic on the public through the simultaneous measurement of public attitudes towards vehicle-generated nuisance and air quality in residential and commercial areas.

Roadside pollutant concentrations were monitored during four London-based surveys involving the measurement of CO, NO_x, gaseous hydrocarbons, SO_2, O_3, carbonyl compounds, smoke and total suspended particulates. At these roadside locations, traffic flow and classification data were collected together with local and regional meteorological data. To extend the database, air quality data was collected from five other cities within the UK. These data were obtained from the relevant local authority monitoring sites and/or DoE Enhanced Urban Network sites.

Monitored air pollutant concentrations were found to be similar to those recorded previously at comparable sites. At the roadside locations, the air quality according to the DoE's public information criteria was typically 'very good' for SO_2 and O_3, but sometimes 'poor' for NO_2. At the urban background locations, air quality was generally very good. Positive and significant correlations were recorded between the major vehicular primary pollutants of CO, NO and NMHC and traffic flow at all sites. NO_2/NO_x ratios were lower at the commercial locations than at the residential locations, reflecting the lack of available O_3 for $NO \rightarrow NO_2$ conversion. Roadside black smoke concentrations were much higher than those typically recorded at rooftop level in the UK, probably indicating the strong influence of diesel vehicle emissions and/or the extreme 'blackness' of diesel particles, and suggesting that the 8-Port technique may over-estimate roadside black smoke concentrations.

Social surveys, utilising questionnaires developed especially for this research, were performed to assess the causes, extent and magnitude of public nuisance from vehicle-derived air pollution at each of the pollutant monitoring sites. The survey data indicates the high relative importance of air pollution from road traffic when compared to other social issues, indicating that concern for the environment is now an established social issue rather than a transient preoccupation. Local environmental issues were generally of relatively low priority, although traffic-related nuisances were very important local environmental nuisances. Indoors, noise from road traffic was the most important vehicle-derived disturbance with the major concerns relating to the soiling of surfaces and the malodour of fumes. Outdoors, disturbance from smoke, fumes and odour was the most frequently complained about traffic-induced nuisance, with danger ranking equally highly. Most respondents were concerned about the effects of fumes upon their health, with adverse effects widely assumed. Significant differences in disturbance between sites in the same and different cities, between females and males and between different age groups were recorded. No significant differences in annoyance were noted between smokers/non-smokers and different socio-economic groupings.

At each location, pollutant concentrations are discussed and the results of the social surveys are presented and interpreted. The relationships between nuisance and pollutant concentrations are examined graphically and a mathematical relationship between black smoke concentrations and disturbance score is produced. This relationship is not considered to be sufficiently accurate for predictive purposes and an alternative method for estimating nuisance is proposed.

Chapter 1
Introduction

1.1 Background

In today's society, the deterioration of environmental quality is one of the most prominent social, scientific and political concerns. Public awareness of environmental problems has increased enormously over the last ten years as topics such as acid rain, nuclear waste disposal, contamination of ground waters, stratospheric ozone depletion and global warming have become popular media issues. As a result, considerable political and scientific resources have been devoted to investigating and tackling these immensely important environmental concerns.

In the United Kingdom, attention has increasingly focused on the quality of air in urban areas, particularly with regard to the role played by motor vehicles. Urban air pollution has been extensively studied in recent years, mainly because approximately 80% of the UK population live in urban areas. Although urban air pollutants arise from a wide variety of sources, road traffic is unquestionably the dominant source of air pollutants in urban areas (QUARG, 1993a). Motor vehicle emissions include:

- exhaust pipe emissions
- fuel evaporative emissions
- engine crankcase blowby
- particulate emissions from wear and tear of tyres and brakes.

Road traffic includes vehicles fuelled by petrol, diesel, compressed natural gas (CNG) and liquified petroleum gas (LPG). These vehicles emit a wide range of inorganic and organic substances including oxides of carbon, nitrogen and sulphur; alkanes, alkenes, alkynes, aromatic and polyaromatic hydrocarbons, aldehydes, ketones, carboxylic acids, alcohols, ethers and heterocycles.

The emission of these vehicle-derived chemical compounds into the ambient atmosphere has caused great concern over possible adverse human health effects. Some of these compounds have been identified as toxic, mutagenic or carcinogenic, and exhaust particulate matter or gases adsorbed onto the surface of particulates can be inhaled and deposited deep within the lungs. Research has also shown that exposure of laboratory animals to diesel exhaust produces morphological and biochemical changes in the lung, increases susceptibilty to bacterial infection, and may even produce systemic toxic effects (National Research Council (NRC)

(USA), 1981a). However, the existence of adverse health effects in humans, including carcinogenisis, has not yet been conclusively demonstrated.

Vehicle emissions, especially those from diesel vehicles, may also cause a number of aesthetic and environmental problems. Diesel engines produce higher levels of particulates, odour and noise than well-maintained petrol engines. The particulates may cause irritation and discomfort to pedestrians, as well as being a major cause of visibility reduction and urban soiling. The odour frequently associated with diesel vehicles has been attributed mainly to the presence of oxygenates, such as formaldehyde and acrolein, as well as sulphur containing compounds, in the exhaust emissions. Although vehicle manufacturers have considerably reduced noise from diesel engines, it is likely that compression-ignition engines will always be noisier than spark-ignition engines. Pollution from vehicles, especially diesel vehicles, is therefore suspected to make a significant contribution to subjective nuisance from air pollution in urban areas.

1.2 Aims and Objectives

Air pollution from road traffic is one of the main factors considered in the environmental appraisal of any new road scheme. The existing Department of Transport assessment considers the emission and roadside concentration of those regulated pollutants which are potentially harmful to the health or well-being of human, animal or plant life, or to ecological systems. However, it does not include a detailed methodology for the evaluation of subjective nuisance from vehicle-generated pollution. The main objectives of this research were to investigate the subjective impacts of vehicle-derived air pollution on the general public and develop a methodology to quantify the induced nuisance. The primary aims of the research were:

- to assess the relative importance to the public of air pollution from road traffic when compared to other social and environmental issues;
- to identify the environmental nuisances which are believed to be traffic generated;
- to discover the extent of various nuisances to the public at work, at home and outdoors in urban areas;
- to quantify the nuisance created by air pollutants from road vehicles;
- and, if possible, to develop a methodology for the prediction of nuisance in urban areas.

1.3 Thesis outline

The thesis consists of eight chapters. This initial chapter provides some background information to, and a brief context for the research project. The principal objectives of the research are outlined together with a summary of the thesis contents.

Chapter 2 reviews previous and current research on public nuisance from vehicle-derived air pollution. From this review, the major disturbances to the public are identified, together with the air pollutants suspected to cause nuisance effects. In addition, the methodologies utilised to obtain this information are briefly scrutinised and their deficiencies highlighted.

Like Chapter 2, the third chapter is also a review, and it may be divided into three broad sections. Initially, the major sources of air pollution are discussed in order to place the contribution of vehicular sources into perspective. Secondly, those pollutants which are vehicle-derived and which are suspected to cause nuisance effects are considered in some detail. Pollutants which may cause human health and environmental effects are not discussed in great detail unless they potentially pose some form of general nuisance to the public. Finally, air quality legislation and control technologies for vehicular pollution are discussed briefly.

Chapter 4 describes the monitoring and assessment techniques utilised in this research. Each survey site location is briefly described before the instrumentation and techniques used for the air quality and social surveys are described and evaluated.

In Chapters 5 and 6, the data from the air quality and social surveys are presented. The main results from the public attitude surveys of traffic nuisance in residential and commercial areas are presented and interpreted in Chapter 5, together with concise explanations of the thinking behind each questionnaire question. Chapter 6 summarises the air quality and meteorological data accumulated at each site and examines and interprets the observed cycles and trends.

The relationship between traffic nuisance and air quality is investigated in Chapter 7 using data described in Chapters 5 and 6, and a method for estimating public nuisance from vehicle-derived air pollution is presented. The eighth and final chapter provides a summary of the main research findings of this exercise and includes recommendations for further research.

1.4 Conferences, Seminars and Workshops

A number of conferences, seminars and workshops were attended during the period of this research, a selection of which are outlined below. Those meetings where presentations were made are marked with an asterisk (#).

Conferences attended

- *Third International Syposium on Transport and Air Pollution* (#).
  Avignon, France, 6-10 June 1994.
  Institut National de Recherche sur les Transports et leur Sécurité (INRETS).

- *National Society for Clean Air and Environmental Protection (NSCA) Annual Conference.*
  Bournemouth, 19-22 October 1992.
  NSCA.

- *The Ninth World Clean Air Congress* (#).
  Montréal, Canada, 30 August-4 September 1992.
  International Union of Air Pollution Prevention Associations (IUAPPA).

- *The Fourth International Symposium on Highway Pollution* (#).
  Madrid, Spain, 18-22 May 1992.
  Middlesex University and ETSI Caminos.

- *Second International Symposium on Transport and Air Pollution* (#).
  Avignon, France, 10-13 September 1991.
  Institut National de Recherche sur les Transports et leur Sécurité (INRETS).

- *Science and Engineering Research Council (SERC)/Careers Advisory Council (CRAC) Graduate School.*
  University of Stirling, Scotland, 20-24 June 1991.
  SERC/CRAC.

- *Energy and the Environment.*
  University of Leeds, England, 3-5 April, 1990.
  University of Leeds.

- *The Third International Symposium on Highway Pollution*
  Munich, West Germany, 18-22 September, 1989.
  Middlesex Polytechnic and Bayerisches Landesamt für Wasserwirtschaft.

Seminars and Workshops attended

- *The Future of EC Transport Research.*
  Westminster Central Hall, London, 16 March 1994.
  Institute of European Trade and Technology

- *Update on US Motor Vehicle Emissions Programme*
  Department of the Environment, London, 20 July 1993.
  Michael Bradley and the Department of the Environment.

- *Symposium on Integrated Pollution Control.*
  The Scientific Societies Lecture Theatre, London, 2 December 1992.
  The Royal Society of Chemistry Environment Group.

- *Investigation of Air Pollution Standing Conference (IAPSC).*
  Confederation of British Industries (CBI), London, 16 December 1991.
  IAPSC.

- *Workshop on Environmental Pollution.*
  Harwell Laboratory, Atomic Energy Authority (AEA), Harwell, 27 November 1991.
  The Aerosol Society.

- *Global Atmospheric Chemical Change.*
  The Scientific Societies Lecture Theatre, London, 21 November 1991.
  The Royal Society of Chemistry Environment Group.

- *The Techniques of Market and Social Research; Interviewing: Fundamental Skills and Advanced Techniques.*
  London, 13-14 November 1990.
  Survey Research Centre.

- *First European Workshop on Urban Runoff.*
  Middlesex Polytechnic, London, 9-13 July 1990.
  Middlesex Polytechnic.

- *Desk Top Publishing Using Ventura - A Short Course.*
  Middlesex Polytechnic, London, 1,4-5 June, 1990.
  Middlesex Polytechnic.

- *The Techniques of Market and Social Research; Question Formulation and Questionnaire Design.*
  London, 30 May 1990.
  Survey Research Centre.

1.5 Publications

During the period of this research a number of publications were produced. These publications are listed below.

- Kendall, M.; Hamilton, R.S.; Williams, I.D. and Revitt, D.M. (1994).
  Smoke Emissions from Petrol and Diesel Engined Vehicles in the UK.
  Proceedings of *Dedicated Conference on the Motor Vehicle and the Environment - Demands of the Nineties and Beyond.* Aachen, Germany, October 31-November 4.

- Williams, I.D. and McCrae, I.S. (1994).
  Road Traffic Nuisance in Residential and Commercial Areas.
  Proceedings of *Third International Symposium on Transport and Air Pollution*, Avignon, France, 6 - 10 June. (Accepted for publication in *Sci. Tot. Environ.*).

- McCrae, I.S. and Williams, I.D. (1994).
  Road Traffic Pollution and Public Nuisance.
  Sci. Tot. Environ., 146/47, 81-91.

- Quality of Urban Air Review Group (1993).
  Diesel Emissions and Urban Air Quality.
  Contributions (consultancy) to a number of chapters in report.
  Second Report of the Quality of Urban Air Review Group, The University of Birmingham, Edgbaston, Warwicks.

- Williams, I.D. and McCrae, I.S. (1992).
  Air pollution and public nuisance from road traffic .
  TRL Working Paper WP/VE/103, Transport Research Laboratory, Crowthorne,

Berks.

- Williams, I.D., Hamilton, R.S. and Revitt, D.M. (1992).
  Public Attitudes to Road Traffic Pollution and Nuisance.
  Proceedings of the *Ninth World Clean Air Congress*, Montréal, Canada, August 30 - September 4. Volume 6, *Risk Assessment, Strategies and Pollution Prevention*, Paper No. IU-14B.07.

- Williams, I. D. (1991).
  Road Traffic Pollution and Public Nuisance.
  Clean Air, **21**(3), 123-131.

- Williams, I. D. (1990).
  Urban Pollution Research Report 20: The Quantitative Analysis of Black Carbons.
  Urban Pollution Research Centre, Middlesex Polytechnic.

Chapter 2

Public Attitude and Opinion Surveys of Traffic Nuisance

2.1 Causes of vehicle-derived nuisance

Three types of nuisance are defined within United Kingdom law. Public and private nuisance are within Common Law while statutory nuisance is defined by Acts of Parliament. Public nuisance is both a civil wrong and a crime punishable by law and takes into account the number of persons affected. Road traffic affects the public in a wide variety of ways, many of which cause some degree of annoyance, and hence vehicle-derived nuisance is likely to fall into all three nuisance categories. The major disturbances to the public from road vehicles (not in any order) are:

a) Pedestrian danger	b) Visual intrusion
c) Severance	d) Noise
e) Vibration	f) Dust and dirt
g) Fumes/smoke/odour	h) Visibility reduction
i) Soiling	j) Physical irritation

It is evident that in a busy traffic situation any or all of items a)-j) above may irritate the public, and these factors are likely to be synergistic in their effects. Many of the factors are inter-related and dependent *eg* dust/dirt and soiling, smoke and visibility reduction, and hence it may be difficult for the public to decide which factor they find the most annoying.

Information about public attitudes and opinions to traffic nuisance is usually obtained through survey data via questionnaires and personal interviews, although at present, there is only a limited data base available. Two organisations who have performed major studies of traffic disturbance in the UK are the Transport Research Laboratory (TRL; previously the Transport and Road Research Laboratory, TRRL) and Social and Community Planning Research (SCPR). In Europe, the Royal Norwegian Council for Scientific and Industrial Research (NTNF) has been running its Traffic and the Environment Programme since 1983, which has studied a broad range of issues relating mainly to the health effects of traffic pollution, but also includes information on traffic disturbance.

Mackie and Davies (1981) have reviewed research performed by TRL on the environmental effects of traffic changes in nine British towns. In these towns, changes in traffic flow due to traffic management schemes or construction of a by-pass allowed an assessment of the nuisance caused by different traffic flows to be performed. They discovered that there was a strong correlation between nuisance and:

- the number of lorries over 16 tons gross vehicle weight,
- the total traffic flow.

The relationship between nuisance/health effects and traffic flow has been reported by a number of workers (*eg* Morton-Williams *et al*, (1978); Aas *et al*, (1991); Bartlett, (1992) and Whitelegg *et al*, (1994)), although nobody to date has been able to show a causal link between traffic exposure and health/nuisance effects.

Mackie and Davies (1981) identified that the public were bothered mainly by five sorts of traffic nuisance:

- Danger
- Noise
- Vibration
- Dust/dirt
- Smoke/fumes

Their conclusion was that each of these factors 'contributed substantially to nuisance but when their significance relative to each other was rated, it varied somewhat between different groups, between sites, and between 'before' and 'after' occasions' (before and after the implementation of road traffic schemes) (see Table 2.1 - note that these figures are ranks, and that a low score represents a higher degree of nuisance).

The data in Table 2.1 do not indicate any readily apparent patterns of disturbance. The implementation of the traffic schemes do not appear to have consistent effects on the relative rankings, *eg* the relative importance of danger from road traffic does not always reduce or increase as a result of the traffic scheme. No single nuisance factor stands out as being the most or the least important, and there are considerable variations between the respondent groups, *eg* dust and dirt is the most important to shop workers and the least important to pedestrians. These inconsistencies indicate the difficulties involved in the quantitative determination of relative nuisance, and suggest that the type of respondent group, and their circumstances, may be important. It should be noted however, that the studies reviewed by Mackie and Davies (1981) were performed with the aim of monitoring public response before and after changes

Table 2.1
Average ranks of importance for different nuisance factors.
(from Mackie and Davies, 1981)

Respondent group	Nuisance factor	Before	After	Overall
People at home	Danger	2.8	2.0	2.4
	Noise	1.6	2.3	2.0
	Vibration	2.4	2.8	2.6
	Dust and dirt	3.1	2.6	2.9
	Smoke and fumes	4.8	4.5	4.6
Pedestrians	Danger	1.4	1.6	1.5
	Noise	2.2	2.4	2.3
	Dust and dirt	4.2	3.2	3.7
	Smoke and fumes	2.4	2.0	2.2
Shop workers	Danger	2.6	3.2	2.9
	Noise	1.6	2.4	2.0
	Vibration	3.6	3.0	3.3
	Dust and dirt	2.0	1.2	1.6
	Smoke and fumes	4.8	4.8	4.8
Office workers	Danger	3.0	2.6	2.8
	Noise	1.0	1.6	1.3
	Vibration	2.8	2.8	2.8
	Dust and dirt	2.8	2.8	2.8
	Smoke and fumes	4.4	4.2	4.3

in traffic flow, and that the public's opinion of traffic nuisance is likely to be different under stable conditions.

Some of the most recent research relating to road traffic annoyance has been published by the Norwegian Institute for Air Research (Norsk Institut for Luftforskning, NILU) on behalf of NTNF. Their research was mainly concerned with the health effects of air pollution from road traffic, but it did include studies on a wide range of traffic-related disturbances. One of the conclusions of their work to date is that:

> Traffic is the most serious environmental problem in our urban towns and built-up areas, and measures aimed at reducing the negative effect of traffic on the environment will, without doubt, improve the well-being of the inhabitants (Aas *et al*, 1991).

This chapter reviews the existing attitude and opinion survey data relating to public nuisance from vehicle-derived air pollutants *ie* items f)-j) above. Naturally therefore, the role of pollutants produced by road vehicles (especially diesel vehicles) is emphasised, although clearly in an ambient urban atmosphere many sources will contribute to the overall nuisance.

2.2 Nuisance from dust and dirt

Dust and dirt are terms that are readily recognised and understood by both the public and the scientific community. Dirt may be defined as unclean matter which soils any object by adhering to it. Dusts are popularly regarded as fine, solid particles which have settled on a surface (*eg* a window ledge) and which can readily be redispersed into the atmosphere by cleaning, washing *etc*. Green and Lane (1964) have attempted a more scientific definition by stating that 'Dusts, in the colloid sense, consist of solid particles dispersed in a gaseous medium as the result of the mechanical disintegration of matter.' This definition suggests that dusts are formed only by the breakdown of matter, and ignores the possibility of formation by chemical reaction or accumulation. In this thesis, dust is defined as dry, solid matter so comminuted as to be easily raised from a surface and dispersed by air currents.

Dust particles have diameters within the range of 1 to 1000 μm. Dusts which are respirable have important health implications and may well contribute significantly to the overall public nuisance from dust. Particles of respirable dust are often regarded as being less than 10 μm in diameter, although a less limiting definition has been provided by the National Society for Clean Air and Environmental Protection (NSCA) (1993), who have defined respirable dust as suspended particulate matter that can be deposited to a significant extent in the lung.

Airborne dust arises from a variety of sources and is always present to some degree. There is thus a need to differentiate between the effects of the possible dust nuisance source and the environmental background. David Shillito (1992) has suggested adopting a system of classifying dust nuisance by deposit type. This classification reflects the source of the dust, the mechanism of its travel and its effects on the public. *Macro-deposits*, including bird droppings, smuts and blobs from chimneys and rain modified dust films, are large, individual, obtrusive deposits. They are clearly visible to the unaided human eye at about a 1 m distance and are usually outdoor problems. *Gritty deposits* consist of large, coarse particles with diameters in the region of 200-1000 μm, and are produced by activities such as construction, heavy materials handling and stockpiling. Grit problems are often associated with strong winds and large paved areas where saltating gritty particles can be generated. *Films of dust* are caused by particles which are sufficiently small (10-100 μm) to be dispersed on the wind rather than to move in saltating motion. These fine dusts often originate from fugitive sources and are too small to be seen by the unaided human eye, becoming visible only through the modification of the appearance of a surface (soiling).

Shillito's classification is a useful tool for the identification of dust nuisances from sources which produce only one type of deposit, although it is difficult to apply to vehicle generated dust/dirt, which includes all three types of deposit. Road vehicle derived dust/dirt includes exhaust particulates rich in carbon (mainly from diesels); resuspended dust (due to vehicle-generated turbulence - includes de-icing salt/sand); particulates from tyres, brake/clutch linings and road/pavement wear; deposited rust/paint and inorganic compounds (*eg* leaded compounds).

A number of surveys have been conducted which include some data on the degree of public annoyance arising from vehicle generated dust and dirt. SCPR (Morton-Williams *et al*, 1978) conducted an extensive national survey in England in 1972 showing that 'Many people believe that traffic is responsible for much of the dust and dirt that settles on the window ledges, curtains or bookshelves in their homes.' Forty-eight percent of those people interviewed considered that 'things get dirty very quickly here', although the respondents were fairly evenly divided as to whether traffic or other sources were mainly responsible for the dirt. Figure 2.1 shows the public response to the question 'How much are you annoyed or bothered by dust and dirt from road traffic?'

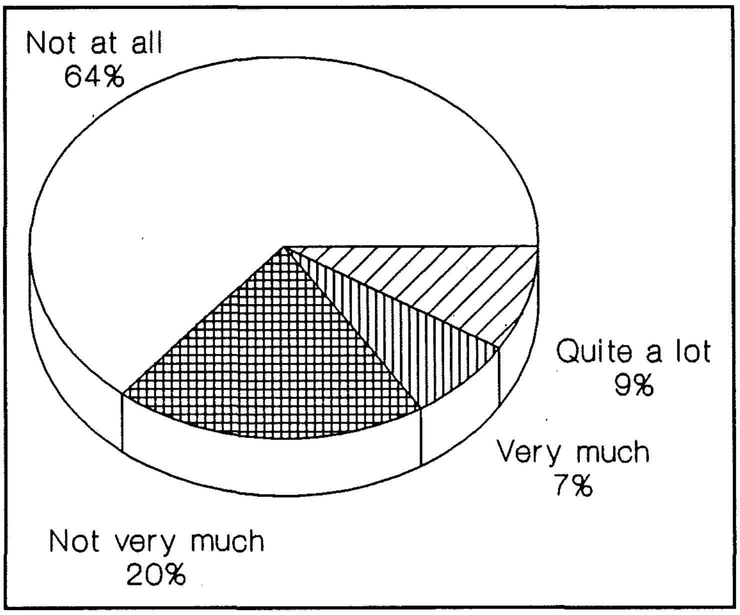
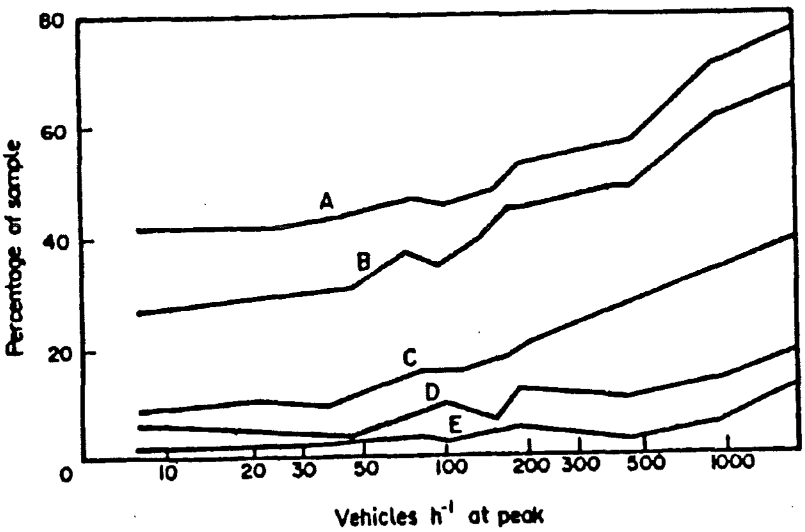


Figure 2.1
Public response to the question 'How much are you annoyed or bothered by dust and dirt from road traffic?' (Morton-Williams *et al*, 1978).

The survey also suggested that there was a relationship between public disturbance from vehicle-derived dust and dirt and increases in vehicle flow. This relationship is shown in Figure 2.2, which seems to indicate an increase in the percentage of people disturbed by dust/dirt as the number of vehicles per hour at peak traffic flow increases. The increase in disturbance becomes slightly more marked once a rate of 200 vehicles per hour is reached. Ashdown Environmental (1989) conclude that:

> This is an extremely modest flow for UK roads and if these results can be taken as representative, it implies that very large numbers of people are bothered by this form of vehicle nuisance.



Key	A) Finds things get dirty quickly B) Disturbed by dust and dirt C) Seriously disturbed by dust and dirt D) Notice fumes E) Seriously disturbed by fumes

Figure 2.2
The relationship between public disturbance due to dust and dirt or fumes in the home and peak hour traffic flow outside the home (Morton-Williams *et al*, 1978).

Overall, SCPR found that noise was the greatest nuisance to people at home with dust and dirt a close second. For pedestrians, dust and dirt ranked third behind pedestrian danger and noise/fumes as a traffic related disturbance. Dust/dirt also ranked third as a traffic-related disturbance (behind road traffic noise and exhaust fumes) in a three site survey performed by NTNF in Norway (Aas *et al*, 1991). The data for this survey are shown in Figure 2.3, and illustrate that the number of traffic-related complaints is site dependent, with respondents from the Vålerenga/Gamlebyen area of Oslo showing the greatest disturbance. The Vålerenga/Gamlebyen area of Oslo has one of the highest traffic densities in Norway, and probably therefore represents a worst-case situation, whereas the other two areas provide a more typical illustration of the Norwegian urban environment (Aas, *et al* 1991).

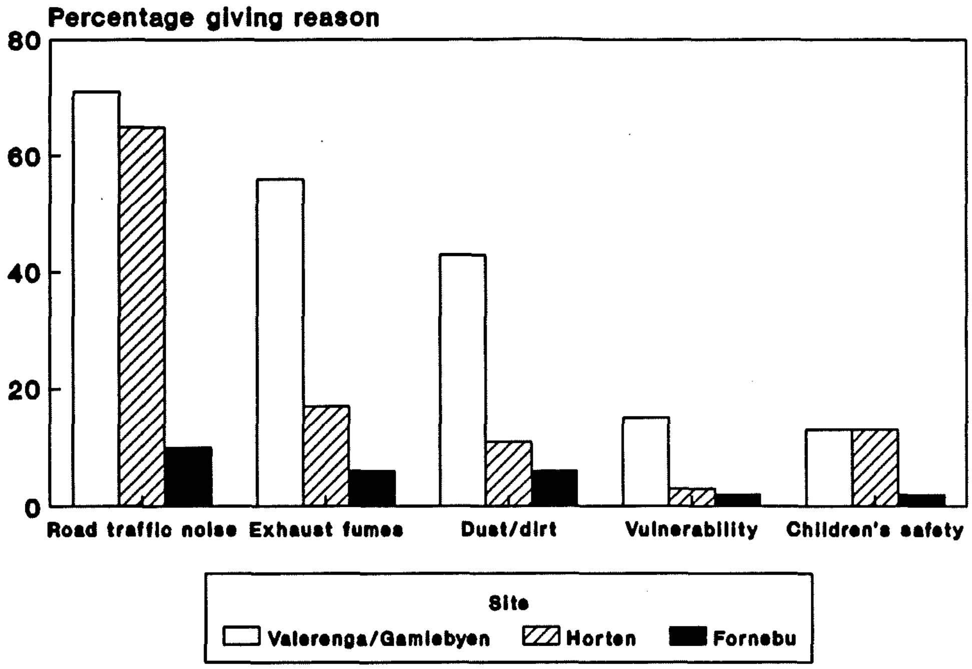


Figure 2.3
Reasons for road traffic being regarded as an annoyance at 3 sites in Norway (Aas *et al*, 1991).

The Norwegian study, like that of SCPR, suggests that there is a relationship between disturbance from dust/dirt and traffic flow. NTNF plotted the percentage of respondents suffering from dirt/grime inside their homes against the daily traffic volumes at the three sites. The data is shown in Figure 2.4, and indicates that the degree of nuisance increases with the increase in traffic volumes. Aas *et al* (1991) have also suggested that the traffic volumes in areas close to the respondents' homes influence the disturbance caused to the public. For example, they noted that in streets with about 10,000 vehicles per day, about 40% were inconvenienced in Horten and about two-thirds in Vålerenga/Gamlebyen. Horten has a much lower traffic density than Vålerenga/Gamlebyen.

A recent study in the UK (Whitelegg *et al*, 1994), claimed to have shown 'a very clear link' between traffic volumes and reported symptoms of ill-health. Their results, though plausible, do not show a causal link between traffic exposure and human health effects.

The 'before and after' studies performed by TRL (see Section 2.1) have suggested that dust and dirt are of greatest nuisance to the public when they are indoors rather than when they are pedestrians. Dust and dirt were found to be a considerable public nuisance during the 'before' studies, but significant reductions in nuisance as a result of traffic changes only occurred where there was a substantial reduction in total traffic flow or where lorries had been re-routed (as was the case at Leeds, where a small traffic change as a result of lorry re-routing produced a large reduction in public nuisance) (see Table 2.2). Thus, while this data also supports the theory that there is a relationship between traffic density and disturbance from dust/dirt, it further suggests that there may be a link between the numbers of lorries and this type of nuisance. Recent research by TRL has investigated means of predicting perceived lorry nuisance using traffic flow variables (Bartlett, 1992).

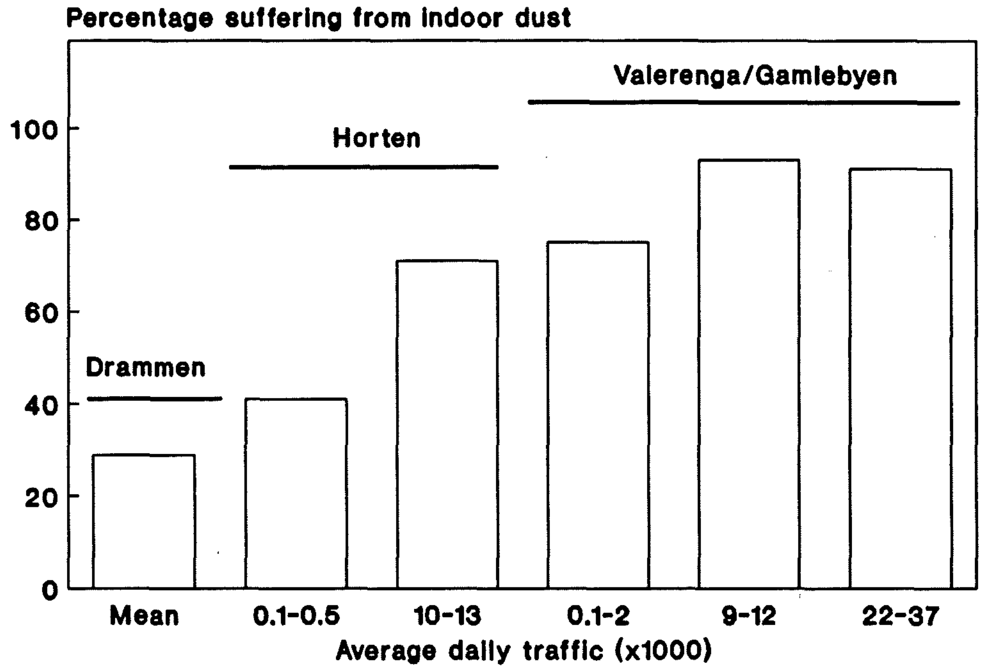


Figure 2.4
Percentage of respondents suffering from dust/grime at 3 sites in Norway plotted against daily traffic volume (Aas *et al*, 1991).

A number of studies (*eg* Aas *et al*, 1991; Riddett, 1987; Hopkinson and Pearman, 1987; Mackie and Davies, 1981; Morton-Williams *et al*, 1978; WYTConsult, 1977; Pearce and Stannard, 1973), have identified dust and dirt as a public nuisance through the use of questionnaires and personal interviews. Public comments included complaints about:

- traffic pollution making buildings and paintwork dirty/discoloured;
- dust/dirt soiling outdoor furniture and washing;
- dust/dirt soiling windows, window sills and curtains;
- dust/dirt getting into cupboards and wardrobes;
- dust/dirt increasing cleaning/maintenance expenses;

- an area becoming generally dirtier (and therefore unattractive) as a result of increased traffic flows.

Shillito (1992) has also recorded complaints about outdoor dust soiling the paintwork of cars, pram and carry-cot surfaces, and indoor dust soiling polished surfaces (*eg* televisions). He further suggests that dust may cause tactile nuisance to people if it is felt on the skin, hair or mouth, and that gritty dust may potentially cause serious damage to the eyes of a contact lens wearer.

Table 2.2
Percentage of people at home bothered 'very much' or 'quite a lot' by dust and dirt (Mackie and Davies, 1981).

Site	% bothered 'very much' or 'quite a lot' by dust/dirt		Traffic change (%)
	Before	After	
Tring	40	29	-41
Mere	62	10	-69
Boughton	-	11	-81
Bridge	70	0	-85
Lewes	60	57	-46
East Grinstead	44	43	-41
Ludlow	58	49	-55
Leeds - A58	55	16	-3
Leeds - A64	33	63	+16
- no before study done			

In summary, the general consensus of the surveys is that dust and dirt does constitute a nuisance to the public. Dust nuisance appears to result from visual and tactile perception of deposited dust/dirt, combined with a dislike of the effects produced (*eg* soiling). Evidence exists which suggests a link between the magnitude of disturbance from dust/dirt and traffic volumes. However, there does not yet appear to have been an attempt to determine the correlation between actual measured levels of dust and the degree of public annoyance.

2.3 Nuisance from smoke, fumes and odour

2.3.1 Smoke and fumes

A major stumbling block to the evaluation of public nuisance is the difference between the public's understanding of the word(s) used to describe a nuisance and the strict definitions employed by scientists. An example of this problem arises when people are asked to describe what type of vehicle pollution bothers them. Words such as smoke, fumes and smells are often used in nuisance questionnaires. However, while some of these words, for example smoke, have a well-established scientific definition, others, such as fumes are very difficult to define. Therefore, in interpreting data derived from public opinion surveys it becomes difficult to pinpoint the exact cause of the public's annoyance. For example, although a respondent may use the word fumes when asked what bothers him/her most about road traffic, the real cause of his/her displeasure could be the malodour.

Smoke is generally defined as 'fine suspended particulate air pollutants ($< 15\ \mu m$ in diameter) as measured by the staining capacity of air' (Harrison, 1986). Smoke is made visible mainly through the presence of small particles of elemental carbon resulting from the combustion of carbonaceous materials (*eg* coal, wood, diesel fuel). The word 'fumes' is very difficult to define, since there is much overlap between fumes, odour and smoke. Fumes have variously been defined as:

> 'the volatile matter produced by and usually accompanying combustion' and 'odour or odourous exhalation (either fragrant or offensive)' (Oxford Universal Dictionary, 1974)
>
> 'a smoke, vapour or gas, especially when irritating or offensive' (Websters, 1983)

The NSCA in their handbook (1993) give 3 definitions of fume(s):

1) An aerosol of fine solid particles, commonly but not always defined as being in the size range 0.0002 to 1 μm in diameter. Fume also arises from the rapid formation of a non-volatile compound by the reaction between two gases or vapours.
2) Often used in the plural ('fumes') for effluents (gases, vapours or aerosols) that usually have a choking or unpleasant smell.
3) The whole of the combustion gases and the particles entrained in them.

SCPR found in their national survey of England in 1971-72 that only 8% of their sample population noticed traffic fumes inside their homes, of which only 1% were bothered 'very much' and 2% 'quite a lot' (Morton-Williams *et al*, 1978). More than 90% of the sample said that they were not bothered at all by traffic fumes in their homes. The response was, however, quite different when people were asked if they noticed traffic fumes outdoors. Over half of the sample (54%) said that they noticed fumes from cars, lorries or buses when they were outdoors, and 23% said that they were bothered 'very much' or 'quite a lot'. The public were also asked what effect(s) they thought that traffic fumes had on people in general, and on themselves personally. SCPR summarised the responses as follows:

> Belief that traffic fumes can have harmful effects is widespread. Many people commented that fumes caused or aggravated respiratory ailments in the population generally. A quarter of the sample claimed that fumes affected their own health. People felt that lorries were by far the worst offenders as sources of traffic fumes (Morton-Williams *et al*, 1978).

In fact, 37% of the public felt that lorries gave out the worst fumes compared with 13% for buses/coaches, 3% for cars and 1% for motorbikes and mopeds. Overall, fumes ranked equal second with noise in importance as a public disturbance.

Figure 2.2 shows the relationship between disturbance from traffic fumes and vehicle flow derived by SCPR. Disturbance generally increases slowly with traffic flow, although this graph gives no indication of the proximity of the respondent's house to the road. This is an important consideration, since Hopkinson and Pearman (1987) have noted a variation in the degree of nuisance experienced with distance from the road. Clearly, the inclusion of supplementary information such as the distance of the respondent's house from the road is necessary in order that the level of nuisance experienced by the public can be put into proper perspective.

Other studies by SCPR (Hoinville and Prescott-Clarke, 1972; Morton-Williams and Prescott-Clarke, 1971) have also indicated that:

- the public perceive traffic fumes as a nuisance and a health hazard;
- when people notice fumes from road traffic, they are invariably bothered or annoyed to some degree.

TRL's studies of the nuisance caused by smoke and fumes are summarised in Table 2.3. The results show a similar trend to those obtained by SCPR in that smoke/fumes tend to be ranked lower than other factors as a nuisance to people in their homes. Table 2.3 shows some large reductions in the number of people claiming to be bothered by smoke/fumes as a result of changes in traffic flow, which again illustrates the relationship between volume of traffic and level of nuisance experienced.

Table 2.3
Changes in percentage of people at home bothered 'very much' or 'quite a lot' by smoke and fumes (Mackie and Davies, 1981).

Site	Per cent bothered 'very much' or 'quite a lot'	
	Before	After
Tring	16	11
Mere	16	1
Boughton	-	0
Bridge	41	0
Lewes	31	24
East Grinstead	17	12
Ludlow	27	9
Leeds - A58	30	5
Leeds - A64	7	43
- no before study done		

At one site (Tring), the TRL mobile laboratory was used to measure ambient levels of sulphur dioxide, hydrocarbons, carbon monoxide, nitrogen oxides and lead, both before and after the implementation of a traffic management scheme. Thus in this study, there was an attempt to link nuisance to atmospheric pollutant concentrations as well as traffic characteristics. In spite of a recorded reduction in traffic flow of 41%, it was not possible to demonstrate any significant decrease in pollutant concentrations because in both periods ambient pollutant concentrations were low. However, apart from hydrocarbons, the pollutants measured would not have been perceptible to the general public and hence 'any attempt to relate people's subjective response to these measured air quality parameters would not therefore be viable' (Ashdown Environmental, 1989).

NTNF have also attempted to link nuisance with pollutant concentrations by comparing information regarding 'annoyance' with an estimated carbon monoxide index for an individual respondent's home (Aas *et al*, 1991; Clench-Aas *et al*, 1991). Their results seem to indicate that annoyance increases as the carbon monoxide levels rise. This observation indirectly supports the relationship derived by SCPR (shown in Figure 2.2) between disturbance from traffic fumes and vehicle flow, since carbon monoxide is primarily produced by road vehicles in urban areas. However, the concentrations of carbon monoxide utilised by NTNF in their index were greatly in excess of values typically found at urban background locations in the UK.

The TRL and SCPR reports conclude that the public's beliefs about smoke/fumes are more influenced by their own beliefs and assumptions than by any physical evidence. This conclusion is regarded as premature by Ashdown Environmental (1989) in the absence of air quality data for readily perceptible pollutants.

In 1986, 1989 and 1993 the Department of the Environment (DoE) commissioned studies to investigate public attitudes towards a number of environmental issues. These studies have indicated that public awareness of the environment as a whole increased rapidly between 1986 and 1989 when considerable media attention was focused on environmental issues (*eg* Global Warming). The 1993 survey has shown that the environment has remained an issue of high relative importance despite four years of recession. This observation contrasts with conventional wisdom that concern about environmental issues wanes during times of recession and may indicate that environmental issues are becoming established as major public concerns. More pertinently, concern about car/traffic exhaust fumes has increased significantly over this period (see Table 2.4). It should be noted however, that many other issues, such as getting rid of nuclear waste, were of more concern to the public than car/traffic exhaust fumes. Although the DoE question did not directly relate to nuisance, a number of other studies have also indicated that the public perceive fumes from traffic as a nuisance (Aas *et al*, 1991; Clench-Aas *et al*, 1991, Hopkinson and Pearman, 1987; Pearce and Stannard, 1973).

Table 2.4
Public response to the question 'How worried do you personally feel about each of these problems?' (DoE, 1986, 1989 and 1993).

	Very worried	Quite worried
Car[1] exhaust fumes (1986)	23	37
Traffic[1] exhaust fumes (1989)	33	42
Traffic exhaust fumes/urban smog[1] (1993)	40	-
[1] The 1986, 1989 and 1993 questions used different wordings.		

Reviews of the effects on the public of a number of traffic management schemes in London have been performed by Ball and Caswell (1982, 1983). Their concern was mainly with smoke from diesel-engined road vehicles, and they stated that '...public concern is with the perceived effects of smoke emissions, and not the visible manifestations of the smoke itself...'. This conclusion was based on the fact that they were unable to find any evidence of public complaints about visibility reduction in the social surveys that they reviewed. They therefore argued that soiling of property was a more accurate reflection of the impact that diesel emissions have on the public, and concluded that emission standards should be changed from a visibility to a soiling-based criterion.

Overall then, the public do appear to experience some nuisance from smoke and fumes, both as pedestrians and in their homes. The ambient levels of smoke and fumes necessary to cause this nuisance have not, however, been established.

2.3.2 Odour

It is not possible to separate odour from the above discussion on smoke and fumes because of the definition and perception difficulties mentioned in Section 2.3.1. However, since some specific diesel odour research has been performed, odour is discussed here as a single issue.

Odour may be defined as a presence that stimulates the olfactory organ (Websters, 1983). Although odours may be instantly recognisable, frequently they defy characterisation, since the identification of odourants is a complex, expensive and time-consuming process. A number of researchers, including Cernansky (1983) and Hare and Springer (1971), have stated that odours from diesel exhausts are a public nuisance. Cernansky (1983) states that odours can:

> Affect human well-being by eliciting unpleasant sensations, by triggering harmful reflexes or other physiological reactions, and by modifying olfactory functions. Unfavourable responses are said to include nausea, headache, and coughing; upsetting of sleep, digestion, and appetite; irritation of eyes, nose, and throat; and destruction of the sense of well-being and enjoyment of food, home and external environment.

Typically, combustion odours result from the combined effects of a multitude of components which cannot be characterised by chemical class or formula. The production of odourants is inherent in the diesel combustion process, although the concentration of odourants in the exhaust depends on the dynamics of the combustion and mixing processes. Generally, diesel engines have slight to strong odour intensities, with direct injection engines being more malodourous than indirect injection engines (Ricardo, 1987). In comparison, petrol-engined vehicles are usually less odourous than diesels, having imperceptible to slight odour intensities.

The environmental impact of diesel exhaust odour is difficult to quantify since odourants are poorly characterised, rapidly dispersed into the atmosphere and are present in low concentrations. However, it is possible that odours in roadside environments are very localised and short-lived (*eg* due to an engine revving at a pedestrian crossing). On this basis, Cernansky (1983) argues that although average ambient odour concentrations may be low, instantaneous odour levels at receptor locations may be high, and it is these short-lived emissions that cause most offense.

In spite of the preceding discussion, there is little evidence to support the notion that vehicle-derived odours are a public nuisance. The results of a recent study of 162 people by NTNF in Vålerenga, Norway, have suggested that there is a correlation between the frequency of being inconvenienced by smells and the (calculated) atmospheric nitrogen dioxide (NO_2) level, with NO_2 being used as an indication of road traffic pollution (Aas *et al*, 1991; Clench-Aas *et al*, 1991). Their results suggest that 13% of the total sample population showed a significant positive relationship between bothersome smells and NO_2 exposure. NTNF also plotted the odds ratio of a set of health parameters versus estimated NO_2 exposure, as shown in Figure 2.5.

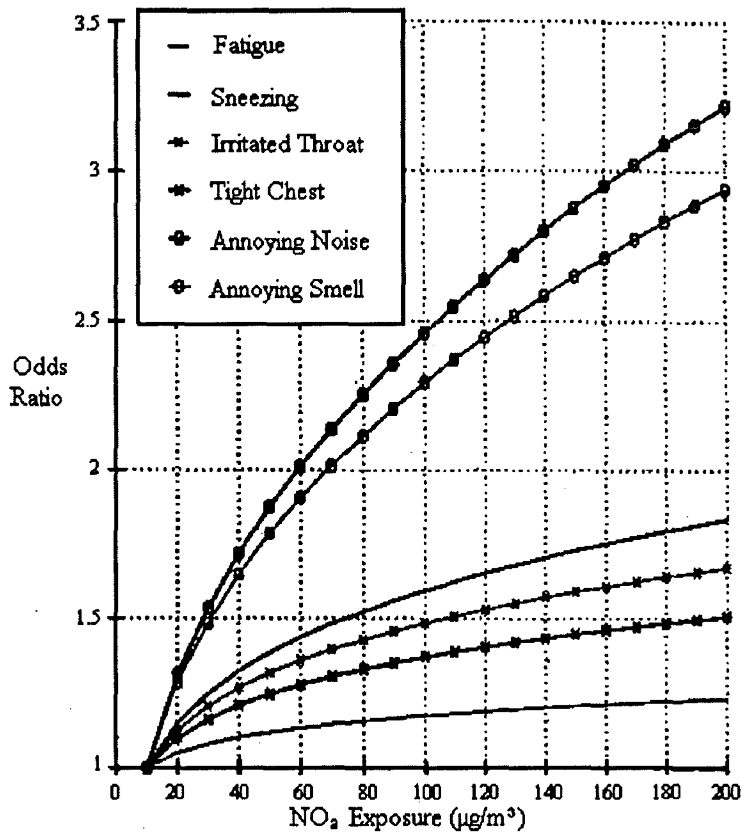


Figure 2.5

The odds ratio of a set of health parameters as a function of estimated air pollution exposure (Clench-Aas *et al*, 1991).

The odds ratio may be interpreted as an increased risk of having a health/nuisance symptom at different concentrations of NO_2 relative to a base NO_2 exposure level (Clench-Aas *et al*, 1991). For example, for NO_2 at 30 $\mu g/m^3$ the odds ratio for being annoyed by smell is almost 1.5 or nearly 50% higher than at a NO_2 level of 10 $\mu g/m^3$ (NTNF's selected base level). The data in Figure 2.5 suggest that odour annoyance increases markedly with estimated exposure to NO_2, although it should be stressed that NO_2 is not a major primary vehicle pollutant (see Section 3.10).

Hare and Springer (1971) and Hare *et al* (1974) attempted to evaluate the public perception of vehicle exhaust odours, but their studies were laboratory-based and provide no hard data on nuisance effects. Research by Springer (1974) indicates a possible link between people's subjective response to diesel exhaust odours and their awareness and attitude towards air pollution. Surveys by SPCR, TRL and NTNF include complaints about the 'fumes' from vehicles, but it appears that the public associate fumes with health effects rather than odour (Ball *et al*, 1990). The public opinion surveys reviewed by Ball and Caswell (1983) also failed to find any evidence of traffic odours causing public disturbance. Karl Springer has commented in 1990 that he feels that vehicle odours will not cause any public nuisance because:

- the reduction of sulphur levels in fuel will cause fewer odourants to be produced;
- the reduction in hydrocarbon emissions from vehicles made necessary by law will reduce odour levels;
- ambient odourant levels will be reduced through the use of catalyst after-treatment to reduce particulate emissions from diesel vehicles (although odour from petrol vehicles may increase due to hydrogen sulphide formation in catalytic convertors).

Hence, although documented evidence shows that motor vehicles emit unpleasant odours into the urban atmosphere, these odours do not appear to cause any significant public annoyance, probably because of their short-lived and localised nature.

2.4 Nuisance from visibility reduction

Light extinction is caused by the scattering and absorption of light by atmospheric particulates and gases. Diesel emissions are a major contributor to urban visibility reduction, being the most important UK source of black smoke and particulate elemental carbon (PEC) (QUARG, 1993a). It has been estimated that PEC is responsible for between 25-45% of visibility reduction (Hamilton and Mansfield, 1991). Limit values for emissions of smoke from diesel road vehicles are specified by British Standard BS AU 141a and EC Directive 72/306/EEC. This legislation was introduced because it was felt that the public were concerned about the visibility reducing effects of diesel smoke. The social surveys that have been reviewed during this literature survey include no evidence that supports this presumption. Although this does not conclusively demonstrate that the public are not bothered by traffic-induced visibility reduction, it does indicate that visibility reduction is not a major public concern.

2.5 Nuisance from soiling

Soiling is generally regarded as the dirtying or blackening of surfaces by particulates. Road vehicles contribute to urban soiling mainly through the deposition of exhaust particulates onto surfaces. Diesel vehicles are the major sources of particulates (especially PEC) and dark smoke in urban areas (see Chapter 3) and are widely regarded as having a greater blackening propensity than petrol engine emission and coal fires (Ball and Caswell, 1983). Assessment of the relative contributions of various sources to urban soiling is complex and may depend on a number of factors, such as:

- the particular soiling/dirt problem under investigation;
- the blackness per unit mass of smoke;
- the particle size distribution;
- the chemical nature of the particles;
- substrate-particle interfacial binding;
- surface orientation;
- micrometeorological conditions.

Public complaints about soiling by vehicle-derived dust/dirt and smoke/fumes have been considered in Sections 2.2 and 2.3. Ball and Caswell (1983) summarise the situation thus:

> Judging by the results of the social surveys, public concern in Britain over soiling of property by road vehicles is widespread, with approximately 33% of the entire population being bothered or annoyed by it.

They go on to state that:

> ...as far as London is concerned, diesel-engined vehicles may well be the main source of soiling, and that a similar pattern could apply in other UK conurbations where smoke control of stationary sources has been carried out.

2.6 Nuisance from physical irritation

Physical irritation includes effects such as coughing, sneezing, blinking and sore or runny eyes caused by irritation of eyes, respiratory tissue, throat etc. These effects are easy to visualise in a busy roadside situation *eg* a wind-blown particle lodging in a person's eye. Although there have been many reports of air pollutants causing direct health effects, the classic examples being the great London smogs of 1952 and 1956, studies of irritation caused by air pollutants are rare. More recently, research by Professor Ross Anderson into a smog episode in London in December 1991 has suggested that the death rate in London increased 10% over the duration of the episode (*The Independent*, 23/6/94). However, no data on nuisance effects was collected during this period.

The Los Angeles County Air Pollution Control District and the Air Pollution Foundation performed a number of studies of eye irritation in the Los Angeles area in the 1950s and 1960s which seemed to indicate a general increase of eye irritation with increasing levels of oxidant (see Figure 2.6) (CRC, 1974). The straight-line relationship derived by the researchers does however, appear to ignore some of the data points below the 'barely noticeable' irritation line.

Other studies (Renzetti and Bryan, 1961; Orcutt and Taylor, 1960) have reported increases in average eye irritation with increasing aldehyde concentrations, but since the measured aldehyde levels were so low and the accuracy of the analytical techniques available at that time was questionable, this data must be regarded as unreliable. Compounds that have been identified as potential irritants in urban situations include ozone, ethylene oxide, biphenyl and a number of aldehydes and ketones (Ball *et al*, 1990).

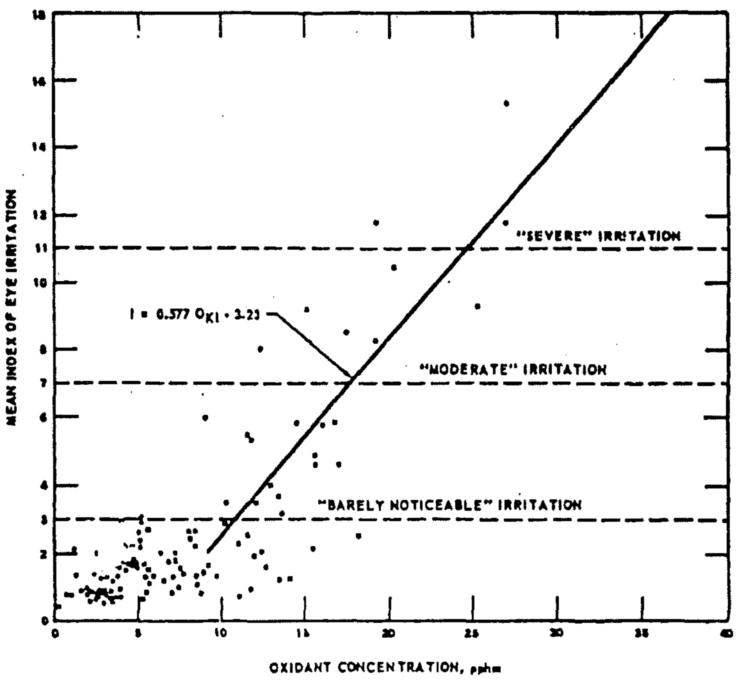


Figure 2.6
Mean index of eye irritation versus oxidant concentration for Los Angeles (Richardson and Middleton, 1957).

In the UK few public complaints directly linking physical irritation to vehicle emissions have been noted to date. A recent Norwegian study has recorded some respondent discomfort from a range of health/nuisance problems in a number of different micro-environments or while doing different activities (Clench-Aas *et al*, 1991). In this study, 162 individuals filled out a self-completion diary on an hour-by-hour basis indicating whether or not they were bothered by the listed health symptoms at their particular location. The exposure of the individuals to NO_2 at each location was estimated on an hourly basis using an air pollution dispersion model. The data summarised in Table 2.5 suggests that people are slightly more bothered by the listed health symptoms when shopping or at work, although the reported figures are quite low. The data illustrated in Table 2.6 indicate a variable level of disturbance with exposure to NO_2, although Clench-Aas *et al* (1991) suggest that there is a slight increase of annoyance with increased exposure to NO_2.

Table 2.5
Mean % of hours with reporting of selected health symptoms at different locations in the Vålerenga area of Oslo (Clench-Aas *et al*, 1991).

	Mean % of hours with symptom at each location				
	Home	Work-place	School/daycare centre	Other places	Travelling* or shopping within hour
Fatigue	3.6	6.6	3.3	1.7	5.6
Nervous/restless	0.6	0.6	0.5	0.3	1.0
Headache	2.0	4.4	1.9	1.7	3.0
Nausea	0.8	0.8	0.5	0.7	1.0
Sneezing/running nose	5.4	9.2	5.5	5.8	8.0
Eye irritation	1.8	2.3	0.0	2.1	2.1
Throat irritation	4.5	8.0	6.0	4.2	6.7
Tightness in chest	2.2	4.1	0.0	1.6	3.0
Coughing	3.0	2.7	4.1	2.2	3.8
Bothersome noise	3.3	7.5	1.1	2.3	9.5
Bothersome smell	1.9	3.5	1.2	1.6	5.4
Number of hours	218.2	60.9	37.1	45.6	37.0

* The individual has travelled or shopped for at least 5 minutes within the hour

In another report summarising similar research (Aas *et al*, 1991), Professor Leiv Bakketeig of the Norwegian National Institute of Public Health has stated that:

> 'I believe that much of the (reported) mucous membrane irritation, such as sneezing, coughing, stinging eyes and runny noses are the result of road dust, although I cannot prove this from the data.'

This statement illustrates that it is currently infeasible to state whether the public consider

Table 2.6

Mean % of time with reporting of health symptoms by level of exposure to NO_2 in the Vålerenga area of Oslo (Clench-Aas *et al*, 1991).

	Level of NO_2 exposure ($\mu g/m^3$)									
	0-5	5-10	10-15	15-20	20-30	30-40	40-60	60-100	100-200	> 200
Mean no. of hours per indiv.	76.7	23.8	24.0	28.2	50.8	33.9	41.0	27.7	7.8	2.1
No. of individuals	157	154	157	157	157	157	157	156	142	54
Fatigue	1.9	3.8	4.4	4.1	5.2	4.5	4.6	4.3	5.8	6.8
Nervous/restless	0.4	0.7	0.6	0.5	0.7	0.8	0.7	0.6	0.2	
Headache	1.1	2.2	2.9	2.7	2.8	3.1	3.1	2.5	1.3	1.9
Nausea	0.6	0.7	0.9	0.9	0.8	1.1	0.9	0.7	0.2	
Sneezing/running nose	3.7	6.1	5.8	6.3	6.5	6.4	7.8	6.5	8.0	17.8
Feeling feverish	0.9	0.9	1.5	1.6	1.6	1.5	1.3	0.8	1.7	
Eye irritation	1.3	2.7	2.5	2.1	2.3	2.0	2.7	2.1	2.2	2.8
Throat irritation	3.1	4.7	5.0	5.6	5.4	6.3	5.8	6.3	5.5	4.9
Wheezing	0.2	0.3	0.3	0.2	0.2	0.4	0.5	0.4	0.2	
Tightness in chest	1.6	2.4	2.4	2.5	2.6	2.4	2.4	2.6	1.8	3.7
Coughing	2.1	3.6	3.1	3.1	3.5	3.3	3.9	3.4	4.1	7.4
Bothersome noise	2.6	3.6	4.0	4.0	4.4	5.0	5.6	6.7	7.0	5.7
Bothersome smell	1.6	2.2	2.0	2.7	2.6	3.1	3.7	4.0	4.5	2.6

physical irritation from vehicle-derived air pollutants as a nuisance because there are insufficient data available.

2.7 Summary of existing surveys

It is evident from the preceding sections that the public do experience a certain degree of nuisance from vehicle-derived pollutants, with most of the public complaints concerning dirt, dust, smoke, fumes and soiling of surfaces. The existing evidence is insufficient to indicate conclusively that odour, visibility reduction and physical irritation are significant causes of nuisance, although where evidence does exist, it seems to indicate that odour and visibility reduction are not major public nuisances.

Evidence derived from social surveys also suggest that the nuisance experienced by a person depends on their situation *eg* at home, work, in a shop or as a pedestrian. The level of nuisance experienced by an individual may be affected by factors such as:

- the proximity of their home/workplace to a road;
- the amount of traffic on the road;
- the type of vehicles using the road;
- the duration of exposure to the air pollutants;
- the type and concentration of air pollutants present;
- the time period during which the individual experiences nuisance effects;
- the duration of the nuisance effect (*eg* is the nuisance continuous or short-lived?);
- personal habits (*eg* smoking);
- socio-economic status;
- the respondent's general awareness of their local environment.

Social survey techniques such as questionnaires and personal interviews are important methodologies for the assessment of people's subjective response to traffic pollutants and can be used to obtain data on many of the above factors. Using these methods, researchers can evaluate both the causes and the level of nuisance experienced by individuals in a particular set of circumstances, and predictive relationships may be derived from the data collected. However, evidence from social surveys alone is insufficient to allow legislators to make judgements about the subjective importance of air pollutants produced by road vehicles. Air quality data obtained in parallel with social survey data is necessary so that the relationship between subjective effects and pollution load can be investigated.

Two attempts have been made in the UK to link the degree of public nuisance to measured levels of air pollutants (Hedicar, 1979; Mackie and Griffin, 1977). Both cases however, suffered from the same deficiencies:

- Ambient urban levels of subjectively important pollutants other than smoke were not investigated. It is clearly important that ambient concentrations of pollutants likely to cause nuisance effects are measured.
- Insufficient data was collected from the social surveys to allow a full analysis of nuisance effects. For example, few direct questions about physical irritation effects have been asked. There is also the problem discussed in Section 2.3 concerning the ambiguity of questions containing the words smoke, fumes and odour.
- Little attempt was made to compare the public's concern about nuisance from road traffic with other concerns they may have, so that concern generated by nuisance effects cannot be put into perspective.

In Norway, research by NTNF (Aas *et al*, 1991; Clench-Aas *et al*, 1991) has suggested that there is a correlation between the frequency of disturbances from health/nuisance effects and pollutant concentrations. The pollutants NTNF utilised, carbon monoxide and nitrogen dioxide, are not however subjectively important (see Chapter 3).

The deficiencies in previous research and the factors affecting nuisance perception outlined above were important considerations during the development of the methodology outlined in Chapter 4.

Chapter 3
Vehicle Emissions and Air Quality

3.1 Introduction

Concern about air quality is a fairly recent phenomenon, and has grown with increasing population density and industrialization. Indeed, during the early stages of the industrial revolution, poor air quality was almost welcomed; a factory chimney belching smoke was a sign of economic activity and progress. However, as the environmental and health effects of air pollution became widely known, legislation was introduced to curb and control the emissions of pollutants into the ambient atmosphere and industries were forced to utilise more environmentally friendly technologies. This legislation is continually revised and updated as air pollution sources become more diverse and complex and are subjected to increasing scientific and public scrutiny.

There are two broad categories of air pollutants; primary and secondary. Primary pollutants are those which are released directly from a source into the atmosphere whereas secondary pollutants are generated by atmospheric chemical reactions between primary (and other secondary) pollutants. This chapter considers briefly the major sources and effects of air pollution before concentrating on those pollutants which are vehicle-derived and which are suspected to contribute to nuisance effects. Air quality legislation and control technologies for vehicular pollution are also discussed briefly.

3.2 Major sources of air pollutants

The major sources of air pollutants may be divided into five categories:

- Natural
- Industrial
- Domestic
- Transportation
- Power stations.

A pollutant may be defined as a substance that is potentially harmful to the health or well-being of human, animal or plant life, or to ecological systems (NSCA, 1993). Natural sources of air pollutants therefore include volcanoes, sand storms, surface dust resuspension and forest fires. The combustion of fossil-fuel for energy is the major anthropogenic source of emissions for most pollutants, particularly in power stations and motor vehicles, but there are many non-combustion related sources. These include industrial processes, coal mines, domestic and industrial solvent use, natural gas leakage in the national distribution network and landfill. Non-combustion sources are particularly important for volatile organic compounds and methane.

The variety of air pollution sources makes estimating the emissions of specific atmospheric pollutants a demanding and time-consuming process. In the UK, emission inventories for each pollutant are usually derived from statistical information by applying appropriate emission factors to annual fuel consumption statistics. The accuracy of estimated emissions is difficult to assess since there is a general lack of reference data. In the UK, national emission estimates are revised annually and any improvements in methodology are applied retrospectively to earlier years. The most recent UK emission inventory was for the year 1992 and was published in 1994 (DoE, 1994). The sources of the principal pollutants in the UK for 1992 are shown in Table 3.1.

Table 3.1
Sources of the principal pollutants in the UK in 1992 (DoE, 1994).

Source	% of total emissions				
	Sulphur dioxide	Black smoke	Nitrogen oxides	Carbon monoxide	Volatile organic compounds[1]
Road transport	2	47	51	90	37
Power stations	69	5	25	1	-
Other industry	21	5	9	2	56
Domestic	3	28	3	4	1
Other	5	15	12	3	6
Total (Kilotonnes)	**3,500**	**457**	**2,750**	**6,708**	**2,556**

[1] Volatile organic compounds does not include methane. The evaporation of petrol during production, storage and distribution is included under other industry. Its evaporation from the petrol tank and carburettors of petrol-engined vehicles is included under road transport.

The data displayed in Table 3.1 indicate that road transport is the most important source of black smoke, nitrogen oxides and carbon monoxide in the UK. Emissions from road traffic generally have a greater effect on local air quality than those from industry, since there is typically more traffic and less industry in urban areas and vehicular tail pipe emissions are at a lower level than industrial emissions. As a result, the pollutant contribution from road transport is likely to be higher in urban areas than indicated by national emission data (QUARG, 1993a). The electricity supply industry produces most of the sulphur dioxide emitted in the UK, while other industry and road transport produce over 90% of the emitted volatile organic compounds.

The UK pollutant emissions by type of fuel are illustrated in Table 3.2. They clearly indicate the importance of fossil fuel combustion, which is the main source of all the principal pollutants with the exception of volatile organic compounds. In many countries, including the UK, air quality monitoring is undertaken by central and/or regional government through a network of selected sites which monitor the atmospheric concentrations of particular pollutants. The atmospheric concentration of a given pollutant is site specific, although values are often given for typical 'rural', 'background', 'urban' and 'industrial' sites. The typical ranges and peak values for gaseous and particulate species found in urban areas are summarised in Table 3.3. Currently, the atmospheric concentrations of 150 substances are monitored in the UK (DoE, 1992).

Table 3.2
UK emissions by type of fuel in 1992 (DoE,1994).

Source	% of total emissions				
	Sulphur dioxide	Black smoke	Nitrogen oxides	Carbon monoxide	Volatile organic compounds
Coal	77	32	25	4	2
Smokeless fuels	1	3	-	2	-
Petroleum:					
Petrol	1	3	31	88	25
DERV	1	44	20	2	6
Gas oil	1	2	6	-	1
Fuel oil	18	3	6	-	-
Other petroleum	1	-	1	-	-
Other gas	-	-	7	-	-
Other emissions	-	13	4	4	66
Total (Kilotonnes)	**3,500**	**457**	**2,750**	**6,708**	**2,556**

3.3 Major environmental effects of air pollution

The effects of air pollution are wide-ranging and well-publicised. They include:

a) acid deposition
b) smog and photochemical smog
c) stratospheric ozone depletion
d) global climate change
e) human and animal health effects
f) effects on vegetation and materials
g) effects on amenity and 'well-being' (nuisance effects, stress *etc*)

Table 3.3

Typical ranges and peak values for gaseous and particulate species (adapted from Graedel, 1990).

Species	Measurement capability	Concentration[a] (ppb)				References
		Urban range	Urban peak	Indoor peak	In-car peak[b]	
Emitted gases						
Carbon monoxide	Routine monitoring (continuous)	$(3\text{-}15)\times10^3$	4×10^4	1×10^5	3×10^4	National Research Council (1981b) US EPA (1985) Mucke *et al* (1984)
Carbon dioxide	Routine monitoring (continuous)	$(3\text{-}6)\times10^5$	6×10^5	3×10^6	-	McRae & Graedel (1979) Spengler & Sexton (1983)
Nitrogen oxides	Routine monitoring (continuous)	10-50	800	500	1×10^3	US EPA (1985) Mucke *et al* (1984) Spengler & Sexton (1983)
Non-methane hydrocarbons	Routine monitoring (continuous)	$(1\text{-}5)\times10^3$	1×10^4	3×10^4	2×10^3	DeBertoli *et al* (1984) Mucke *et al* (1984) Tilton & Bruce (1980)
Sulphur dioxide	Routine monitoring (continuous)	3-20	300	20	-	National Research Council (1981b) US EPA (1985)

[a] Averaging times are annual for urban range except shorter where noted by (s); daily for urban peak; one or two hours for indoor and auto interior data.
[b] Concentrations as measured within the passenger compartment of an automobile.

Table 3.3 cont.
Typical ranges and peak values for gaseous and particulate species (adapted from Graedel, 1990).

Species	Measurement capability	Concentration[a] (ppb) Urban range	Urban peak	Indoor peak	In-car peak[b]	References
Product gases						
Ozone	Routine monitoring (continuous)	90-210	350	200	-	National Research Council (1981b) US EPA (1985) Tuazon *et al* (1981)
Nitrous acid	Event monitoring	0.2-4(s)	8	5	-	Harris *et al* (1982) Pitts *et al* (1985b) Sjodin & Ferm (1985)
Nitric acid	Event monitoring	1-5	30	-	-	Spicer (1977) Tuazon *et al* (1981)
Peroxyacetyl-nitrate	Event monitoring	5-10	25	-	-	Tuazon *et al* (1981)
Hydrogen peroxide	Event monitoring	0.2-2(s)	-	-	-	Kok *et al* (1986)
Formaldehyde	Event monitoring	3-60	50	$1x10^3$	-	National Research Council (1981b) National Academy of Sciences (1981) Tuazon *et al* (1981)

[a] Averaging times are annual for urban range except shorter where noted by (s), daily for urban peak; one or two hours for indoor and auto interior data.
[b] Concentrations as measured within the passenger compartment of an automobile.

Table 3.3 cont.
Typical ranges and peak values for gaseous and particulate species (adapted from Graedel, 1990).

Species	Measurement capability	Concentration[a] ($\mu g/m^3$)				References
		Urban range	Urban peak	Indoor peak	In-car peak[b]	
Particle species						
Lead	Routine monitoring	0.1-0.7	1.0	0.1	-	US EPA (1985), Tosteson *et al* (1982)
Elemental carbon	Event monitoring	1-15	35	-	-	Countess *et al* (1980), Wolff (1985)
Organic carbon	Event monitoring	5-20	40	-	-	Countess *et al* (1980), Wolff (1985)
Nitrate	Routine monitoring	1-10	15	0.7	-	Graedel & Schwartz (1977), Graedel *et al* (1986)
Sulphate	Routine monitoring	1-20	30	5	-	Graedel & Schwartz (1977), Graedel *et al* (1986)
Poly-aromatic hydrocarbons (PAH)	Event monitoring	$(5\text{-}10)\times10^{-2}$(s)	0.1	10	-	Lahmann *et al* (1984), Seifert *et al* (1983) Moschandreas *et al* (1981)
Nitro-PAH	Event monitoring	$(1\text{-}3)\times10^{-4}$(s)	3×10^{-4}	-	-	Gibson (1982), Pitts *et al* (1985a)
Total suspended particulates	Routine monitoring	30-75	400	500	-	Bennett *et al* (1985), US EPA (1985) Spengler & Sexton (1983)
Inhalable particles	Routine monitoring	5-80	120	-	-	Lioy *et al* (1983), Wolff *et al* (1985b)
Respirable particles	Routine monitoring	10-75	210	500	150	Budiansky (1980), DeBertoli *et al* (1984) National Research Council (1981b)

[a] Averaging times are annual for urban range except shorter where noted by (s); daily for urban peak; one or two hours for indoor and auto interior data.
[b] Concentrations as measured within the passenger compartment of an automobile.

Effects a)-d) are discussed briefly in Sections 3.3.1-3.3.4 below, while a discussion of effects e) and f) is incorporated into Sections 3.6-3.12.

3.3.1 Acid deposition and acid rain

Acid deposition can occur in three ways: dry deposition, occult deposition and wet precipitation. The primary precursors of acid deposition are sulphur and nitrogen oxide emissions, mainly from power stations and motor vehicles. These primary pollutants are converted into sulphuric and nitric acids through atmospheric oxidation reactions with ozone and related compounds. Sulphur dioxide has an atmospheric lifetime of several days and may be transported over great distances, whereas nitrogen oxides oxidise more rapidly and are therefore more likely to contribute to localised deposition. Clearly, the longer the pollutants remain in the atmosphere, the greater the opportunity for chemical reactions and of subsequent deposition in precipitation. Consequently wet and occult deposition are the main forms of acid deposition in areas remote from sources while dry deposition is greater in urban and rural areas which are close to emission sources (UK Terrestrial Effects Review Group, 1988).

The environmental effects of acid deposition include:

- increased acidity in freshwater lakes, which has subsequently led to an increased mobilisation of trace metals, and damage to aquatic ecosystems;
- increased acidity of groundwater, which has caused a lowering of the alkalinity of municipal water supplies and concern about possible heavy metal contamination of drinking water;
- extensive damage to forestry, particularly in Germany, Scandanavia and the UK;
- an increased corrosion and erosion of physical structures;
- impoverishment of soils.

3.3.2 Smog and photochemical smog

The word 'smog' was originally created by a London physician, Dr Harold Des Voeux, who used it to describe smoke-polluted fog to the general public during a health congress in 1905. The most well-known smog episode occurred in London during December 1952, when smoke produced from domestic chimneys and power stations together with unusual meteorological conditions combined to create the now infamous 'Killer Smog'. This episode led to over 4,000 deaths, mainly amongst the young, the elderly and the infirm, and forced the Government to appoint a Committee on Air Pollution under the chairmanship of Sir Hugh Beaver. The recommendations of the 'Beaver Committee' led directly to the Clean Air Act of 1956 and indirectly to the Clean Air Act of 1968. This legislation has resulted in a general reduction of smoke from coal combustion and in the associated smog episodes.

Photochemical smog is a more recent phenomenon, and results from a series of complex atmospheric chemical reactions between nitrogen oxides, hydrocarbons and sunlight producing a range of compounds including ozone, peroxyacetyl nitrates, peroxides, aldehydes and ketones (Dutkewitcz, 1992). Photochemical smog episodes have been recorded in a number of urban areas including Mexico City, Berlin, Tokyo, Sydney, London, Athens, Cape Town and particularly in Los Angeles. They have a range of health and environmental effects, including damage to plants, corrosion of materials, impairment of pulmonary function and irritation of the eyes and nose.

3.3.3 Stratospheric ozone depletion

The stratospheric ozone layer is important for two reasons; it shields the earth from potentially damaging ultraviolet radiation and plays a role in regulating the earth's temperature. Recent research has however shown evidence for serious springtime ozone depletion over the Antarctic, with record levels of depletion recorded over the UK in the Spring of 1993 (The Independent, 28/4/93). There is also evidence of a more general thinning of the global ozone layer. Stratospheric ozone is destroyed during reactions with chlorine and bromine atoms, which are released into the atmosphere by substances such as chlorofluorocarbons (CFCs), halons, carbon tetrachloride and methyl chloroform. These substances are emitted into the atmosphere through their use as aerosol propellants, refrigerants, foam blowing agents, fire extinguishers and solvents.

3.3.4 Global climate change

Global climate change has emerged only recently as a major scientific and political issue. The term refers to the warming of the surface of the Earth and its surrounding air due to the emissions of 'greenhouse gases' into the atmosphere. Greenhouse gases cause infra-red radiation to be retained in the Earth's atmosphere (the Greenhouse Effect), creating a temperature sufficiently warm to allow life on Earth. The two most abundant greenhouse gases, water vapour and carbon dioxide, have been present naturally in trace quantities in the atmosphere for the vast majority of the Earth's history and are the most important contributors to the Greenhouse Effect. However, as a result of previous and current human activities, further greenhouse gases have been emitted into the atmosphere causing an 'enhanced' greenhouse effect. These gases include carbon dioxide (principally from fossil fuel combustion and deforestation), methane (from rice paddies, enteric fermentation and gas leakage), nitrous oxide (from biomass burning, fertilizer use and fossil fuel combustion) and CFCs (from industrial usage). Computer models have predicted increases in average global surface temperature of approximately 1 °C by 2030 and 3 °C before the end of the next century if cuts are not made in greenhouse gas emissions (Leggett, 1990), although uncertainties in the models mean that the precise degree of future warming is unclear. This type of global warming would have major effects on sea level and on the global vegetation belts.

3.4 Air pollutants produced by road vehicles

Road vehicles are fuelled mainly by petrol and diesel, although other fuels such as methanol, hydrogen, compressed natural gas (CNG) and liquified petroleum gas (LPG) do find limited usage in some countries. Both petrol (spark ignition) and diesel (compression ignition) engines operate under high pressures and temperatures, producing exhaust emissions containing a wide range of organic and inorganic substances. The major primary pollutants produced by motor vehicles include carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HCs), volatile organic compounds (VOCs), sulphur oxides (SO_x) and particulates (including lead compounds). Vehicle emissions are also associated with a range of secondary pollutants including ozone (O_3) and peroxyacetyl nitrates (PAN). In the 1980s, UK emissions from road traffic increased rapidly, as illustrated in Table 3.4.

Table 3.4
Increase in UK estimated emissions from road transport (1980-1990) (DoE, 1992).

Pollutant	% increase
Carbon monoxide	46
Nitrogen oxides	72
Volatile organic compounds	12
Black smoke	75
Sulphur dioxide	50
Carbon dioxide	43

Air pollution from road vehicles has increased despite the introduction of emission controls, mainly because of the rapid growth of road traffic and the increasing average distances travelled by vehicles. The current global fleet of cars, lorries and buses is over one half billion, which represents an increase of about ten fold in forty years (Walsh, 1994). The number of UK licensed motor vehicles increased by 65% from 14,950,000 in 1970 to 24,673,000 in 1990. Vehicle numbers are expected to continue growing, with a predicted increase in the UK of anything from 83-142% (from 1990 levels) by the year 2025 (The Economist, 3/3/90). This increase in road vehicles is reflected in the UK consumption of motor spirit and DERV, which rose from 19,268,000 tonnes in 1970 to 34,964,000 tonnes in 1990, an increase of 81% (BRF, 1992). Vehicle usage increased by 50% to over 400 billion vehicle kilometres in the decade 1980-1990 (DoT, 1991). The transport sector has also become the largest UK energy user, consuming nearly 20 billion therms of energy in 1990 (DoEnergy, 1992).

Emissions from diesel vehicles are of particular importance to this research for the reasons outlined in Section 1.1. Although diesel-fuelled vehicles accounted for only 10.6% of the total UK vehicle fleet in 1991, they accounted for over 30.8% of the total road vehicle fuel consumption. This demonstrates the usage of diesels for haulage over long distances. Diesels contribute less pollutants than petrol-engined vehicles to the overall pollutant burden, but they are important sources of NO_x, particulates and (possibly) polyaromatic hydrocarbons. Over 450 individual compounds have been identified in diesel exhaust, some of which are carcinogenic, odourants and/or irritants. An extensive list of diesel pollutants has been produced by the TRL (Williams and McCrae, 1992).

3.5 Air pollutants contributing to nuisance effects

The pollutants likely to be major contributors to nuisance effects are listed in Table 3.5. Particulates appear in every category, indicating their relative importance to overall nuisance effects. Hydrocarbon and oxygenated compounds also feature prominently, whereas gaseous pollutants such as CO and NO_x, which are the major pollutants derived from road vehicles, appear to make very little contribution to nuisance effects.

Table 3.5
Pollutants contributing to nuisance effects.

Nuisance	Pollutant
Dust/dirt	Particulates
Fumes/smoke/odour	Particulates Volatile organic compounds (*eg* Carbonyls, Alcohols, Hydrocarbons)
Visibility reduction	Particulates Hydrocarbons Secondary pollutants (*eg* PAN, Ozone, Hydroxyl radicals) Nitrogen oxides (nitrates) Sulphur oxides (sulphates)
Soiling	Particulates
Physical irritation	Particulates Hydrocarbons Secondary pollutants Volatile organic compounds

In Sections 3.6-3.12 of this Chapter, the sources and ambient concentrations of pollutants which may contribute to nuisance effects are discussed, and the contribution from road vehicles to the overall pollutant burden is evaluated. The potential health and environmental effects of individual pollutants are also mentioned but not discussed in any great detail, since this would be beyond the scope of this research.

3.6 Sources and ambient concentrations of particulate matter

Atmospheric particulate matter is generated by both natural and anthropogenic sources. It includes a wide range of substances and materials such as smoke, metallic compounds and aerosols formed through atmospheric chemical reactions (Sherwood and Bower, 1970), and has been the subject of much research, resulting in the establishment of a considerable amount of scientific jargon. In order to avoid any confusion, the terms used in this thesis are defined below.

Particles are defined as 'aggregations of matter, either solid or liquid, larger than individual molecules' (Lodge *et al*, 1981). Particle sizes are expressed as aerodynamic diameters, unless otherwise stated. The aerodynamic diameter refers to unit density spherical particles with the same aerodynamic properties (*eg* falling speed).

Suspended Particulate Matter (SPM) and *Total Suspended Particulates (TSP)* are general terms, embracing all airborne particles (QUARG, 1993a).

An *Aerosol* is a suspension of solid and/or liquid particles in a gas.

PM_{10} is a term used to describe particles which are able to pass through a size selective inlet with a 50% efficiency cut-off at 10 μm aerodynamic diameter (QUARG, 1993a).

Particles may also be described as inhalable or respirable (Graedel, 1990). *Inhalable particles* are those which can enter the human nose or mouth during normal breathing. Those inhalable particles which are able to penetrate to the unciliated regions of the deep lung (the alveolar region) are termed *respirable particles* (particles of < 2.5 μm aerodynamic diameter are often reffered to as respirable (QUARG, 1993a)).

Smoke is defined as 'suspended particulate air pollutants with a diameter of less than 15μm, arising from the incomplete combustion of fossil fuels' (DoE, 1985). There are two types of smoke, depending on the measurement technique utilized. *Black smoke* is measured by reflectance, whereas *gravimetric smoke* (TSP/SPM) is measured in terms of mass.

3.6.1 Suspended Particulate Matter/Total Suspended Particulates

Research (*eg* Lodge *et al*, 1981) has identified three separate size groupings of particles in the ambient atmosphere:

- the nucleii mode ($<0.2\ \mu m$)
- the accumulation mode (0.2-$2\ \mu m$)
- the coarse particle mode ($>2\ \mu m$).

Each mode behaves virtually independently of the other modes. The nucleii mode represents particles recently formed from combustion sources. Particles in this mode are formed by condensation from the gaseous phase and have a short atmospheric lifetime. Accumulation mode particles have an atmospheric lifetime of days and are formed by:

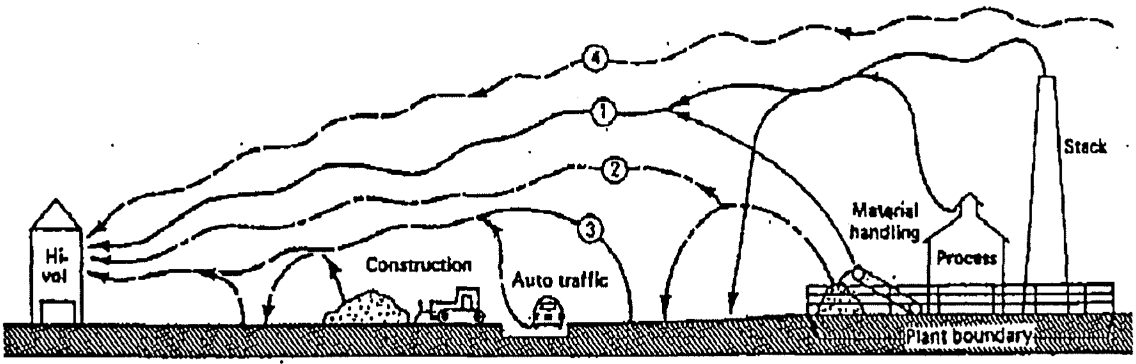
- coagulation of particles from the nucleii mode;
- condensation on existing material.

Coarse particles are generally produced by mechanical processes, such as comminution. They are few in number and usually have very short atmospheric lifetimes of a couple of hours before they are removed by rainfall and sedimentation. The vast majority of coarse particles are derived from natural sources such as sea spray, sand storms, erosion, forest fires and volcanic eruptions. Globally, particulate emissions from these natural sources greatly exceed anthropogenic particulate emissions. The origins of TSP in an urban/industrial area and the routes followed by its various components between sources and receptors (hi-vol samplers) are illustrated in Figure 3.1 (Yocom *et al*, 1981).

During a study in Leeds in 1982/3, Clarke *et al* (1984) identified the main components of the TSP in an urban area. The major components were:

- elemental carbon, from combustion processes
- organic compounds, mainly partially or unburned hydrocarbons
- soil-derived minerals, due to resuspension
- sulphates from SO_2 oxidation
- nitrates from NO_x oxidation
- ammonium salts, from ammonia neutralisation of airborne acids

◆ sodium and magnesium chloride, from marine sources
◆ calcium sulphate, from building materials and rocks/soils



Key	Classification	Definitions and examples
1	Traditional sources (industrial)	'Virgin' (non-resuspended) material arriving at the sampling point directly from point and process fugitive sources within a plant complex.
2	Nontraditional sources (industrial)	Fugitive dust from wind blown storage piles, open materials handling and resuspended dust from traffic on dusty plant roads.
3	Nontraditional sources (urban)	Dust from construction and demolition activities. Re-entrained dust from road traffic, playgrounds, car parks etc.
4	Background material	Particulate matter of both natural and anthropogenic origin advected from points outside the air quality control jurisdiction.

Figure 3.1
The origins of total suspended particulate matter (Yocom *et al*, 1981)

In urban areas, the most ubiquitous man-made particulate source is the motor vehicle. Lodge *et al* (1981) have stated that 'today the particulate pollution pattern of a typical US city tends to be controlled predominantly by vehicular traffic', and Horvath *et al* (1988) stipulate that 'the aerosol in a non-industrial town normally is dominated by emissions from vehicles'. Vehicular particulate emissions are defined as matter collected on a filter paper from a diluted exhaust at a temperature below 52°C, excluding condensed water vapour (McCrae, 1991). Diesel vehicles produce 60-70% of the particulates derived from road vehicles, despite the fact that they constitute less than 20% of UK motor traffic. A diesel vehicle has been estimated to emit 10 times more particulates than a petrol vehicle under urban driving conditions (van den Hout and Rijkeboer, 1986) and 30-100 times more particulates than a catalyst equipped petrol vehicle (Holman, 1983).

The combustion of fossil fuels in vehicles generates particulates through a complex interaction of chemical and physical processes. The particulates generated by these processes consist mainly of organic compounds adsorbed onto carbon-based agglomerates. These organic compounds include unburned, oxygenated and polycyclic aromatic hydrocarbons. In diesel engines, the majority of particulates are produced in the cylinder during combustion, although some minor secondary agglomeration does occur in the exhaust system (Horrocks, 1987). Pierson *et al* (1983) have noted that diesel soot (carbon) emissions increase with increasing ambient temperature. It has been estimated that 65% of diesel generated particulates are less than 1 μm in size, with some 50% being smaller than 0.5 μm (Ricardo, 1987). This is illustrated in Figure 3.2, where particles collected from the exhaust of a diesel lorry are pictured using a scanning electron microscope (Segarra, 1992).

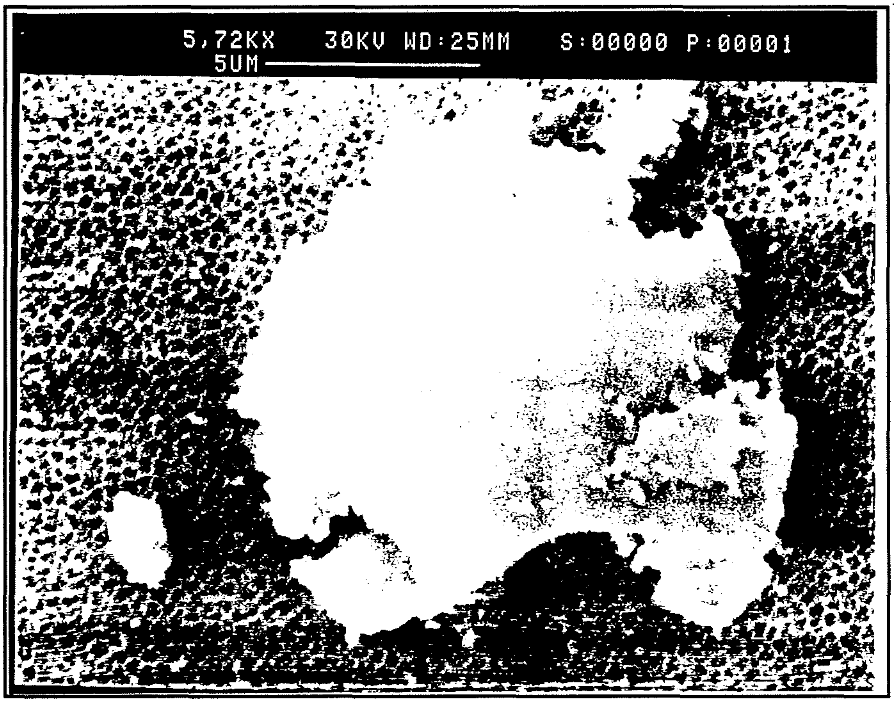


Figure 3.2
Particles from the exhaust of a diesel-engined lorry, pictured using a scanning electron microscope (Segarra, 1992).

Segarra (1992) has also been able to capture pictures of some large diesel exhaust particles using scanning electron microscopy. The particle shown in Figure 3.3 is approximately 70 μm in length, and was captured from the exhaust of a 2 l (*ie* light-duty) diesel-engined Austin Montego.

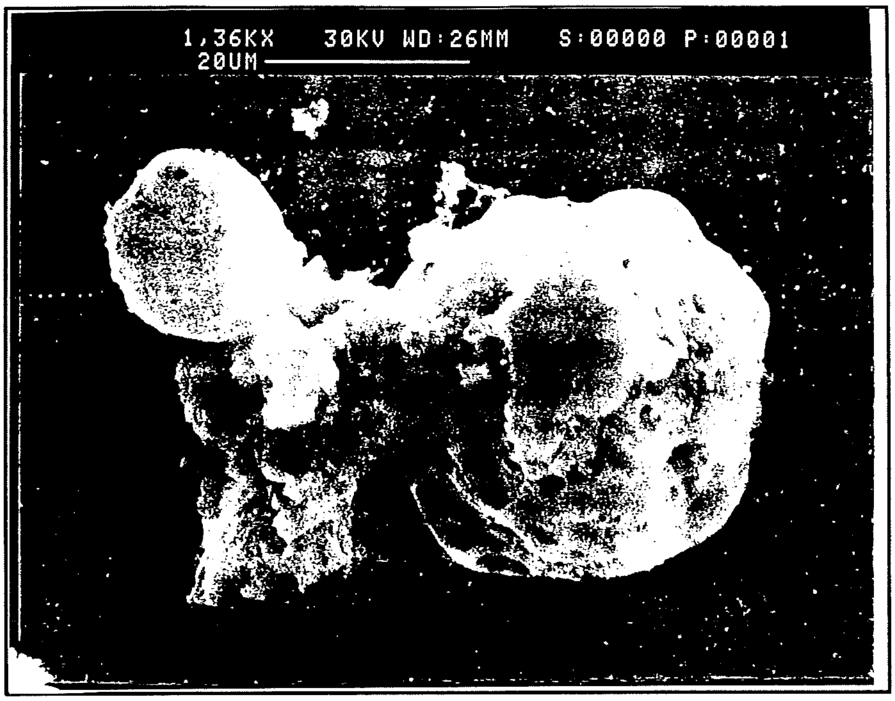


Figure 3.3
A large particle from the exhaust of a 2 l diesel-engined Austin Montego, pictured using a scanning electron microscope (Segarra, 1992).

The typical composition of particulate matter from heavy duty diesels is illustrated in Figure 3.4, the results being obtained over the US transient cycle.

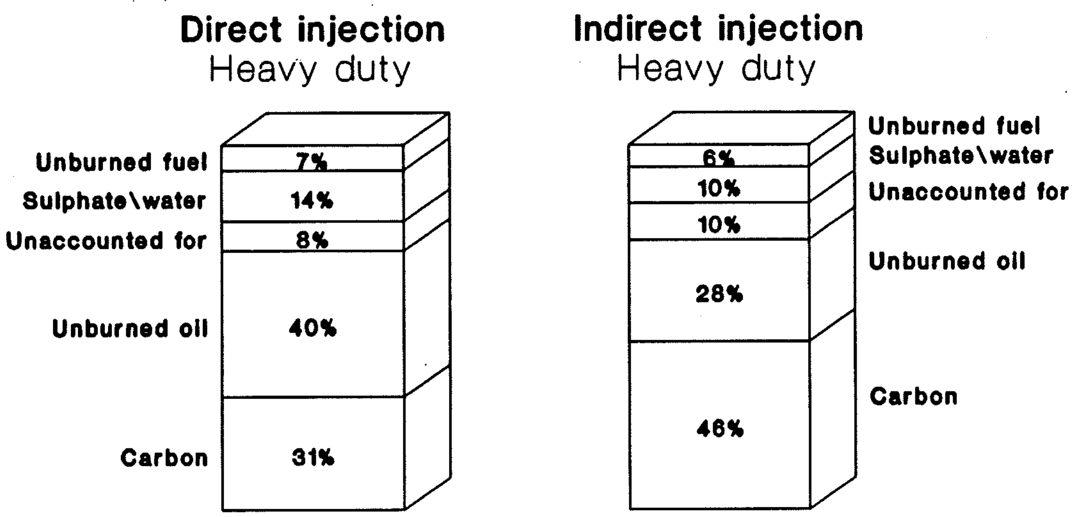


Figure 3.4
Composition of particulate matter
(Typical results obtained over US transient cycle) (Ricardo, 1987)

It is worth noting:

- The high percentage of elemental carbon present. Braddock and Gaebele (1977) have reported that elemental carbon particles accounted for 64 to 91% of the particulate matter produced by a light-duty diesel passenger car. In the UK, it has been calculated that diesel emissions contribute 80-95% of atmospheric particulate elemental carbon (PEC) at both urban and national level (QUARG, 1993b).
- The significant contribution made by unburned oil.
- Trace metals and other emitted elements account for an insignificant portion of the total particulate mass (Braddock and Gaebele, 1977).

Wolff *et al* (1982) have estimated that carbon comprises 10-20% (by weight) of urban aerosols. Particulate elemental carbon contributes nearly half of this amount, with the major contribution arising from fuel combustion in diesel engines (Wolff and Klimisch, 1982). Wolff *et al* (1981) have estimated that diesel vehicles contribute 20.4% of the fine elemental carbon and 14.7% of the fine organic carbon particulate in the Denver area. Obviously these figures will vary from place to place, but it is clear that diesel vehicles can contribute a significant amount of PEC to the atmosphere in urban areas. Table 3.6 shows the total European PEC emissions by mass for 1987. In every single country, PEC emissions from diesel vehicles dominate. Table 3.3 shows typical urban organic and elemental carbon concentrations.

Motor vehicles also produce particulates through sources other than fuel and oil combustion. Particulate matter is generated directly through tyre, clutch and brake abrasion, the comminution of material previously deposited on roads, and processes such as rusting and paint flaking. The particulate matter produced by these processes includes asbestos (from clutch plates and brake linings), finely divided rubber particles (from tyre wear and road surface abrasion) and metallic materials such as copper and cadmium (from brake linings and tyre wear, respectively). In addition, particulates can be produced indirectly through the resuspension of material deposited on road surfaces as a result of vehicle induced turbulence. The practice of road salting during icy weather is another source of particulates influenced by motor vehicles.

Typical urban concentrations of TSP are shown in Table 3.3 with typical figures for the London area shown in Table 3.7. TSP is a very widely monitored pollutant, with national sampling networks in many industrialised countries of the world. Concentrations of TSP vary greatly from one area to another, depending on site situation, topography, the nature of the local sources and climatic conditions.

Table 3.6
European PEC emissions[a].
Total PEC emissions (1987) (10^3 kg a^{-1}).

Country	Solid fossil fuels	Natural gas	Auto gasoline	Jet fuel	Distillate		Residual oil	Total ($x10^6$)	Diesel (%)
					Diesel	Other			
Austria	9	1	50	22	3,190	125	60	3.5	92.3
Belgium	18	2	57	57	6,080	530	58	6.8	89.4
Denmark	12	0	31	68	3,070	345	29	3.6	86.3
Finland	7	0	35	30	3,110	236	60	3.5	89.4
France	38	6	371	297	26,600	2,040	174	29.5	90.1
Germany FR	210	12	510	396	28,500	3,975	208	33.8	84.3
Greece	45	0	40	104	3,120	230	56	3.6	86.8
Iceland	0	0	2	7	480	4	2	0.5	97.0
Ireland	3	0	17	30	1,030	90	25	1.2	86.2
Italy	29	8	244	195	27,700	1,340	566	30.1	92.1
Luxembourg	2	0	7	10	500	35	5	0.6	89.4
Netherlands	12	8	68	140	6,500	160	33	6.9	93.9
Norway	2	0	35	52	2,770	175	16	3.1	90.8
Portugal	3	0	21	49	2,800	65	60	3.0	93.4
Spain	44	1	137	210	14,000	440	164	15.0	93.4
Sweden	6	0	82	67	3,500	390	62	4.1	85.2
Switzerland	0	4	67	95	1,400	630	13	2.2	63.4
Turkey	52	0	50	27	10,150	190	138	10.6	95.7
UK	126	12	444	582	20,150	715	248	22.3	90.4
OECD Europe	618	56	2,268	2,438	164,650	11,715	1,977	183.7	89.6

[a] Original fuel consumption figures from OECD, 1989.

3.6.2 PM_{10}

Ambient concentrations of PM_{10} have only recently been monitored in the UK, and so there is only a limited data base available. Urban concentrations generally range between 10-45 $\mu g/m^3$, with short term peaks extending to over 60 $\mu g/m^3$ (QUARG, 1993a). The moving average in London is fairly stable at approximately 30 $\mu g/m^3$ (QUARG, 1993a).

Table 3.7
Typical ambient TSP concentrations in London.

Site	Site type	TSP ($\mu g/m^3$)	TSP range ($\mu g/m^3$)	Reference
M25	Motorway	58.7	28.1-127.4	McCrae (1991)
M11 - North Circular intersection	Motorway	100.12	43.5-218.5	McCrae (1991)
Vauxhall Bridge Rd	Urban	73.0	39.4-130.1	McCrae (1991)
Brompton Rd	Urban	100.6	72.9-156.3	McCrae (1991)
County Hall	Urban	30 (summer) 59 (winter) 45 (annual)	-	Ball & Hume (1977)
Archway Rd	Urban	43	-	Harrop *et al* (1989)
Tottenham	Residential	50	-	Harrop *et al* (1989)
West London	Residential	20	-	Lewandowski *et al* (1989)
Central London	Urban	24	-	Lewandowski *et al* (1989)
Central London	Urban	63	-	Lewandowski *et al* (1989)
East London	Residential\ industrial	28	-	Lewandowsi *et al* (1989)

The diurnal variation in hourly mean concentrations of PM_{10} at the London EUN site in Bloomsbury during May-July 1992 is displayed in Figure 3.5.

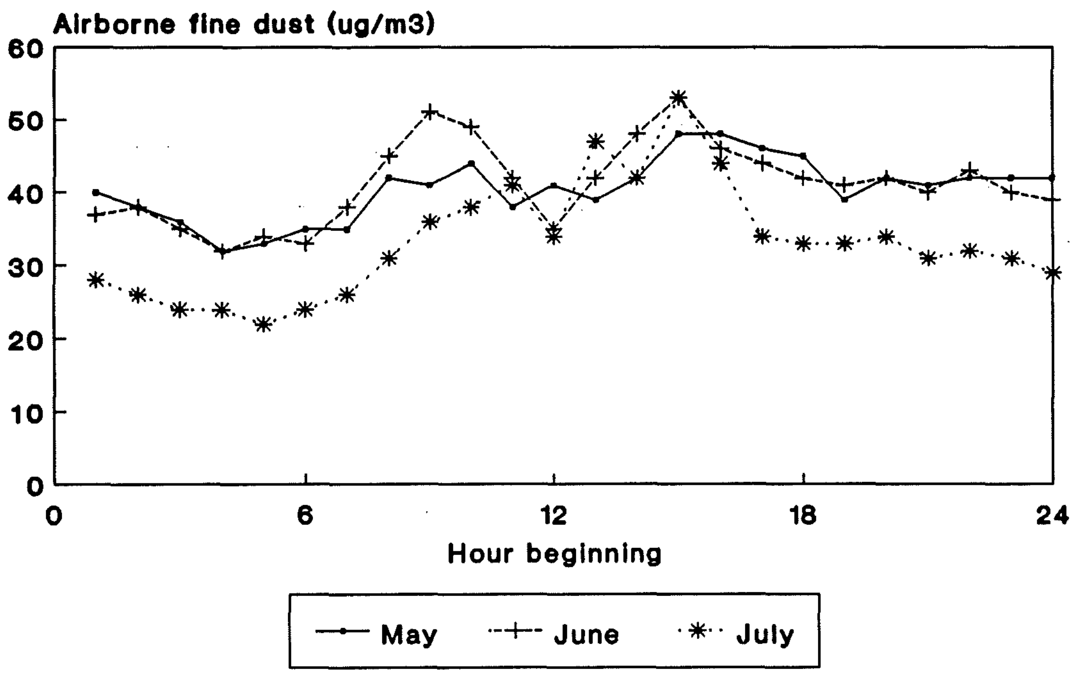


Figure 3.5
Diurnal variation in hourly mean concentrations of PM_{10} at the London EUN site in Bloomsbury in 1992.

The data shows some similarity to time-series plots for traffic dominated pollutants such as CO, although at this site only a weak correlation between PM_{10} and CO values was obtained. The Quality of Urban Air Review Group (1993a) have suggested that variations in PM_{10} concentrations are more likely to be influenced by meteorological factors such as windspeed and rainfall.

3.6.3 Black smoke

Trends in average urban black smoke concentrations are shown in Table 3.10. The data shows that urban emissions of black smoke fell by 48% between 1978/9-1988/9, mainly because of reductions in domestic and light industry emissions.

Table 3.8

Black smoke*: trends in average urban concentrations in the UK (DoE, 1990)

Year	Concentration index 1981/2=100 (23 $\mu g/m^3$)
1978/9	113
1979/80	109
1980/1	83
1981/2	100
1982/3	74
1983/4	78
1984/5	67
1985/6	67
1986/7	66
1987/8	64
1988/9	59

* Black smoke as given in this table is taken to be suspended matter collected on filter paper in accordance with British Standard (BS) 1747:Part 2.

The percentage composition of UK black smoke emissions from coal and diesel combustion from 1982-1992 is shown in Figure 3.6. The diagram clearly shows that motor vehicles have become the most important UK source of black smoke, with emissions from road transport more than doubling from 22% of total emissions in 1982 to 47% in 1992 (DoE, 1994). Over the same time period, emissions from domestic sources fell from 55% to 28% of total emissions. These figures add weight to the claim made 15 years ago by Ball and Hume (1977), who estimated that the vehicular contribution to the annual mean black smoke concentrations in Greater London could be as much as 77%, with the proportion increasing during high pollution incidents.

In connection with the estimation of vehicle emissions, the differences between 'smoke' and 'black smoke' need to be emphasised. The term smoke refers to primary particles irrespective of their darkness. However, because measurements of airborne smoke by the smoke stain technique depend upon the blackening of a filter paper, the term black smoke was introduced to allow for the different soiling capacities of smoke particles from different sources. Black smoke is calculated by multiplying of the mass or concentration of smoke by a soiling factor.

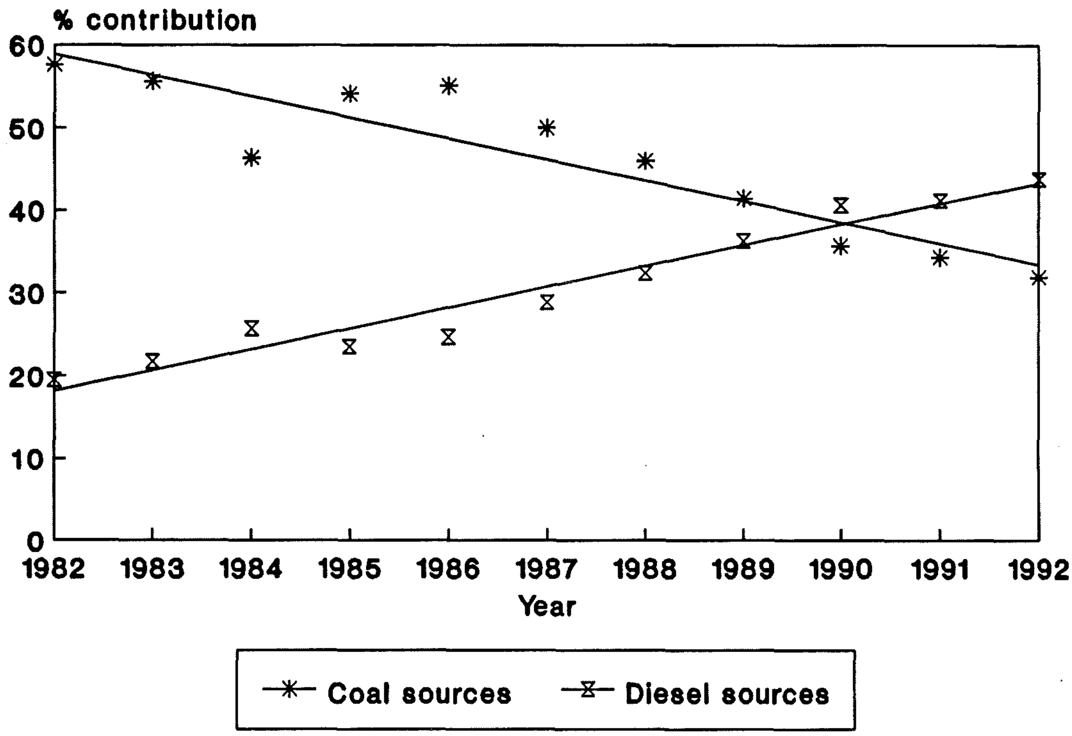


Figure 3.6
Percentage contribution to UK black smoke emissions from coal and diesel combustion, 1982-1992 (adapted from DoE figures, 1994).

Calculations of emissions can be made as follows. Table 3.9 (adapted from Table 6.8 in the First QUARG Report, 1993a) shows relevant emission factors. Emissions are then calculated as shown in Table 3.10.

Table 3.9
Smoke emission factors and relative soiling factors for vehicle fuel used in the UK.

	Smoke emission factor (% by mass)	Soiling factor relative to coal	Black smoke emission factor (% by mass)
Motor spirit	0.15	0.43	0.065
Diesel fuel	0.60	3.0	1.8

Table 3.10
Smoke and black smoke emissions from motor vehicles in 1992.

	Fuel consumption (tonnes)	Smoke emission (tonnes)	Black smoke emission (tonnes)
Motor spirit	23.9×10^6	35.8×10^3	15.5×10^3
Diesel fuel	11.1×10^6	66.6×10^3	199.8×10^3

Extending this approach to data from 1982-1992 generates Figures 3.7 and 3.8, which clearly display the differing vehicular contributions to smoke and black smoke emissions, and emphasise the need to distinguish between these two types of particulates. It needs to be remembered that the monitoring technique will record only *one* of the particulate matter types described above *eg* the smoke stain technique BS 1747 measures black smoke, whereas the Tapered Element Oscillating Microbalance (TEOM) used in the Enhanced Urban Network (EUN) measures gravimetric PM_{10} levels which are likely to be close to smoke concentrations.

3.6.4 Health and environmental effects of particulate matter

Suspended particulates have a range of detrimental health and environmental effects which depend on their size and chemical composition. Respirable particles (those finer than 10 μm) can deposit in the nose and throat and may cause irritation and discomfort. They may aggravate diseases such as bronchitis, asthma and cardiovascular problems, and there is a strong correlation between suspended particulates and infant mortality (Walsh, 1986). Respirable particles can also penetrate deep into the human lung, potentially causing a slowing of the pulmonary clearance mechanism (NRC, 1981b). Carbonaceous particulates from road vehicles are usually respirable, since they are generally less than 2 μm in diameter. As a result, they are considered to be a health hazard in their own right (McCrae, 1991), especially as they provide a site for the adsorption of compounds such as polycyclic aromatic hydrocarbons (PAHs), which have shown genotoxic and carcinogenic activity (Klingenberg and Winneke, 1990; Löforth, 1985).

Diesel particulate matter generally causes more concern than that from petrol engines. The National Swedish Environmental Protection Board (1983) has reported that the mutagenicity of particulates from diesel vehicles is about an order of magnitude higher than for petrol vehicles, which is generally consistent with other research (Holman, 1989). Van den Hout and Rijkeboer (1986) have suggested that the mutagenic activity of the particulate phase calculated on a per kilometre basis is 6 times greater for a diesel engine than for a petrol engine without catalyst technology, and up to 30 times greater than for one with catalytic emission control.

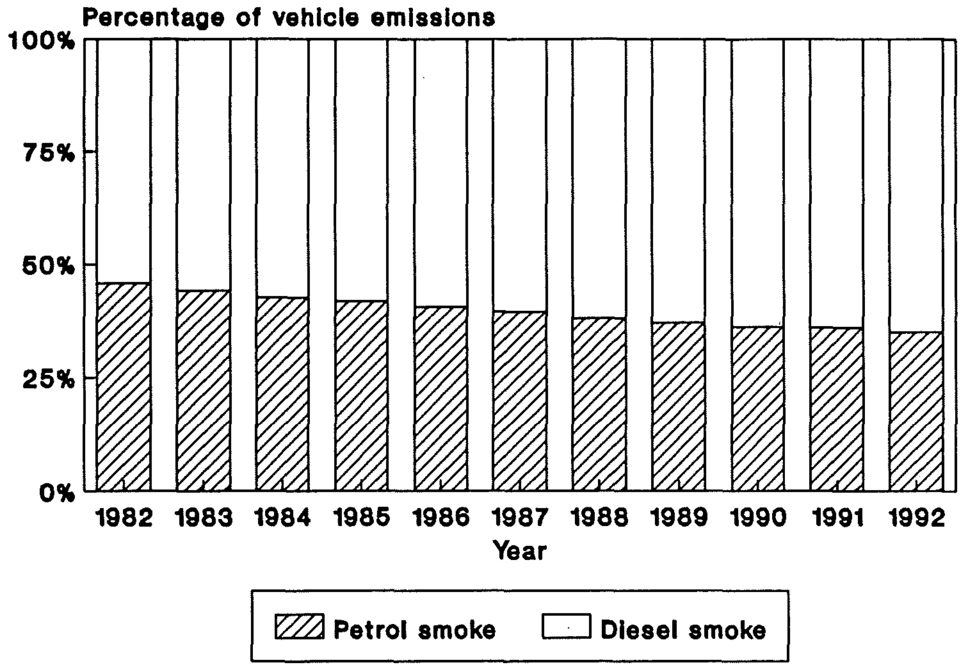


Figure 3.7
Relative contribution of petrol and diesel vehicles to vehicular smoke emissions

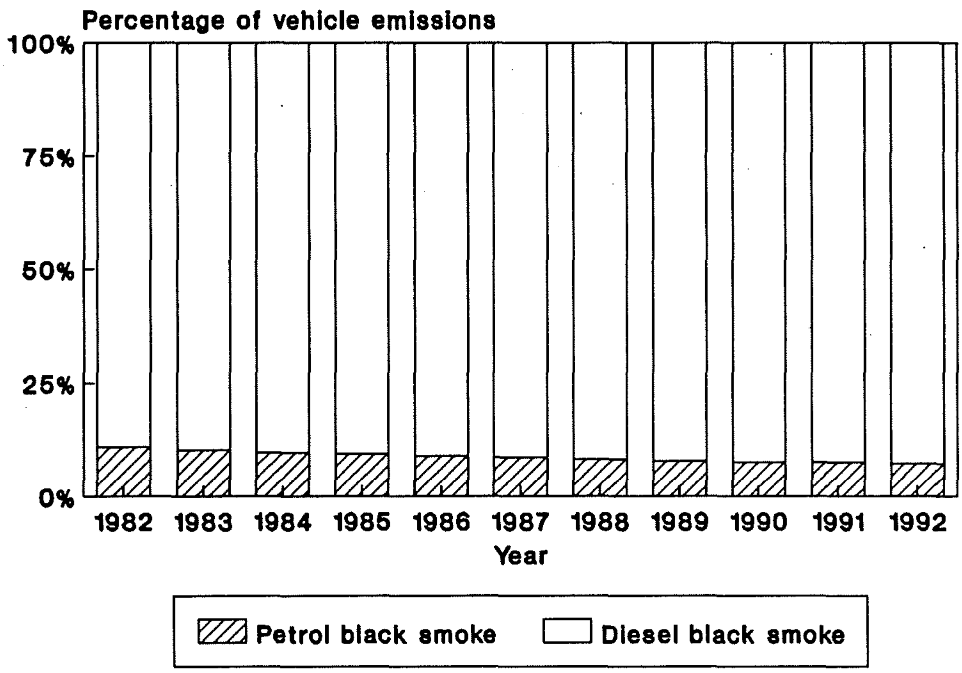


Figure 3.8
Relative contribution of petrol and diesel vehicles to vehicular black smoke emissions.

However, studying the health effects of individual pollutants is extremely difficult, and the US NRC (1981a) have stated that in epidemiological studies of occupational exposure to diesel engine emissions, excess cancer of the lung, or any other site has not been convincingly demonstrated. Since then a number of other studies have suggested more strongly a link between diesel emissions and lung cancer, and Holman (1989) states that 'it is clearly prudent to conclude that greatly increased numbers of diesels could lead to a significant increase in cancers'. Much more recent evidence linking airborne particulates to a wide range of adverse health effects (such as respiratory and cardiovascular deaths and incidence of asthma attacks) has been produced in the United States (Dockery *et al*, 1993).

Particulates may also contribute to visibility reduction, particularly in urban areas. Light extinction is caused by the scattering and absorption of light by atmospheric particulates and gases. In addition, carbon particles may act as nucleii for haze formation. Diesel emissions are a major contributor to urban visibility reduction, being the most important UK source of black smoke and PEC. In the UK, Hamilton and Mansfield (1991) have estimated that PEC is responsible for 25-45% of visibility reduction, while in the Netherlands it has been estimated that diesel vehicles contribute 13% to large scale visibility reduction (van den Hout and Rijkeboer, 1986). In the US, it has been predicted that a 20% increase in light-duty diesels in California could increase statewide EC emissions by 80% and reduce visibility by 10-20% (Holman, 1989) (although this was prior to the introduction of particulate controls).

Particulates can produce accelerated deterioration of masonry, paints, fabrics and textiles due partly to the catalytic activity of PEC which can accelerate the production of sulphuric acid. Urban particulates can also produce staining and decay of building facades, particularly alongside heavily trafficked roads. Diesel engined vehicles are blamed for much urban soiling, mainly because the soiling potential of diesel smoke is 6 times that of petrol smoke and 3 times that of coal smoke (Mansfield, 1989). This is largely because diesel smoke contains a high percentage of PEC, which is a powerful soiling agent due to its high optical absorptivity.

Considerable economic costs may arise from the soiling of buildings. Van den Hout and Rijkeboer (1986) have estimated that major cleaning of buildings and monuments is required every 8 years in the Netherlands in order to maintain their aesthetic appearance. Mansfield (1989) estimated that the value of the UK stone cleaning market in 1987 was £74,000,000.

3.7 Sources and ambient concentrations of hydrocarbons (HC)

Hydrocarbons are defined by chemists as compounds containing only hydrogen and carbon and include alkanes, alkenes, alkynes and aromatic compounds. Over 700 hydrocarbon compounds have been identified as atmospheric species (Graedel *et al*, 1986), of which approximately 130 are alkanes and 150 are alkenes/alkynes. These compounds are derived from a multitude of anthropogenic and natural sources, including fossil fuel combustion, oil and petroleum refineries and storage depots, manufacturing industries, commercial and geogenic gas leaks, biological processes, volcanoes, tobacco smoke and agricultural and forest burning programmes.

Although ideally it would be desirable to measure the concentrations of individual hydrocarbons in the atmosphere on a routine basis, many researchers measure only methane, non-methane (NMHC) and total hydrocarbons (THC). Methane, the most ubiquitous hydrocarbon found worldwide, has a background concentration of 1.3-1.4 ppm (McIntyre and Lester, 1980), but since methane is relatively unreactive, NMHC levels are often more useful. Typical atmospheric concentrations of NMHCs at urban and rural sites in the UK are shown in Table 3.11 (QUARG, 1993a). These data were obtained using adsorption tubes to collect the HC samples and gas chromatography to separate the HCs, with analysis by flame ionisation or electron capture.

The vehicle-derived hydrocarbons which are of major concern with regard to human health concerns are aromatic hydrocarbons such as benzene and toluene, and polyaromatic hydrocarbons (PAHs) such as benzo(*a*)pyrene and anthracene. The major atmospheric source of benzene is road vehicle exhaust and evaporative losses during petroleum handling, while toluene is the most abundant organic pollutant derived from petrol (Ball *et al*, 1991). Benzene and toluene are important indoor as well as outdoor pollutants with cigarette smoke being a significant respiratory source.

Benzene is a known human carcinogen and therefore no safe level can be recommended. The annual mean concentration of benzene in London is 10-12 $\mu g/m^3$ (Ball *et al*, 1991), although Bailey *et al* (1990) have suggested that the annual kerbside mean concentration in London is 28-31 $\mu g/m^3$. Hourly kerbside levels may be much higher, perhaps up to 60 $\mu g/m^3$ (Ball *et al*, 1991). Background levels of toluene are low, probably less than 0.75 $\mu g/m^3$. The annual mean toluene level in London is approximately 25 $\mu g/m^3$, with a kerbside mean of about 72 $\mu g/m^3$, although hourly means at the 98th percentile level may exceed 250 $\mu g/m^3$ (Bailey *et al*, 1990).

Natural sources of PAH include forest fires and volcanic activity, while anthropogenic sources include motor vehicles, industrial and domestic heating emissions, tobacco smoking and refuse

Table 3.11
Annual average NMHC concentrations (ppb) at urban and rural sites in the UK (QUARG, 1993a).

Site	Harwell (rural)	Middlesbrough (rural)	Great Dun Fell (rural)	West Beckham (rural)	Teddington (urban)
Ethane	3.948	8.304	2.097	2.804	2.547
Ethylene	2.232	5.948	0.986	1.546	1.993
Propane	1.763	6.913	0.857	1.313	5.607
Propene	0.429	5.913	0.162	0.270	2.422
i-Butane	2.041	5.705	0.335	0.722	2.128
n-Butane	3.511	6.826	0.708	1.637	3.281
Acetylene	2.433	5.513	0.779	1.396	2.175
i-Pentane	1.726	4.073	0.315	0.855	1.652
n-Pentane	0.739	2.025	0.192	0.443	0.883
n-Hexane	0.917	0.793	0.098	0.144	5.780
Benzene	0.814	1.914	0.343	0.725	1.982
Toluene	1.495	2.584	0.501	0.999	1.431
Ethyl Benzene	0.366	0.533	0.129	0.244	1.544
(*m*+*p*)-Xylene	0.773	2.123	0.277	0.537	5.983
o-Xylene	0.377	0.879	0.115	0.242	1.349
Time period	1986-1990	1992	1989-1991	1989-1991	1988-1991
Number of samples	486	534	166	186	19

burning (Nikolau *et al*, 1984). In vehicle exhaust, lower molecular weight PAHs are found in both gaseous and particulate-associated phases, while higher molecular weight PAHs are generally particulate associated (Harrison and Johnson, 1985). Williams *et al* (1986) have shown that the major PAH components of diesel exhaust particulates are naphthalene, fluorene, phenanthrene and their alkyl derivatives. More recent research by Williams *et al* (1989) has indicated that much of the particulate-associated PAH derives from unburned fuel, with some high molecular weight (5-ring) PAHs being formed in-cylinder. At low air/fuel ratios (AFR), the ratio of PAH particulate emission to PAH content in the diesel fuel increased markedly. AFR was also established as a significant determinant of PAH emissions from spark-ignition engines, and cold starts were found to increase emissions substantially. Typical ranges and peak values for total PAHs are shown in Table 3.3.

Current levels of hydrocarbon emissions are very uncertain and source apportionment is therefore difficult. However, it has been estimated that 33% of hydrocarbon emissions in the UK were derived from road transport in 1983, compared with 36% from industrial processes and 23% from gas leakage (Davies, 1989). Some estimates of the relative contribution of transport sources to volatile hydrocarbon emissions in the UK are shown in Table 3.12.

3.7.1 Health and environmental effects of hydrocarbons

The adverse effects of hydrocarbons are well documented (*eg* NRC, 1981b; Ball *et al*, 1991) since a number of PAHs have been identified as carcinogenic (*eg* benzo-*a*-pyrene, dibenzo-*ah*-pyrene), mutagenic or toxic, although it should be noted that a range of scientific uncertainties make it impossible to quantify the contribution of vehicle-derived HCs to adverse health effects in humans. These uncertainties are reflected by the results of a recent review by the IARC (1989), who concluded that diesel engine exhaust is probably carcinogenic, and that petrol engine exhaust is possibly carcinogenic.

Atmospheric HCs react with NO_x and other pollutants under certain meteorological conditions resulting in photochemical smogs (see Section 3.3.2). These photochemical smogs contribute to visibility reduction and contain compounds which may cause damage to vegetation, corrosion of materials, localised skin effects, impairment of pulmonary function, genetic reproductive and development effects, irritation of the eyes and nose, and behavioural and neurotoxic effects (*eg* Ball *et al*, 1991; Davis *et al*, 1987; Handa *et al*, 1980).

3.8 Sources, ambient concentrations and effects of volatile organic compounds (VOCs)

VOC is an umbrella term for a 'class of organic compounds which evaporate easily and

Table 3.12
Estimates of the relative contribution of road transport sources to hydrocarbon emissions in the UK in 1983 (Derwent *et al*, 1987; unless stated otherwise).

Hydrocarbon	Petrol exhaust	Diesel exhaust	Evaporation of petrol	% from transport
Methane	33.0	0.8	0.0	9.2
Ethane	3.14*	0.0	0.0	14.5
Propane	0.68*	0.0	0.0	12.6
n-Butane	33.1	0.0	18.0	64.9
i-Butane	14.5	0.0	3.6	55.2
n-Pentane	25.2	0.0	6.7	24.2
i-Pentane	44.7	0.0	58.1	46.9
Ethylene	33.4	5.2	0.0	63.3
Propylene	12.0	3.4	0.0	46.2
Acetylene	31.0	4.4	0.0	79.9
Toluene	61.8	0.0	2.0	42.8
o-Xylene	18.0	0.0	0.0	18.1
m-Xylene	21.2	0.0	0.0	20.6
p-Xylene	15.9	0.0	0.0	16.3
Ethylbenzene	18.0	0.0	0.0	18.1
1-Butene	0.5	1.9	2.7	24.8
2-Butene	0.3	0.0	5.2	33.1
1-Pentene	0.7	1.2	4.3	32.1
2-Pentene	0.7	0.0	2.3	51.7
2-Methyl-*1*-butene	0.7	0.0	4.3	42.0
3-Methyl-*1*-butene	0.7	0.0	0.8	53.6
2-Methyl-2-butene	1.4	0.0	6.5	41.8
Butylene	0.5	0.0	0.0	100

* From Bailey *et al*, 1990

contribute to air pollution mainly through the production of secondary pollutants such as ozone. VOCs include some hydrocarbons and other, more complex organic substances' (including oxygenated and halogenated organics) (NSCA, 1993). VOCs are derived from a large number of sources including vegetation, manufacturing and industrial processes, evaporation of solvents, biogenic processes and the combustion of fossil fuels. The US EPA (1985) estimate that 37% of atmospheric VOCs are produced by motor vehicles, 37% from industrial activities,15% from solid waste and miscellaneous sources and 10% from volatilization of organic solvents. The estimated emissions by emission source in the UK for 1982, 1987 and 1992 are shown in Table 3.13.

A number of VOCs have been identified as odourants and/or irritants and atmospheric VOCs take part in the reactions which generate photochemical smog. Hydrocarbons have been discussed in the previous section and other VOCs suspected to cause irritation to the public are discussed in this section as separate groups.

Table 3.13
VOCs[1]: estimated emissions[2] (1000 tonnes) by source category in the UK (DoE, 1994).

Emission source	1982	1987	1992	% of total in 1992
Power stations	12	13	12	-
Domestic	75	64	36	1
Commercial/public service	1	1	1	-
Iron and steel	1	1	1	-
Other industrial combustion	2	2	2	-
Non-combustion processes	290	292	295	12
Extraction and dist. of fossil fuels	250r	313r	345	13
Solvent use	752	752	752	29
Road transport[3]	882r	915r	949	37
Railways	9	9	8	-
Civil aircraft[4]	3	3	4	-
Shipping[5]	13	11	14	1
Waste treatment and disposal	57	57	57	2
Forests[6]	80	80	80	3

[1] Excluding methane.
[2] Most of the figures in this table are based on constant emission factors.
[3] Includes evaporative emissions from the petrol tank and carburettor of petrol-engined vehicles.
[4] Includes only those emissions associated with ground movement and take off and landing cycles up to 1 km from the airport.
[5] Includes only those emissions from shipping within coastal waters (<12 miles).
[6] An order of magnitude estimate of natural emissions from forests.
r Revised figures.

3.8.1 Aldehydes

Aldehydes have the general formula RHC=O, where R represents an organic stem. Atmospheric aldehydes may be divided into three groups:

- saturated aliphatic
- olefinic
- cyclic and aromatic.

Many aldehydes are volatile and most of the aldehydes in urban air are present as gases. Graedel *et al* (1986) have listed over 100 aldehydes that are present in the urban atmosphere from sources which include manufacturing and industrial processes, fossil fuel combustion, incinerators, sewage treatment, animal waste, vegetation, microbiological processes and tobacco smoke.

Formaldehyde is the most abundant atmospheric aldehyde, and is produced by man-made and natural sources as well as *in situ* by photochemical reactions (Grosjean *et al,* 1990). Typical background levels of formaldehyde are of the order of a few ppb (Shepson *et al*, 1991) while Lowe and Schmidt (1983) have recorded formaldehyde concentrations over the mid-Atlantic in the range 0.1-0.3 ppb. Urban concentrations tend to be higher, typically 5-40 ppb (Graedel, 1990; Lawson *et al*, 1990; Kuwata *et al*, 1983; Grosjean, 1982; Grosjean *et al*, 1990; Grosjean and Williams, 1990), although levels approaching 100 ppb are expected during severe photochemical smog episodes (Ball *et al*, 1991). It has been generally assumed that formaldehyde accounts for a significant fraction of the total aldehydes in urban air (perhaps up to 70-80%), and that automotive sources dominate anthropogenic emissions of carbonyls (Grosjean, 1982). Formaldehyde is the major aldehyde in both petrol and diesel vehicle exhaust (Lies *et al*, 1986; Kleindienst *et al*, 1988), but as Ball *et al* (1991) state 'it is not always easy to establish whether formaldehyde arises from atmospheric photochemistry or directly as a primary pollutant from the exhaust'.

This point is also applicable to other aldehydes, such as acrolein, acetaldehyde, propanal, pentanal, hexanal, crotonaldehyde and benzaldehyde, which are found both naturally and in diesel exhaust. Acetaldehyde is usually the second most abundant carbonyl compound found in urban areas, with a typical urban range of 2-39 ppb (Hoshika, 1977; Kuwata *et al*, 1983; Grosjean *et al*, 1990; Kuwata *et al*, 1979; Grosjean, 1982). Background concentrations of 0.3-0.7 ppb acetaldehyde have been recorded (Shepson *et al*, 1991; Schulam *et al*, 1985). Urban concentrations of other aldehydes are usually <5 ppb.

It has been reported that diurnal patterns exist for formaldehyde and acetaldehyde concentrations (Grosjean, 1982; Shepson *et al*, 1991; Lawson *et al*, 1990; Tanner and Meng, 1984); seasonal variations have also been observed by Cleveland *et al* (1977) who reported formaldehyde concentrations which were considerably higher in summer than in winter. Aldehyde concentrations are dependent on photochemical activity, with concentrations being higher on days with more photochemical activity. Cleveland *et al* (1977) have also reported that daytime formaldehyde concentrations in New Jersey decrease from workdays to Saturdays to Sundays corresponding to a reduction in motor vehicle traffic (see Figure 3.9).

Lawson *et al* (1990) have reported an association between ambient concentrations of formaldehyde and primary pollutants from motor vehicles. Throughout the duration of their study, formaldehyde exhibited a daily morning and afternoon peak. The morning peak was correlated with to nitrogen oxide and PEC concentrations; the afternoon peak was associated with the arrival of photochemically produced ozone at the site. These data suggest that mobile sources contribute significantly to ambient aldehyde concentrations.

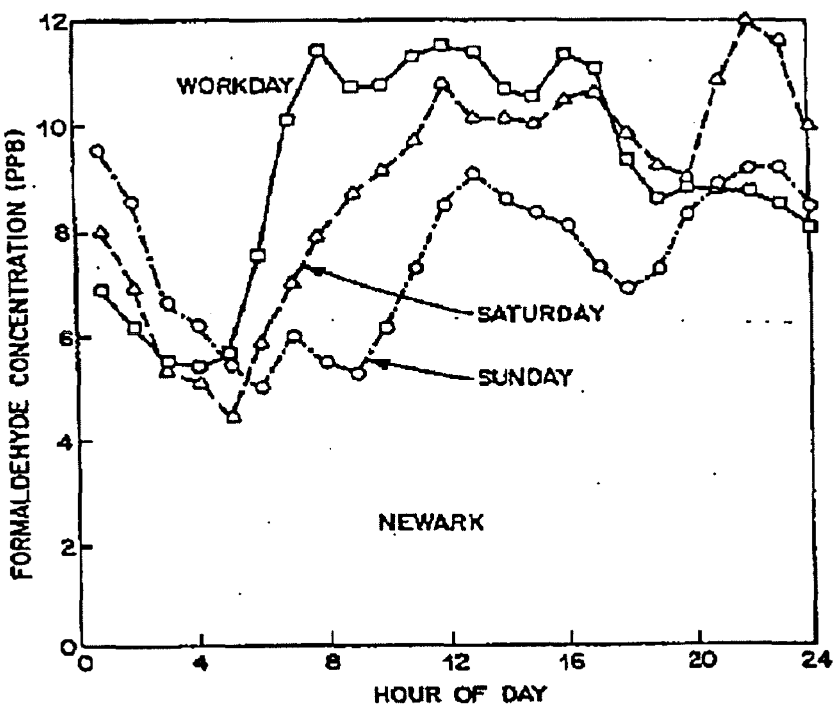


Figure 3.9
Average diurnal concentrations of formaldehyde at Newark, New Jersey, for different days of the week, from 1 June to 31 August for the years 1972-1974 (Cleveland *et al*, 1977).

Swarin and Lipari (1983) suggest that aldehyde exhaust emissions are dependent on the type of engine and fuel utilised, and that diesel engines produce significantly higher levels of aldehydes than petrol engines. Many aldehydes are known to be present in diesel exhaust and concentrations of selected aldehydes in diesel exhaust are shown in Table 3.14. Formaldehyde emissions from methanol and petrol fuelled cars have been measured by Williams *et al* (1990). Formaldehyde emissions were highest when methanol was utilized as fuel and decreased considerably as the petroleum fraction of the fuel was increased. This is significant since alcohols are used widely as vehicle fuel in Brazil and are being increasingly considered as potential alternative fuels to petrol and diesel.

Aldehydes play a critical role in oxidative tropospheric photochemical processes, as their photolysis represents a significant source of atmospheric free radicals (Calvert and Stockwell, 1983). Aldehydes contribute to photochemical smog and many are recognised irritants of the skin, eyes and nasopharyngeal membranes. Formaldehyde is a confirmed animal carcinogen and a suspected human carcinogen. Studies have indicated an increased incidence of nasal cancers in rats exposed to high formaldehyde concentrations (15 ppm) (Kerns *et al*, 1983), and a large number of different epidemiological studies have investigated the potential association of formaldehyde exposure with human cancer over the last 20 years (Starr, 1990). The epidemiological literature on formaldehyde has been evaluated by the Ad Hoc Panel on Health Aspects of Formaldehyde (1988), who concluded that there is no convincing evidence of a relationship between malignancy and formaldehyde exposure. Furthermore, they felt that even if a relationship did exist, the excess risk, in absolute terms, must be small.

Table 3.14
Concentrations of selected aldehydes in diluted diesel exhaust* (Marnett, 1990).

Aldehyde	Cold Start[a]	Hot Start[a]
Formaldehyde	539	428
Acetaldehyde	115	80
Propionaldehyde	57	24
Acrolein	57	24
Crotonaldehyde	11	6
Benzaldehyde	9	NA

* Concentrations are given in ppb, and dilution factor is 10:1
[a] Federal Test Procedure driving cycle.
Note: NA = not available.

3.8.2 Ketones

Like aldehydes, ketones contain the C=O functional group but have a slightly different general formula ($RR_1C=O$). Over 220 individual ketones have been identified in the atmosphere (Graedel *et al*, 1986). Aliphatic ketones are common atmospheric constituents (although their atmospheric concentrations are not high) and arise mainly from biological processes (*eg* sewage treatment), industrial use and fossil fuel combustion. Few olefinic ketones have been detected in urban air and cyclic ketones are produced primarily by vegetation. However, nearly 150 aromatic ketones have been identified in the atmosphere, many of them resulting from the combustion of coal, petroleum and biomass (Graedel *et al*, 1986).

Despite their apparent abundance, the atmospheric concentrations and chemistry of ketones has been little studied, and practically no data on ambient levels exist. Grosjean *et al* (1990) have reported the urban concentrations of a number of ketones in Brazil; acetone (10-20 ppbv), 2-

butanone (0-13 ppbv), 3-butene-2-one (0-1.5 ppbv) and C_5 ketones (0-0.5 ppbv). Acetone has also been found in rural (1-3 ppbv) and remote (0.1 ppbv) atmospheres; while 2-butanone has also been found in rural areas (0.5 ppbv) (Grosjean *et al*, 1990; Snider and Dawson, 1985).

The possible importance of ketones as environmental irritants stems from research completed in the early 1970's by A. D. Little Inc. (1970, 1971), in which a number of ketones were identified as contributing to the overall odour from diesel exhausts.

3.8.3 Alcohols

Alcohols contain the hydroxyl (-OH) functional group and have the general formula ROH. Over 230 different alcohols have been identified in the atmosphere, with more than 70 being aliphatic alcohols (Graedel *et al*, 1986). The C1-C5 aliphatic alcohols are derived from numerous sources including manufacturing and industrial processes, solvent evaporation, vegetation, tobacco smoke and combustion of fossil fuels and biomass. The smaller olefinic alcohols, such as but-2-en-1-ol, are generally derived from diesel and turbine emissions, whereas larger compounds are emitted by vegetation. Aromatic alcohols, such as cresols and xylenols, are produced primarily by distillation of petroleum fuels or biomass.

There is very little data available concerning atmospheric concentrations of alcohols, but the few studies that have been reported suggest typical concentrations of 5-10 ppb in urban areas (Bellar and Sigsby, 1970; Hanst *et al*, 1975; Holzer *et al*, 1977; Snider and Dawson, 1985). Hanst *et al* (1975), suggest that ambient alcohol levels are influenced more by random emissions from direct sources than by generation through photochemical reactions since they do not appear to follow regular diurnal patterns.

3.8.4 Heterocycles and other organics

Heterocycles are organic compounds that contain rings possessing atoms other than carbon and hydrogen, such as oxygen, sulphur and nitrogen. A number of heterocycles and other organics such as lactones, ethers and acids (*eg* nitrous acid) have been identified in vehicle exhaust. Nitrogen, sulphur and halogen containing organic compounds all participate in atmospheric chemical reactions which contribute to photochemical smog, and some of these compounds (*eg* nitroarenes) have been identified as carcinogenic (Graedel *et al*, 1986). Very little data is available regarding the atmospheric concentrations of these compounds. As far as nuisance effects are concerned, epoxyethane (ethylene oxide) has been identified as an irritant, although:

> No data are available concerning levels of ethylene oxide in air, water, or soil,

following emission from production plants ..... and there are no data indicating that ethylene oxide occurs is a natural product (WHO, 1985).

3.9 Sources, ambient concentrations and effects of secondary pollutants

Atmospheric chemical reactions between primary pollutants (and indeed other secondary pollutants) generate compounds known as secondary pollutants. The most important secondary pollutants are ozone (O_3), peroxyacetyl nitrates (PAN) and hydroxyl radicals ($OH^\cdot$).

Stratospheric ozone is produced naturally, although some may be transported to the troposphere by large scale air movements (Cocks and Kallend, 1988). Tropospheric ozone is formed by the reaction of nitrogen dioxide with sunlight producing oxygen atoms which react subsequently with oxygen molecules in the presence of a third body (M). The nitrogen dioxide is formed by the oxidation of nitric oxide, which is largely emitted from combustion sources.

$$NO + O_3 \rightarrow NO_2 + O_2$$

$$NO_2 + hv \rightarrow NO + O(^3P)$$

$$O(^3P) + O_2 + M \rightarrow O_3 + M$$

A photo-stationary state is established rapidly since these reactions are fast. Although these processes cannot produce more ozone than is originally present, the following reactions occur in the presence of a reactive hydrocarbon (RH) (Cocks and Kallend, 1988):

$$RH + OH + O_2 \rightarrow RO_2 + H_2O$$

$$RO_2 + NO + O_2 \rightarrow \text{Carbonyl} + 2NO_2 + HO_2$$

$$HO_2 + NO \rightarrow NO_2 + OH$$

$$\textbf{Overall} \quad RH + 2NO + 2O_2 \rightarrow \text{Carbonyl} + 2NO_2 + H_2O$$

The overall equation for these reactions shows that NO_2 is produced without consuming ozone. This disturbs the stationary state, which is restored by decomposition of some of the NO_2 to NO and O_3, resulting in net ozone formation.

Background concentrations of ozone are of the order of 10-80 $\mu g/m^3$ (0.005-0.04 ppm), with some seasonal variations interspersed with irregular maxima due to specific meteorological events (WHO, 1979a). Typical urban concentrations of ozone are shown in Table 3.3, but:

> since photochemical oxidants are the products of sunlight-induced photochemical reactions, elevated concentrations of oxidants in urban areas are generally restricted to a 4-to-6-hour period within a day, representing only 15-25% of the 24-hour interval. For this reason, the reporting of oxidant or ozone data as daily, monthly, or yearly means can be misleading when evaluating trends or comparing oxidant concentrations in different cities. Thus, oxidant or ozone data are usually reported in terms of highest 1-hour concentrations or in terms of the number of days with hourly concentrations exceeding a specified value or the number of hours when a given range of concentrations occurred within a year. However, they may also be given as instantaneous or five minute peak concentrations or frequency distributions (WHO, 1979a).

Ozone concentrations are often lower in urban/industrial areas than in rural areas due to the reaction between O_3 and NO (QUARG, 1993a). Temporal variations in ozone concentrations result from:

- variations in oxidant precursors;
- variations in atmospheric transport and dilution of pollutants;
- variations in meteorological conditions and other atmospheric variables involved in the photochemical reaction process (WHO, 1979a).

Generally however, monthly mean and peak O_3 concentrations are higher in spring and summer than in winter months, with daily levels usually highest around midday since O_3 destruction frequently occurs during peak morning and afternoon traffic periods. An example of the diurnal variation of ozone concentrations in London is illustrated in Figure 3.10. Diurnal variations often decrease during winter.

Ozone causes increased susceptibility to respiratory infections and is a strong pulmonary irritant. It has also been claimed that ozone causes coughing, eye, nose and throat irritation, and headaches, particularly in people who exercise (Holman, 1989). McDonnell *et al* (1983) have shown that acute (2-hour) exposures of exercising adults to levels of ozone as low as 0.12 ppm causes a reduction of mean vital capacity accompanied by a cough. Other researchers

(Avol *et al*, 1984; Lippman *et al*, 1983; McDonnell *et al*, 1985) have reported similar findings which can be accounted for specifically by the O_3 content of the air. However, there is currently no conclusive evidence from environmental chamber exposures that adverse respiratory effects are caused by synergy between O_3 and other pollutants.

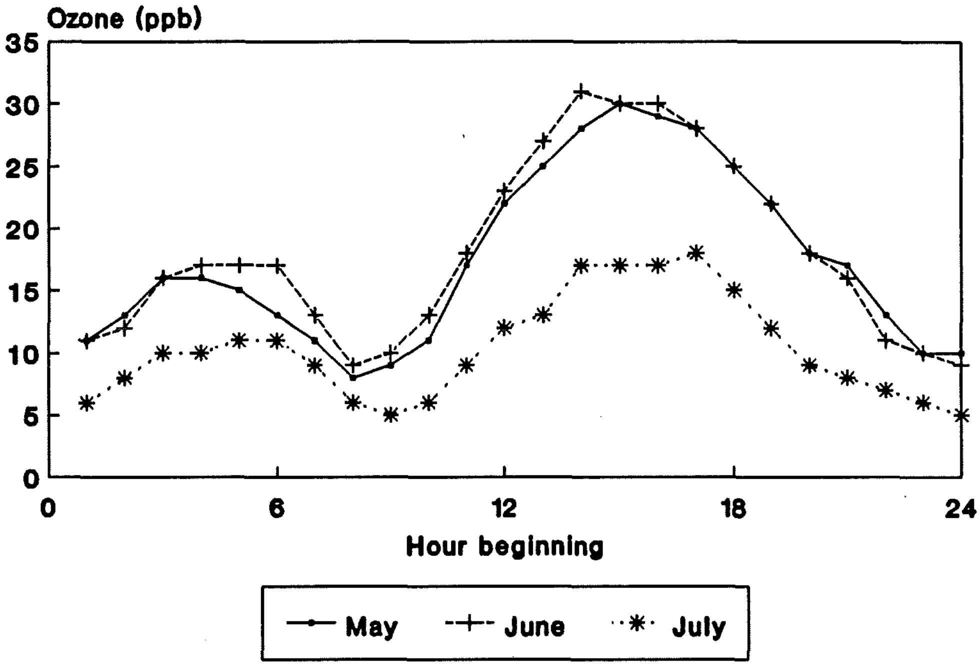


Figure 3.10
Daily variations of hourly mean ozone concentrations at the London EUN site in Bloomsbury in 1992.

As far as environmental effects are concerned, ozone contributes to ground level haze, photochemical smog, and elevated or long-term exposure may also cause vegetation damage (Dohmen, 1987). Ozone is also associated with the degradation of rubber and a number of other polymers, the induction of fading in dyes and damage to photographic materials and books (Ball *et al*, 1991)

PAN is formed by chemical reactions involving HCs and NO_x, and its levels therefore follow a similar pattern to those of ozone. Typical urban and peak concentrations of PAN are shown in Table 3.3. PAN is a powerful eye irritant, although irritation usually occurs at concentrations of about 0.1 ppm (Brimblecombe, 1986) which is considerably higher than even peak urban values.

The hydroxyl radical is an important precursor of numerous atmospheric reactions, some of which ultimately result in the formation of sulphuric and nitric acids which are readily soluble in water and may be removed from the atmosphere as 'acid rain'. Hydroxyl radicals are produced by the photodissociation of hydrogen peroxide and possibly also by several other reactions, including the photodissociations of nitrous and nitric acids. In the atmosphere, hydroxyl radicals react with hydrogen, hydrocarbons, aldehydes and nitric oxides, creating products which contribute to photochemical air pollution (PAP). In severe cases (usually in heavily motorised cities), the reactions producing PAP can produce reduced visibility, eye irritation and damage to vegetation and materials.

3.10 Sources and ambient concentrations of nitrogen oxides (NO_x)

The most important nitrogen compounds present in urban areas are NO and NO_2. Other nitrogen oxides, such as dinitrogen pentoxide (N_2O_5) and nitrogen trioxide (NO_3) may be important in the chemistry of particular pollution episodes, while nitrous oxide (N_2O), dinitrogen trioxide (N_2O_3) and dinitrogen tetroxide (N_2O_4) do not contribute significantly to urban air pollution (QUARG, 1993a). Natural sources of nitrogen oxides are ubiquitous, and include lightning, volcanic eruptions and bacterial action in the soil. Annual natural global emissions of NO_x far outweigh anthropogenic NO_x emissions (WHO, 1977). Natural background concentrations of NO_2 range from 0.4-9.4 $\mu g/m^3$ (0.0002-0.005 ppm) and those of NO from 0-7 $\mu g/m^3$ (0-0.006 ppm) (WHO, 1977).

Anthropogenic sources of NO_x are dominated by the combustion of fossil fuels, mainly by vehicles and power stations. Compounds such as NO, NO_2, N_2O, nitrous (HNO_2) and possibly nitric (HNO_3) acids are emitted into the atmosphere from road traffic. These oxides are formed in combustion processes as nitrogen in the air and the fuel combines with oxygen at temperatures of 1800°C or higher (Mellanby, 1989). Nitric oxide is the major contributor to oxidised nitrogen pollution, but at ambient temperatures NO is oxidised to the more toxic secondary pollutant NO_2, a process which is accelerated by the presence of reactive hydrocarbons and ozone (see Section 3.9). Nitrogen dioxide can be decomposed by ultraviolet light to NO, thus producing an equilibrium situation. It has been estimated that NO contributes 90-95% by volume of the total NO_x emissions, although this figure varies considerably from one source to another (WHO, 1977).

Road transport was responsible for 53% of the UK emitted NO_x in 1992 (see Table 3.15), and is therefore the major contributor to NO_x pollution. In fact, the majority of emitted NO_x is produced by fuel combustion, with motor spirit contributing 30% and DERV 20% of the total

NO_x in 1992 (DoE, 1994). Williams (1987) has reported that motor vehicles can account for 70% of low to medium level NO_x emissions (*ie* emissions at street level), which could have important consequences for urban air quality. At low speeds, vehicles typically emit 3.5g NO_x/km (McCrae, 1988).

Table 3.15
Nitrogen oxides (NO_x)[1]: estimated emissions[2] by emission source in the UK (DoE, 1994).

Emission source	1982	1987	1992	% of total in 1992
Power stations	799	826	694	25
Domestic	67	74	73	3
Commercial/public service	61	61	58	2
Refineries	37	33	37	1
Iron and steel	47	50	47	2
Other industrial combustion	186	165	152	6
Non-combustion processes	12	13	9	-
Extraction and dist. of fossil fuels	54r	73r	88	3
Road transport	876r	1,205r	1,398	51
Railways	35	35	32	1
Civil aircraft[3]	10	12	14	-
Shipping[4]	119	101	130	5
Waste treatment and disposal	12	12	12	-
Agriculture	5	4	4	-

[1] Expressed as nitrogen dioxide equivalent.
[2] Most of the figures are based on constant emission factors.
[3] Includes only those movements associated with ground movement and take off and landing cycles up to 1 km.
[4] Includes only those emissions from shipping within coastal waters (<12 miles).
r Revised figures.

Urban NO_x concentrations follow similar diurnal and seasonal patterns to urban carbon monoxide concentrations, with pronounced morning and evening peaks attributable to automobile sources. Figure 3.11 shows diurnal trends in NO and NO_2 concentrations in Delft, Netherlands. Note that the graphs for spring and summer show a time drift in the NO_2 peak, indicating conversion of NO to NO_2 via photochemical reactions. Table 3.3 indicates typical ranges and peak values for NO_x concentrations.

3.10.1 Health and environmental effects of nitrogen oxides

Nitrogen dioxide is regarded as a pulmonary irritant, and acute exposures to NO_2 have been shown to increase inspiratory and expiratory flow resistance (WHO, 1977). These respiratory symptoms can cause irritation and eventually lead to oedema, or even emphysema. Recent research by Robert Davies, Professor of Respiratory Medicine at St Batholemew's Hospital in

London, has indicated that NO_2 from car exhausts damages the sensitive skin that lines the nose, increasing susceptibility to hayfever, asthma and eczema (*The Independent*, 13/6/91). Nitrogen dioxide appears to have a characteristic odour, and the lowest NO_2 level reported for odour perception is approximately 200μg/m^3 (0.11 ppm) (WHO, 1977). NO_2 may cause plant damage, and this effect is more pronounced when NO_2 and SO_2 occur simultaneously. Exposure to NO_2 has been shown to have detrimental effects on a range of materials, including textile dyes, and it also contributes to pollutant haze. Nitrogen oxides play important roles in atmospheric chemistry and have a major role in acid deposition (see Section 3.3).

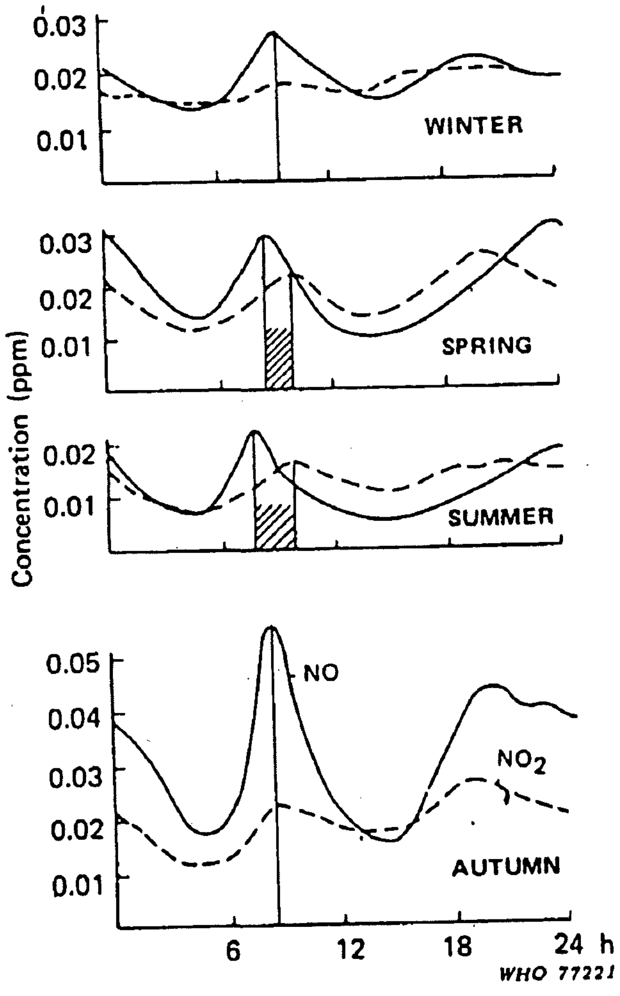


Figure 3.11
Diurnal trends in nitric oxide and nitrogen dioxide concentrations in Delft (WHO, 1977).

3.11 Sources and ambient concentrations of sulphur oxides (SO_x)

Globally, emissions of sulphur compounds into the atmosphere by natural sources approximately equal those derived from anthropogenic sources. Natural sources of SO_x include volcanoes and wind-blown aerosols from the sea surface. Man-made sources of SO_x are dominated by emissions resulting from the combustion of fossil fuels for heating and energy production, although industries such as petroleum refining, metal smelting and wood pulping also make significant contributions. Table 3.16 illustrates SO_2 emissions in the UK in 1991. SO_X emissions from vehicles are directly related to the sulphur content of the fuel. The sulphur content of diesel and petroleum fuels are shown in Table 3.17, although it should be noted that the EC proposes to limit the sulphur content of diesel fuel to 0.05% by weight (Amendment to EC Directive 87/219/EEC, 1992).

Table 3.16
Sulphur dioxide (SO_2): estimated emissions by emission source in the UK (1000 tonnes) (DoE, 1994).

Emission source	1982	1987	1992	% of total in 1992
Power stations	2,748	2,830	2,427	69
Domestic	202	171	103	3
Commercial/public service	170	107	84	2
Refineries	165	102	131	4
Iron and steel	101	80	83	2
Other industrial combustion	667	481	518	15
Non-combustion processes	26	22	14	-
Extraction and dist. of fossil fuels	2r	2r	2r	-
Road transport	49	26	62	2
Railways	8	4	3	-
Civil aircraft[1]	2	2	3	-
Shipping[2]	57	45	60	2
Agriculture	15	8	8	-

[1] Includes only those movements associated with ground movement and take off and landing cycles up to 1 km.
[2] Includes only those emissions from shipping within coastal waters (<12 miles).
r Revised figures.

Table 3.17
Sulphur content of diesel and petroleum fuels (% mass).
(adapted from McCrae, 1988 and QUARG, 1993a)

Fuel	1980	1982	1984	1986	1993
Auto spirit	0.03	0.06	0.04	0.04	0.04
Auto diesel	0.26	0.23	0.20	0.21	0.20

During combustion, the sulphur is oxidised to sulphur dioxide which is discharged into the atmosphere via the exhaust system. Small quantities of SO_2 are further oxidised to SO_3, which immediately dissolves in the existing water vapour to form a sulphuric acid aerosol. Sulphuric acid is eventually formed in the atmosphere from the emitted SO_2.

It has been estimated that SO_x emissions from road vehicles account for approximately 2% of the UK national emissions (DoE, 1994). Even though this figure is small in comparison with other anthropogenic sources, vehicle-derived SO_x are emitted at ground level, which clearly has implications for urban air quality in the breathing zone. Harrop *et al* (1989) found that almost 10% of SO_2 emissions were derived from transportation sources in the London Borough of Haringey, while Bennett (1987) has suggested that 50% of roadside SO_2 in urban areas is derived from automotive sources. It is to be expected that diesel vehicles will produce more SO_x than petrol vehicles, since diesel fuel contains 4-5 times as much sulphur as petroleum.

SO_2 is one of the most widely monitored of air pollutants, with national sampling networks in many parts of the world. Typical concentration values and peak ranges of gaseous SO_2 are shown in Table 3.3. Natural background levels of SO_2 are approximately 5 $\mu g/m^3$ (QUARG, 1993a). Generally SO_2 emissions are declining, as illustrated in Table 3.16, mainly due to legislative control measures.

3.11.1 Health and environmental effects of sulphur oxides

The health and environmental effects of SO_2 have been widely studied. Sulphur dioxide can aggravate existing respiratory diseases, bronchitis, emphysema and contribute to the development of others when high concentrations of smoke are present (Stern, 1976). Some conflicting evidence from human exposure to SO_2 alone has indicated slight effects on respiratory function at 2.1 mg/m^3 (0.75 ppm) but not at 1.1 mg/m^3 (0.37 ppm), although sulphuric acid mists affect pulmonary function at 0.35 mg/m^3 (WHO, 1979b). Some synergistic effects on pulmonary function from joint exposures to SO_2 and hydrogen peroxide and SO_2 and O_3 have been reported (WHO, 1979b). Direct action of gaseous SO_2 on vegetation can cause plant damage (NSCA, 1993), while other effects include damage to paint, dyes, textiles, leather and photographic materials and discolouration of paper (Ball *et al*, 1991). Sulphuric acid mists can also cause plant injury and contribute to visibility reduction. SO_x play a major role in the phenomenon of acid precipitation which has caused extensive environmental damage in Europe (see Section 3.3.1).

3.12 Sources and ambient concentrations of carbon monoxide (CO)

Carbon monoxide is a colourless, odourless, tasteless gas that is slightly less dense than air. The significance of natural sources of CO for man are uncertain (WHO, 1979c), but anthropogenic sources are dominated by motor vehicle emissions. The incomplete combustion of carbon-containing fuels in vehicles is by far the most important source of CO, but it is also produced by heat and power generators, carbonisation of fuel, incineration of refuse, faulty domestic cooking and heating appliances and biological processes.

Natural background levels of CO are low, typically in the range 10-200 ppb (WHO, 1979c; QUARG, 1993a), and typical urban and peak values are shown in Table 3.3. Road vehicles accounted for 90% of total CO emissions in 1991 (see Table 3.18), of which 87% was derived from petrol engines (DoE, 1994).

Table 3.18
Carbon monoxide (CO): estimated emissions[1] by emission source in the UK (1000 tonnes) (DoE, 1994).

Emission source	1982	1987	1992	% of total in 1992
Power stations	48	49	45	1
Domestic	493	423	258	4
Commercial/public service	12	10	7	-
Refineries	2	1	2	-
Iron and steel	25	29	25	-
Other industrial combustion	42	43	42	1
Extraction and dist. of fossil fuels	22r	30r	36	1
Road transport	4,589r	5,480r	6,029	90
Railways	14	13	12	-
Civil aircraft[2]	8	9	11	-
Shipping[3]	18	15	19	-
Waste treatment and disposal	220	220	220	3
Agriculture	1	1	1	-

[1] Most of the figures in this table are based on constant emission factors.
[2] Includes only those movements associated with ground movement and take off and landing cycles up to 1 km.
[3] Includes only those emissions from shipping within coastal waters (< 12 miles).
r Revised figures.

Emission rates of CO from motor vehicles are variable and depend on the type of vehicle, its speed, the state of tune of the engine, engine capacity, engine temperature and driving mode. Average CO emissions are highest at low speeds (@35g/km/veh), usually dropping to a low point at 75 km/h (@10g/km/veh) and increasing again at speeds of 150 km/h (@20g/km/veh) (Rogers, 1984). Light-duty diesels generally emit lower levels of CO than petrol-engined vehicles due to their greater relative efficiency, although emissions can rise considerably if the engine is poorly maintained (McCrae, 1991).

Concentrations in urban areas are closely related to road traffic density and weather conditions. Diurnal patterns in urban areas usually show peaks corresponding to the morning and evening rush hours. Elevated concentrations of CO can also be found in confined spaces such as tunnels, garages, car parks and loading bays. High indoor levels of CO may be found in areas with cooking or heating appliances that are faulty or do not have flues.

3.12.1 Health and environmental effects of carbon monoxide

The most important health effect of CO is to reduce the oxygen carrying capacity of the blood. This is due to the fact that CO forms a strong coordination bond with the iron atom of the protohaem group in haemoglobin producing carboxyhaemoglobin (COHb). The production of COHb diminishes the oxygen carrying capacity of blood which can impair physical co-ordination, vision and judgement and affect the central nervous and cardiovascular systems (QUARG, 1993; WHO, 1979c).

The mass concentration of CO in the blood at any time depends on several factors, including the volume of air inhaled, the concentrations of inspired CO and O_2, the time of exposure and the COHb levels present in the blood before inhalation of contaminated air. The effects of COHb are concentration dependent (WHO, 1979c):

- at levels of $<10\%$ COHb; few people are affected;
- between 10-60% COHb; headaches, dizziness, nausea, convulsions and collapse can occur;
- at levels $>60\%$ COHb; the heart and respiratory rates become depressed which can lead to coma;
- at levels of >80-90% COHb death can result.

Exposures to low levels of COHb for short durations are unlikely to produce any permanent effects since the COHb content of blood declines by approximately 50% after 4 hours away from direct exposure (WHO, 1979c). Typical exposures to vehicular derived CO are usually low, producing COHb levels of $<5\%$, although higher concentrations may be encountered where vehicles operate in confined spaces.

3.13 Motor vehicle emission regulations

The emission of pollutants from motor vehicles is regulated in a large number of individual countries and states. The regulations state the maximum permissible emission rates of each pollutant from a road vehicle under prescribed test conditions and also represent the minimum emission standards with which car manufacturers need to comply. These controls are aimed mainly at the primary pollutants CO, NO_x and HCs, and also diesel-derived particulates and SO_2.

The regulations adopted by each country/state have developed since their initial introduction to take into account new instrumentation technologies and test procedures. For example, within the European Union (EU), the United Nations (UN) regulation ECE 15 has been amended 5 times since it was originally introduced in 1970. European vehicular emission legislation generally lags 6 to 10 years behind control measures within the USA, with the State of California having the toughest regulations (McCrae, 1991).

3.14 Air quality legislation

Stern (1976) has stated that 'air quality standards ... are legal upper limits imposed on levels of pollutants in ambient air during a given period of time', and are designed to limit the emissions from all sources. This definition has been extended by Georgiades *et al* (1988), who state that:

> Environmental standards apply to public places and are aimed at safeguarding public health and protecting the material, biological and plant life environment. A distinction needs to be made between values having force of law, where any infringement leads as a matter of course to the application of measures to ensure limits are respected, and those serving for guidance or that are regarded as no more than desirable or recommended limits.

The limit values are selected via a mixed scientific and non-scientific process. Scientific considerations include:

- the physical and chemical properties of the pollutant under consideration;
- its toxicity, likely ability to be accumulated, absorbed etc;
- possible reactions with other atmospheric compounds;
- the effects of exposure to the human population (especially sensitive groups) and to the environment;
- uncertainties in data.

The limits are based on scientific information and other considerations which may include political, economic, technical, ethical, philosophical and safety factors. Air quality criteria from

3 different regulatory bodies are illustrated in Tables 3.19-3.21. Within the UK, the Department of the Environment has recently introduced public information air quality criteria for SO_2, NO_2 and O_3. These criteria are used in publicising air quality information via the media by banding pollution concentrations into four categories; very good, good, poor and very poor.

Table 3.19
World Health Organisation ambient air quality standards

Pollutant	Averaging time	Time-weighted average
Carbon monoxide	8 hour mean 1 hour mean 30 mins 15 mins	10 mg/m^3 30 mg/m^3 60 mg/m^3 100 mg/m^3
Nitrogen dioxide	Annual mean 24 hour mean 4 hour mean 1 hour mean	30 $\mu g/m^3$ 150 $\mu g/m^3$ 95 $\mu g/m^3$ 400 $\mu g/m^3$
Sulphur dioxide	Annual mean 24 hour mean 1 hour mean 10 min mean	30 $\mu g/m^3$ 100 $\mu g/m^3$ 350 $\mu g/m^3$ 500 $\mu g/m^3$
Ozone	24 hour mean 8 hour mean 1 hour mean	65 $\mu g/m^3$ 100-120 $\mu g/m^3$ 150-200 $\mu g/m^3$
Peroxyacetylnitrate	8 hour mean 1 hour mean	80 $\mu g/m^3$ 300 $\mu g/m^3$
Formaldehyde	30 mins	100 $\mu g/m^3$
Particulate matter	24 hour mean 1 hour mean	100-150 $\mu g/m^3$ 40-60 $\mu g/m^3$

Table 3.20
European Union Limit and Guide Values

Pollutant	Type	Value ($\mu g/m^3$)
Nitrogen dioxide (85/203/EEC)	Limit value[a] Guide value[a] Guide value[b]	200 135 50
Sulphur dioxide (82/884/EEC)	Guide value[a] Guide value[b]	40-60 100-150
Suspended particulates (80/779/EEC)	Guide value[a] Guide value[b]	40-60 100-150

[a] The 98th percentile of hourly average concentrations measured throughout a calender year.
[b] 24 hour mean value

Table 3.21
Limit values for ground level suspended particulates and associated values for SO_2 (as measured by the black smoke method[1]) Directive 80/779/EEC.

Reference period	Limit value for sulphur dioxide	Associated value for suspended particulates	Absolute limit value for suspended particulates
Year[4]	80 $\mu g/m^3$ 120 $\mu g/m^3$	>40 $\mu g/m^3$ ≤ 40 $\mu g/m^3$	80 $\mu g/m^3$
Winter[4]	130 $\mu g/m^3$ 180 $\mu g/m^3$	>60 $\mu g/m^3$ ≤ 60 $\mu g/m^3$	130 $\mu g/m^3$
Year (24 hour measuring periods)	250[2,3] $\mu g/m^3$ 350[2,3] $\mu g/m^3$	>150[2] $\mu g/m^3$ ≤ 150[2] $\mu g/m^3$	250 $\mu g/m^3$

[1] The results of the measurements of black smoke taken by the OECD method have been converted into gravimetric units as described by the OECD.
[2] 98 percentile of all daily mean values throughout the year.
[3] Not to be exceeded for more than 3 consecutive days.
[4] Medium of daily mean values taken over selected period.

3.15 Reducing vehicle emissions

In recent years, there has been increasing pressure from scientists, environmental pressure groups and an ever more environmentally aware public to find methods of abating vehicular pollution. Motor vehicle manufacturers have responded with improved vehicle technologies and better pollution control systems, while governments and legislative bodies have introduced progressively tougher emission regulations and air quality criteria. However, these strategies are unlikely to be sufficient if, as expected, the global vehicle population approximately doubles over the next few decades (Walsh, 1994). A more comprehensive strategy is therefore necessary, requiring the cooperation of vehicle manufacturers, fuel/oil companies, governments (both national & local), legislative bodies, road construction companies, transport planning organisations as well as the general public. Current technology and future suggestions for reducing vehicle emissions include:

Improved vehicle technology

- electronic engine management systems
- air injection systems
- crankcase ventilation
- evaporative emission controls
- weight reduction
- aerodynamic improvements
- insulated thermal reactors
- improvements in tyres and accessories

- on-board diagnostics
- development of two-stroke engines and electric vehicles

Improved fuels/oils

- reduction of fuel vapour pressure
- elimination of leaded fuels
- reduction of sulphur in fuels
- improvements in lubricants and additives
- use of 'alternative' fuels

Exhaust after-treatment

- catalytic converters (including pre-heated catalysts and catalytic trap oxidisers for diesels)
- exhaust gas recirculation
- particulate traps

Inspection and maintenance programmes

- regular inspection of in-service vehicles
- identification of vehicles which require remedial maintenance

Fiscal incentives

- reduced taxes on environmentally-friendly fuels and vehicles

Traffic management schemes

- speed limits
- integration of land use planning and transport planning
- traffic light coordination
- car sharing

Modal shift

- increased use of public transport

3.16 Conclusions

Emissions from motor vehicles are playing an ever increasing role in urban air pollution, with concentrations of NO_2 and particulates (especially PM_{10}) causing special concern. The relative contribution of diesel vehicles to the urban concentrations of these 2 pollutants is likely to increase because of the lag of diesel vehicle technology for the removal of exhaust emissions behind that for petrol vehicles. This situation may be exacerbated by the recent upsurge in the proportion of diesel vehicles in the UK.

When considering public nuisance effects from vehicle-derived air pollution particulates have been identified as the most important pollutant. The concentrations of HCs and VOCs in urban atmospheres may cause some public nuisance through their contributions to photochemical smogs, odour and physical irritation, but they are unlikely to be as important as particulates. Typical UK urban concentrations of CO, NO_x and SO_x are unlikely to cause a significant degree of irritation to the public.

Chapter 4
Monitoring and Assessment Techniques

4.1 Introduction

The reliability and usefulness of survey data is ultimately dependent on the quality of the techniques used to obtain the information. The techniques need to be accurate, reproducible, suitable for their desired function and (preferably) thoroughly tested. Any potential user must be aware of the limitations and shortcomings of the techniques so that s/he can utilise the collected data in an appropriate fashion. The data may also be dependent on the location in which it is collected, thus requiring the interpreter to be aware of the characteristics of individual sites. This Chapter therefore describes:

- the characteristics of the sites selected for study during this research;
- evaluates the techniques utilised for the air quality surveys;
- evaluates the techniques used for measuring the attitudes and opinions of the public towards vehicle-derived pollution.

4.2 Description of sites

The locations selected for study during this research project were monitored under two distinct sets of circumstances. One set of locations was monitored using a mobile monitoring station (the TRL mobile laboratory) to perform roadside air quality surveys and trained researchers from Middlesex University to perform social surveys. At these locations, the monitoring and assessment techniques were developed and improved while extensive air quality and public opinion data sets were collected. However, this type of monitoring is time-consuming and expensive, and in order to extend the database quickly and efficiently a second set of locations were monitored using air quality and social survey data from outside agencies. At this second set of locations, the air quality data was provided by the local authority and the social survey data was collected by an independent market research company (Public Attitude Surveys Ltd; PAS) using the survey techniques developed at the previous locations.

Two types of site were selected for study at each set of locations; a commercial site and a residential site. Each site type had similar distinctive characteristics. The commercial sites were usually busy shopping areas while the residential sites were usually situated in housing estates near to the central commercial district. Each type of site contained roads with similar traffic type and flow characteristics *eg* the commercial sites contained roads which carried a significant proportion of commercial and public transport vehicles, and characterised by slow-moving traffic. Detailed descriptions of the individual sites are outlined in Sections 4.2.1-4.2.3.

4.2.1 Ealing sites

The pilot survey was conducted at two sites in the London Borough of Ealing. Ealing is a reasonably affluent district to the west of London, with a central commercial sector and large residential estates to the north and south of the main highway (Uxbridge Rd; A4020). It is an extremely busy commuter area, with rail and underground links to central London and ready access to the M4 and M25 motorways via the North Circular road (A406). The sites were carefully chosen as characteristic of a relatively busy residential street (Site E-R) and a busy commercial street (Site E-C).

The residential site (Site E-R), was located to the north-east of the town centre in Westbury Rd, a fairly quiet street containing mainly private detached and semi-detached housing and some multi-storey flats (Figure 4.1). The southern end of Westbury Rd connects with Madeley Rd, a heavily trafficked residential street which runs from the town centre to the North Circular road. The TRL mobile laboratory was parked on the western side of Westbury Rd and the local air quality was monitored between the middle of March and the end of April 1991. Household social surveys were also performed during the same time period in Westbury Rd, Madeley Rd and Haven Lane.

The commercial site (Site E-C) was based in Ealing High St, a busy one-way street in the centre of the town (Figure 4.2). The street contains a number of small shops, the central post office, some offices, one of the main entrances to a popular new shopping complex called 'The Broadway Centre' and several bus stops. It is also adjacent to the main highway through the town centre upon which large numbers of buses travel and where the traffic is frequently slow-moving or stationary due to the presence of traffic lights. The mobile laboratory was parked outside The Royal Bank of Scotland on the eastern side of the High St from the end of May to the beginning of July 1991, during which period air quality monitoring was performed continuously. The business and pedestrian social surveys were conducted throughout the town centre between February and July 1991.

4.2.2 Wood Green sites

The follow-up survey was performed in Wood Green, in the London Borough of Haringey. Wood Green is located in north London and is less prosperous than Ealing, although equally busy. It is situated to the south of the busy North Circular Road and has rail and underground links with central London. This location was chosen for study since its residential and

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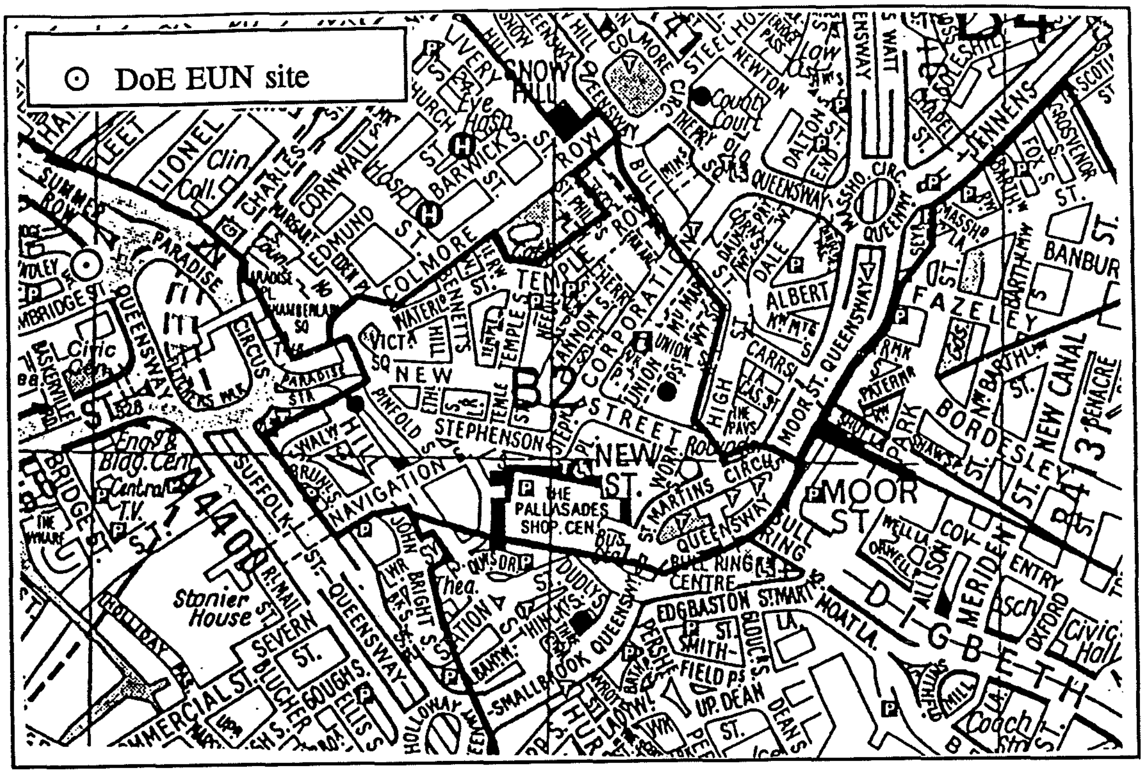


Figure 4.5
The location of the commercial site, Sparkbrook, Birmingham.

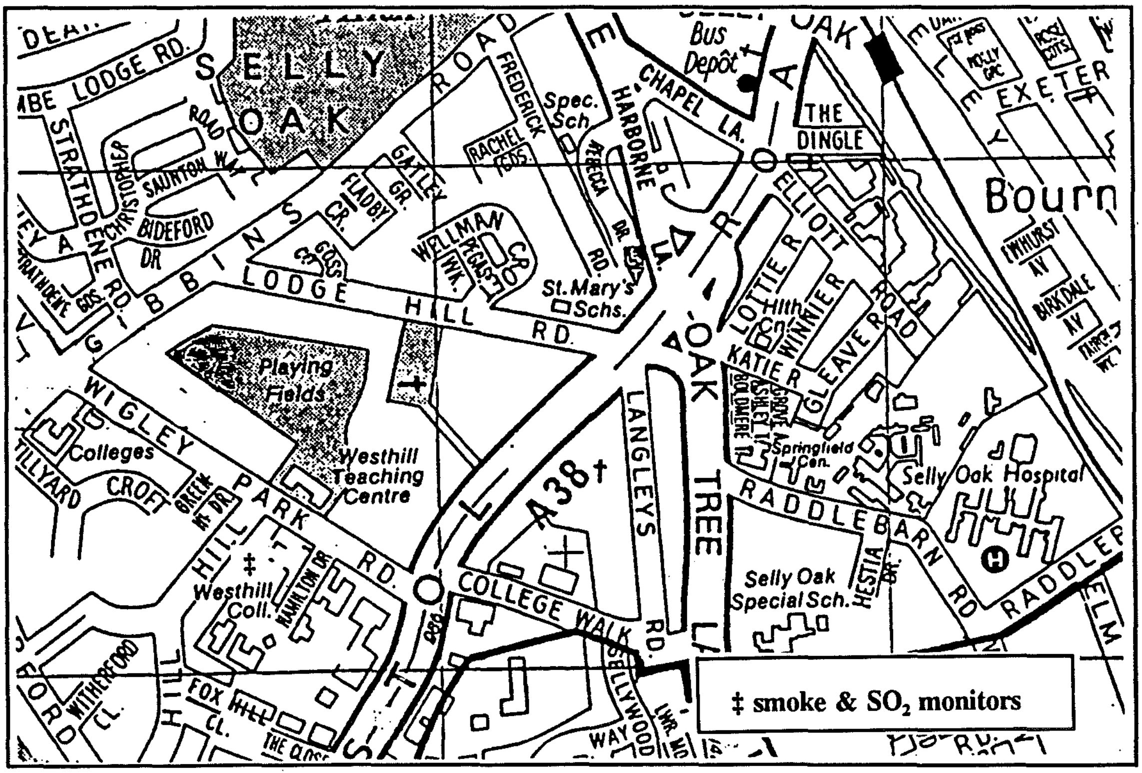


Figure 4.6
The location of the residential site, Selly Oak, Birmingham.

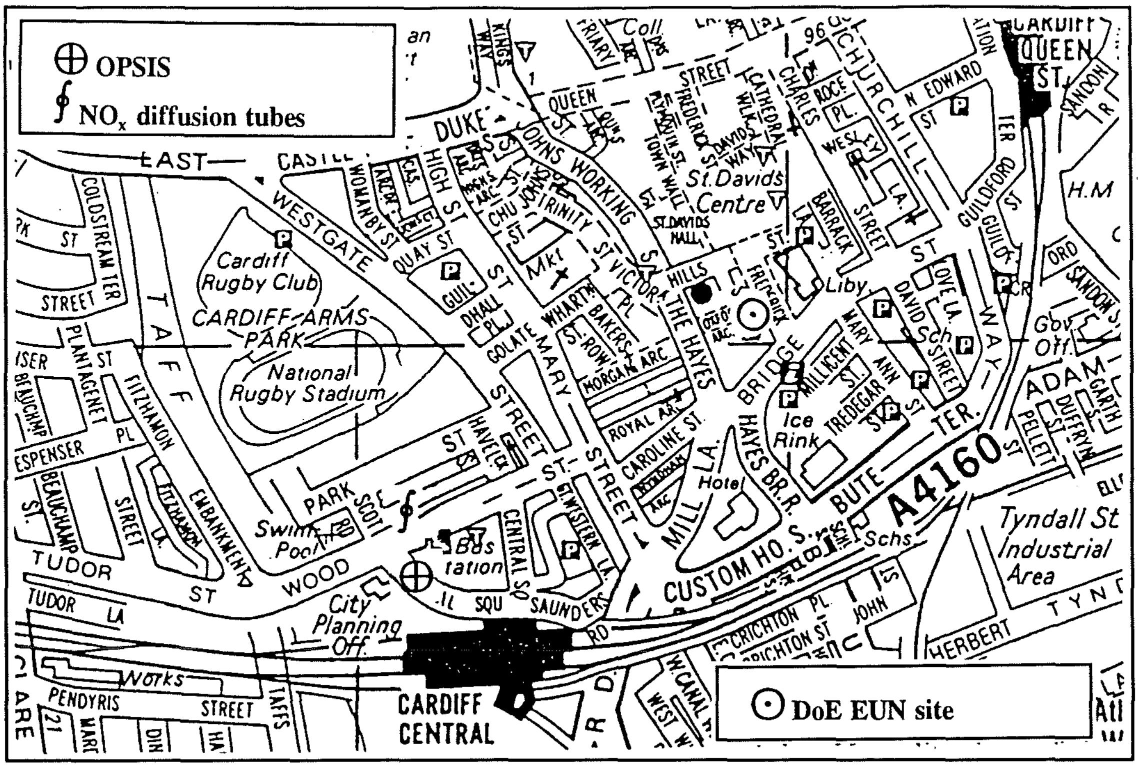


Figure 4.7
The location of the commercial site, Cathays, Cardiff.

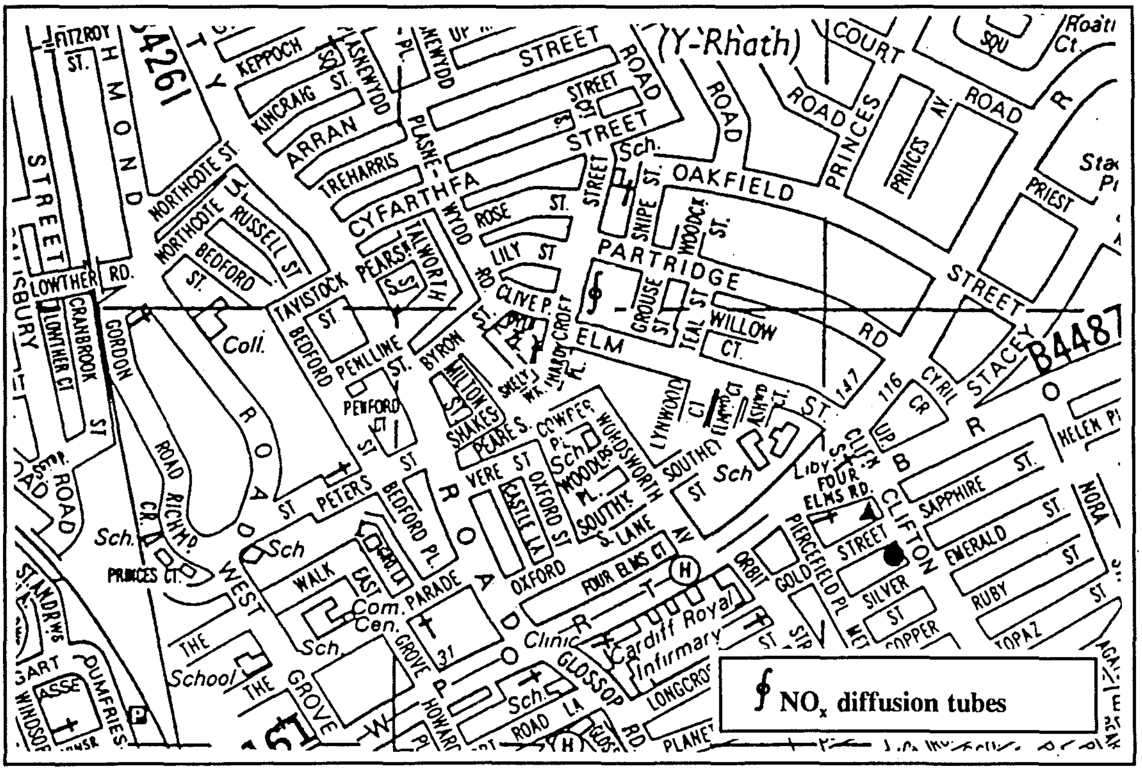


Figure 4.8
The location of the residential site, Plas Newydd, Cardiff.

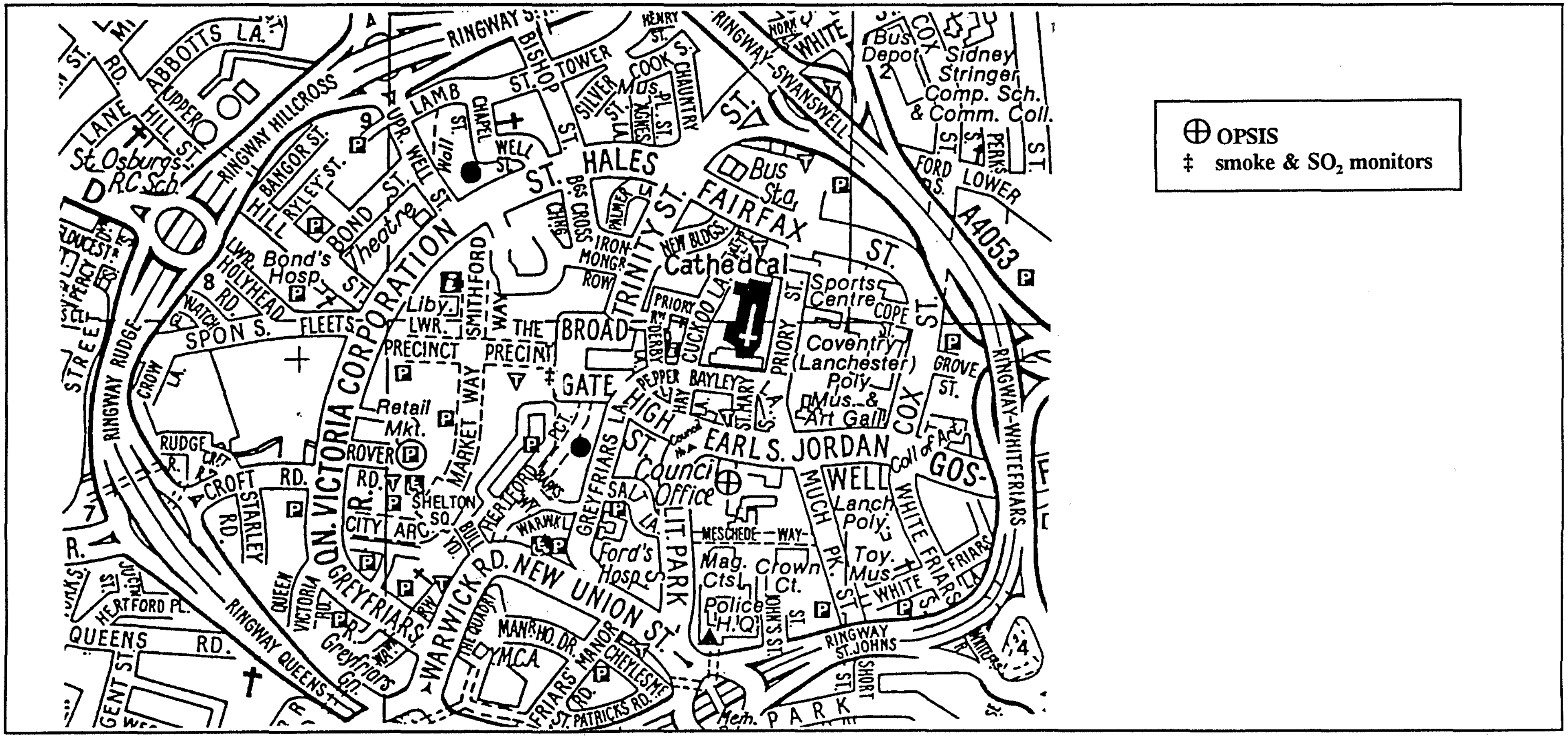


Figure 4.9
The location of the commercial and residential sites, St Michael's, Coventry.

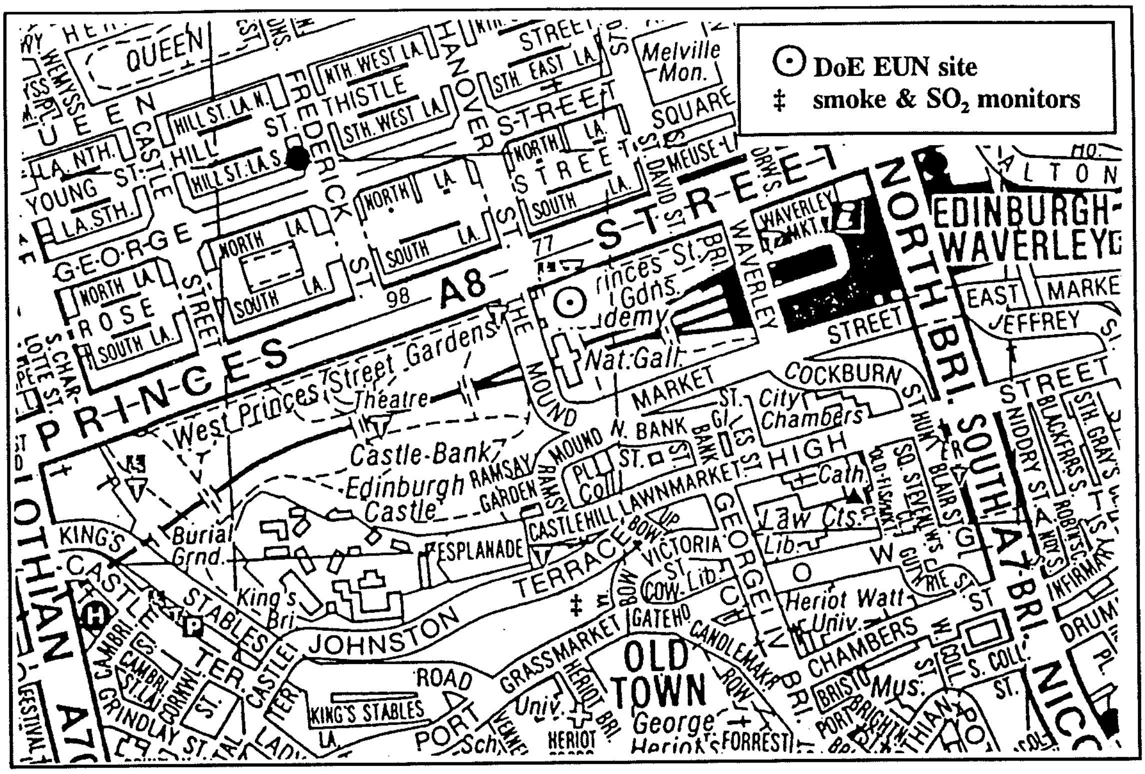


Figure 4.10
The location of the commercial site, St Giles/Holyrood, Edinburgh.

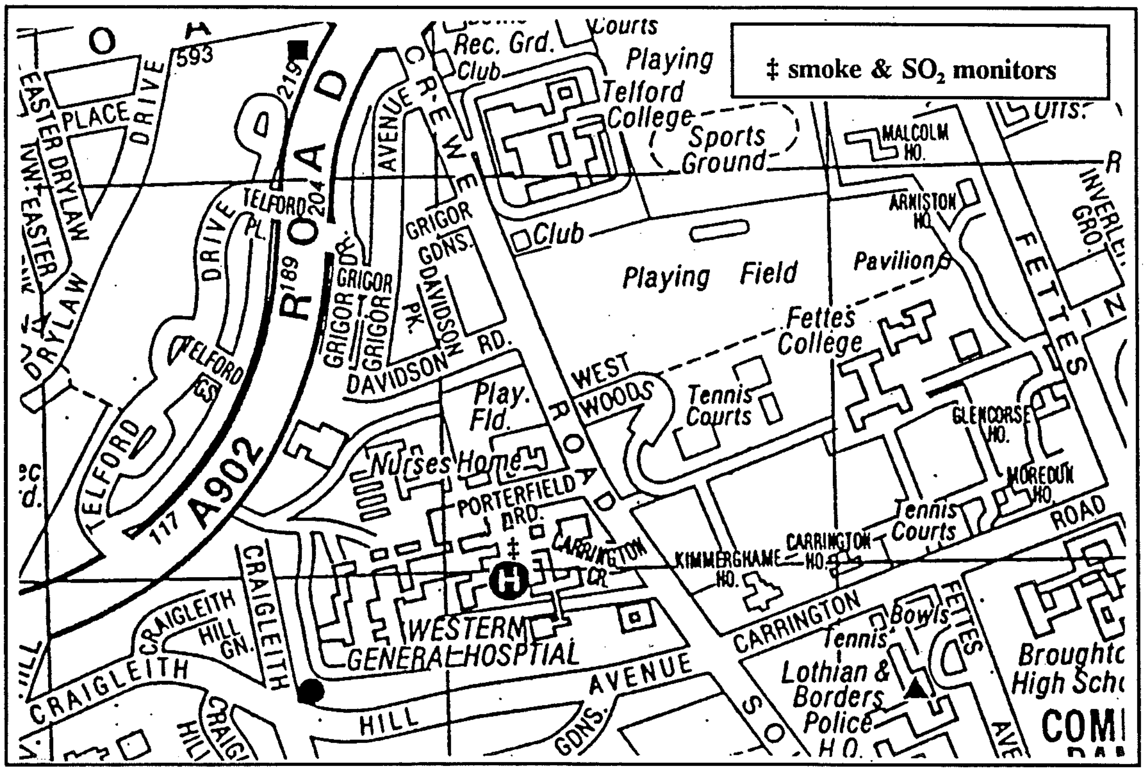


Figure 4.11
The location of the residential site, Telford, Edinburgh.

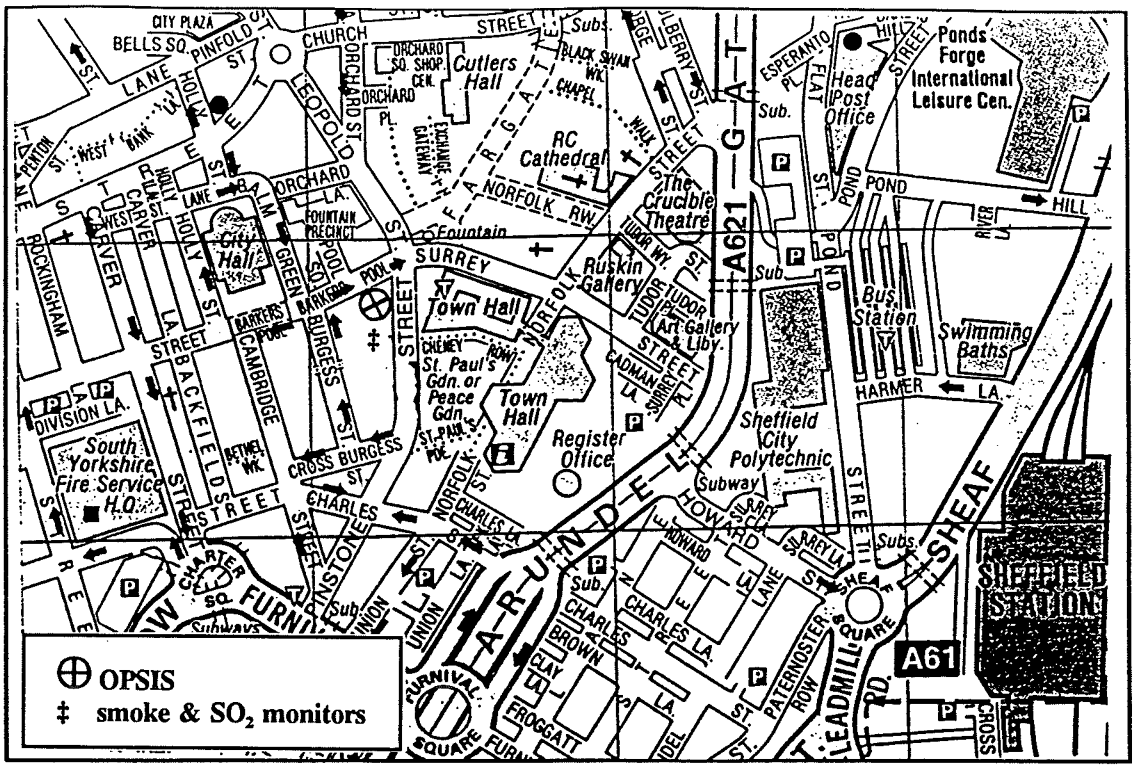


Figure 4.12
The location of the commercial site, Netherthorpe, Sheffield.

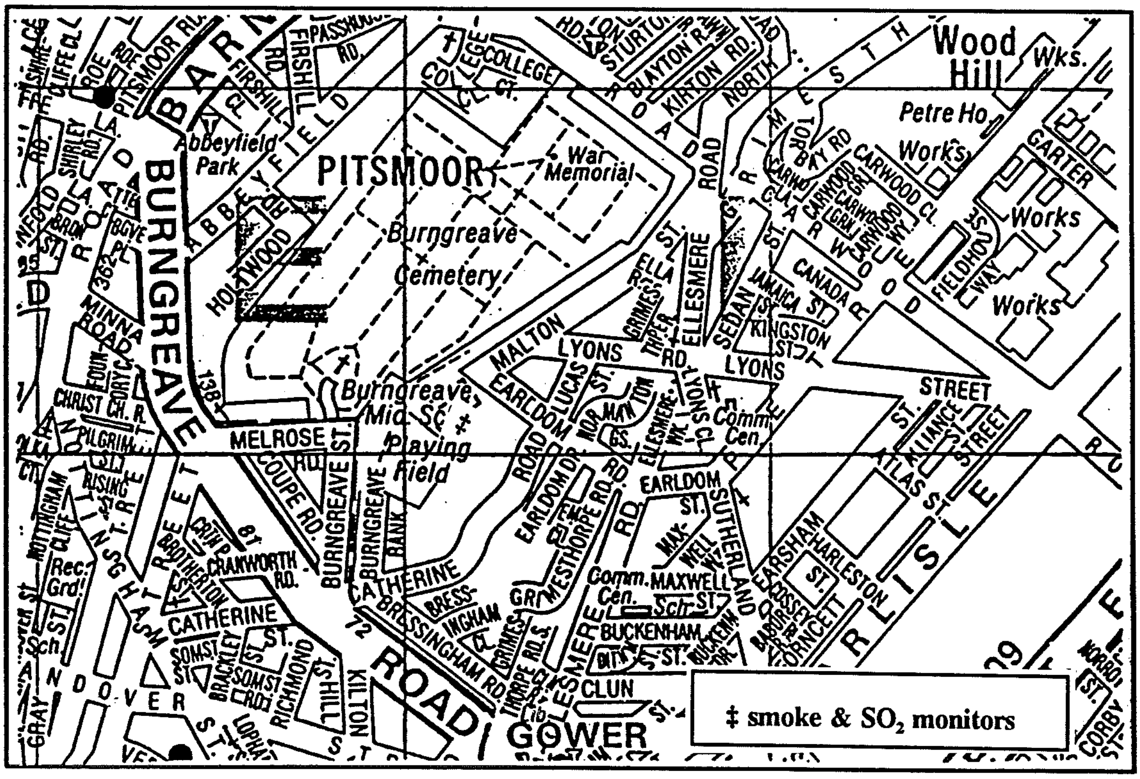


Figure 4.13
The location of the residential site, Burngreave, Sheffield.

above cabinet systems for rack mounted equipment, compressed air generators and the sample manifold. The calibration gas cylinders are situated securely on the side walls at the rear of the vehicle. This smaller mobile laboratory allows easier site parking while still permitting ready access to the analysers for maintenance and sufficient space for storage and experimental work.

The power supply (240 V, 30 A) to the laboratory was obtained at all four locations from a street lighting circuit via a residual current device. This supply was connected by an armoured cable to a wall mounted fuse box within the laboratory. In order to facilitate the operation of the equipment within the laboratory under optimum conditions, the original vehicle was fitted with wall-mounted heaters, extractor fans and vents so that a relatively constant temperature and humidity environment could be maintained. The replacement vehicle, being smaller than the original, is warmed sufficiently by heat generated from the operation of the analysers and therefore did not require wall-mounted heaters.

The instruments installed within the mobile laboratory may be divided into four main categories (McCrae, 1991):

- Those used to monitor specific pollutants, both gaseous and particulate.
- Those used to monitor meteorological parameters.
- Those used to collect and store data.
- Those used in calibration and gas supply.

A brief description of the setup and operation of this equipment is outlined in Sections 4.3.2 - 4.3.7.

4.3.2 The monitoring and analysis of gaseous pollutants

The mobile laboratory is equipped to monitor carbon monoxide, ozone, nitrogen oxides (nitric oxide, nitrogen dioxide and total), gaseous hydrocarbons (methane, non-methane and total) and sulphur dioxide. Gaseous samples are collected via a 15 cm manifold, set 1.6 m above ground level (*ie* in the region of an adult's breathing zone), through which ambient air is continuously drawn. The gaseous pollutants are detected by rack-mounted commercially available analysers and pollutant concentrations are recorded on a data logger. At each of the two locations described in Sections 4.2.1 and 4.2.2, readings were logged once every second and 15 minute averages were calculated and stored on disc.

Plate 4.1
The TRL mobile laboratory, Mobile Laboratory 1.

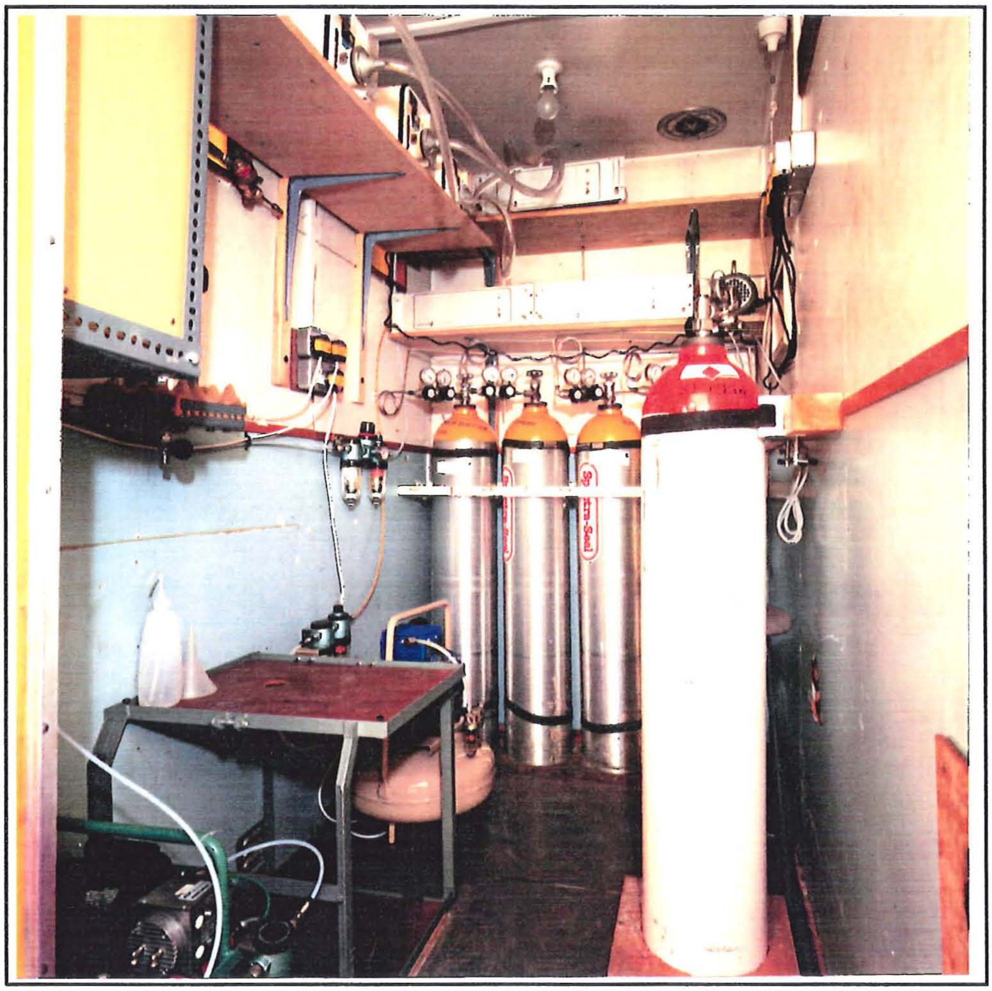


Plate 4.2
The TRL Mobile Laboratory 1; calibration gas supply and particulate pumps.

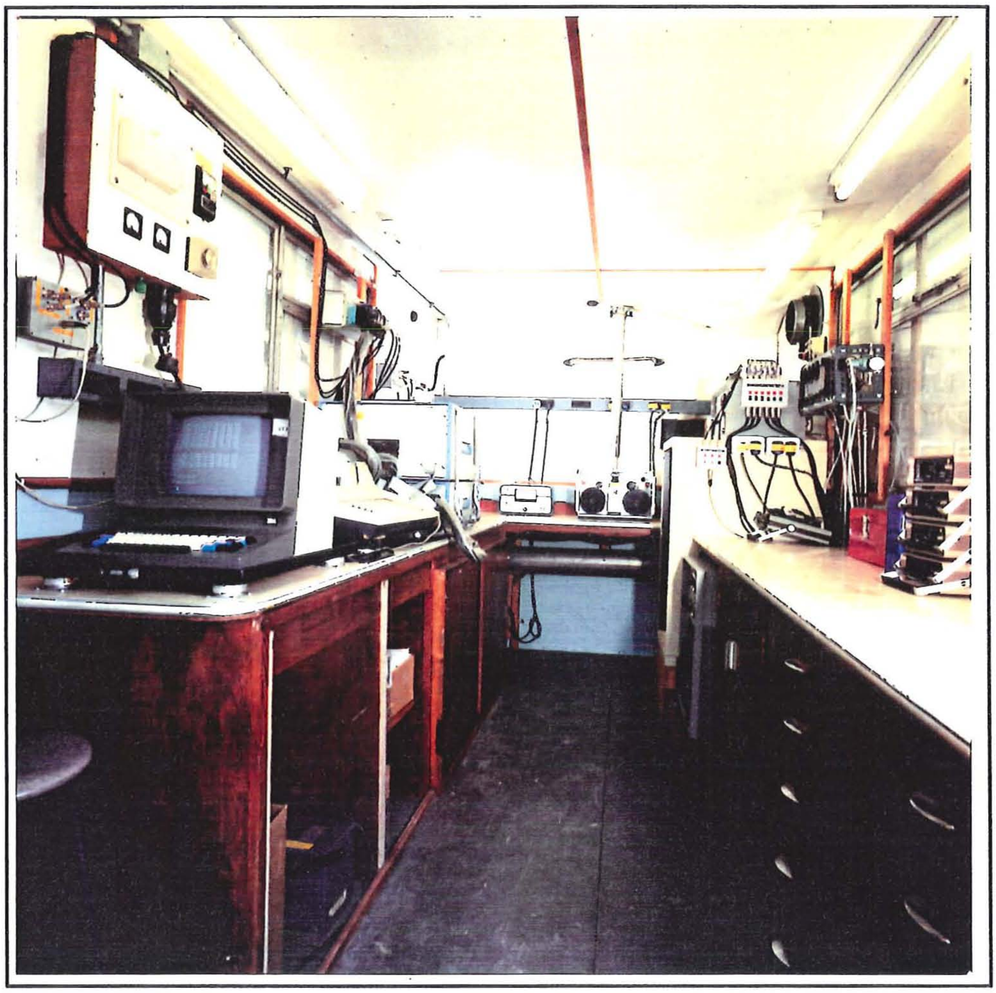


Plate 4.3
The TRL Mobile Laboratory 1, analytical facilities.

Plate 4.4
The TRL mobile laboratory, Mobile Laboratory 2.

Plate 4.5
The TRL Mobile Laboratory 2, analytical facilities.

Table 4.2
Pollutants monitored in TRL's mobile laboratory.

Pollutant	Detection Principle	Sampling Period
Carbon monoxide	Infra-red (Gas correlation)	Continuous
Nitrogen oxides	Chemiluminescence	Continuous
Gaseous hydrocarbons	Flame ionisation	Continuous
Ozone	Ultra-violet absorption	Continuous
Sulphur dioxide	Ultra-violet fluorescence	Continuous
Total suspended particulates	Gravimetric	24 hours 4 hours (peak traffic times)
Smoke	Reflectance	24 hours
Carbonyl compounds	HPLC with UV/visible detector	2-3 hours (peak traffic times)

In order to minimise the potential particulate build-up, sample lines are composed of PTFE tubing (which has an inert and low-friction surface) and in-line particulate filters (Millipore 0.8 μm) are installed within the sample line, between the intake manifold and the instrument back plate (McCrae, 1991). The PTFE tubing and the in-line particulate filters are periodically replaced, with the replacement interval being dependent upon the ambient particulate concentration within the environment under study. The tubing on the instrument side of the in-line filter is usually composed of stainless steel. A schematic of the gas handling system is shown in Figure 4.14.

4.3.2.1 Carbon monoxide (CO)

Ambient carbon monoxide was monitored on a continuous real time basis using a rack mounted, Thermo Electron Instruments, Model 48 infra-red gas correlation analyser. The technique is highly specific and sensitive to CO, although since infra-red absorption is a non-linear measurement technique, the instrument electronics have to transform the basic analyser signal into a linear output via a calibration curve (Thermo Electron, 1982). The instrument has excellent long term stability in terms of zero and span and its internal microcomputer automatically compensates for changes in pressure and temperature.

In gas filter correlation spectroscopy, infra-red radiation is directed sequentially through a rotating gas filter and a bandpass filter into the sample cell. An in-built pump draws sample air into this cell (a multiple pass optical bench) at a flow rate of 1.0 l/min. The infra-red radiation is absorbed by any sample gas within the cell before it exits to a detector via a preamplifier.

The rotating gas filter contains two partitioned gases, nitrogen and carbon monoxide. The high concentration CO gas filter cannot be attenuated further by any CO in the sample cell, therefore producing a reference beam. In contrast, the nitrogen filter is transparent to CO, allowing the infra-red radiation passing through the sample cell to be attenuated by any CO in the sample air. Interferences from other gases within the sample cell are kept at a minimum as these gases absorb both the reference and sample beam equally.

The instrument has ten selectable full-scale ranges from 1 to 1000 ppm, and is an US EPA reference method for CO in the range 0-50 ppm. The equipment has high sensitivity due to the long path length within the sample cell, giving a lower detectable concentration of 0.2 ppm and a precision of +/- 0.1 ppm (Thermo Electron, 1982).

4.3.2.2 Oxides of nitrogen (NO_x)

Nitrogen oxides were monitored continuously using a rack mounted Monitor Labs, Model 8840 chemiluminescence detection device. The technique is based on the chemiluminescence of activated nitrogen dioxide (nitrogen dioxide in an excited atomic state, NO_2^*) produced by the chemical reaction between nitric oxide (NO) and ozone (O_3) (Equation 4.1). The activated species (NO_2^*) rapidly returns to its lower energy state (Equation 4.2), emitting broad-band radiation in the range 500 - 3000 *nm* with a maximum intensity at approximately 1100 *nm* (Monitor Labs, 1982).

Equation 4.1 $NO + O_3 = NO_2^* + O_2$

Equation 4.2 $NO_2^* = NO_2 + hv$

This emitted radiation produces a current in a photomultiplier tube which is directly proportional to the NO concentration in the air sample since one NO molecule is required to produce one NO_2^* species.

The chemiluminescence technique measures only NO within an air sample, and thus the instrument is divided into two channels which contain two complete detection systems. Sample air entering the unit with a flow rate of 500 cm^3/min is split into two streams. In one stream NO is measured directly, but in the other the NO_2 fraction of the air sample has to be reduced to NO by a catalytic converter prior to entry into the reaction chamber so that the total NO_x in the sample can be measured. The NO_2 concentration signal is therefore not measured directly, but has to be derived by electronically subtracting the NO signal from the NO_x signal. This is clearly a possible source of error since the NO_x values may include contributions from the conversion of species such as ammonia, nitro-PAHs, organic nitrates, nitric and nitrous acids to NO.

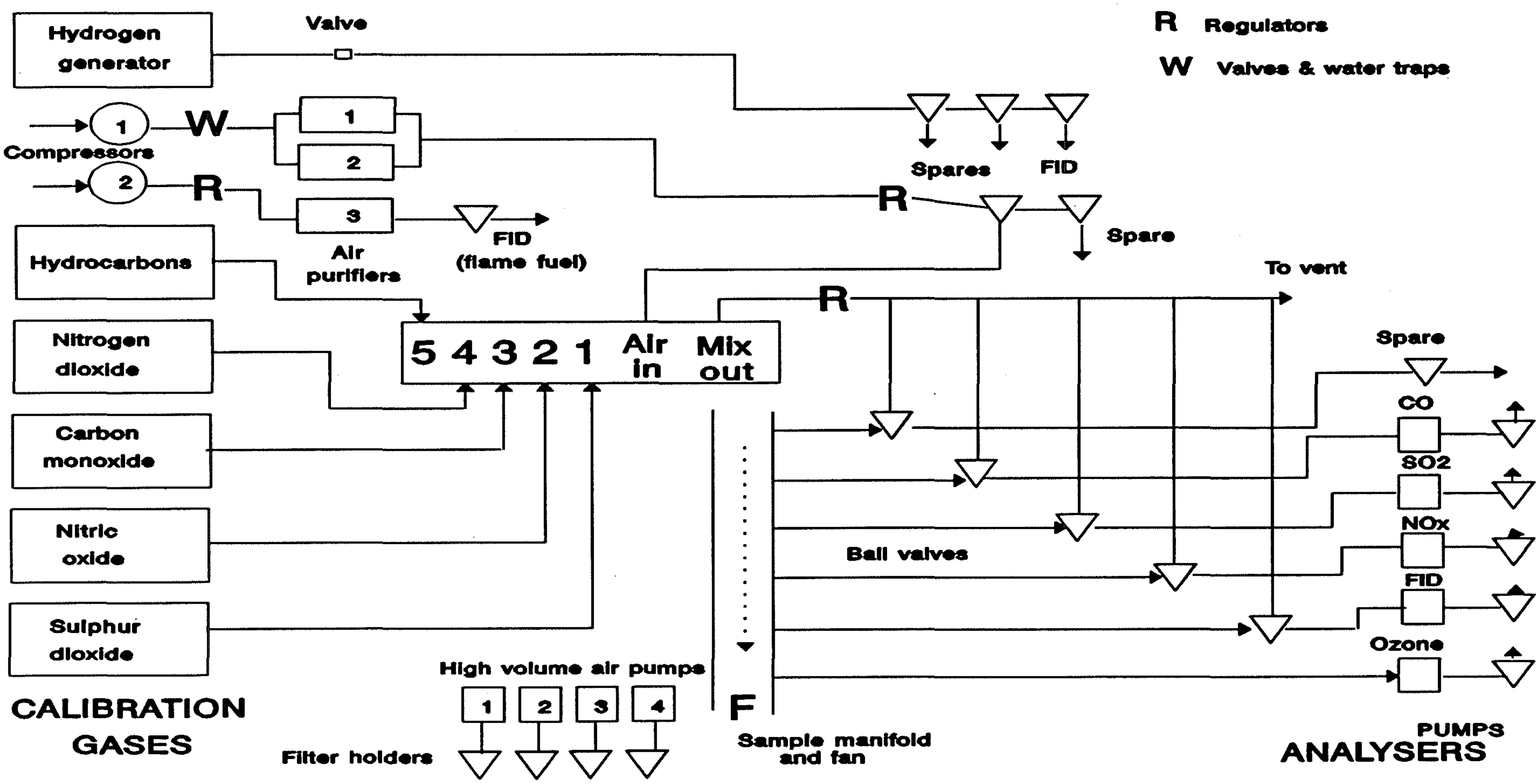


Figure 4.14
Schematic diagram of the TRL mobile laboratory's gas handling network.

The instrument has eight selectable full-scale ranges from 0.05 to 10 ppm, and is an US EPA reference method for NO_2 in the ranges 0-0.5 and 1.0 ppm. It has a minimum detectable concentration of 2.0 ppb, with a rise-and-fall time (the time interval between a step change in input concentration and 95% of final response) of three minutes (Monitor Labs, 1982).

4.3.2.3 Sulphur dioxide (SO_2)

The continuous monitoring of sulphur dioxide was achieved using a rack mounted Monitor Labs, Model 8850 fluorescence analyser. The analyser uses the principle of ultra-violet excitation of SO_2 molecules in the far ultra-violet to produce a fluorescent output proportional to the SO_2 concentration (Monitor Labs, 1984). Sample air is passed into a reaction chamber at a flow rate of 500 cm^3/min, where it is subjected to a beam of mechanically chopped ultra violet (UV) radiation with a narrow wavelength range (190 - 203 *n*m). The resulting fluorescence, between 240 and 420 *n*m, is detected by an optically tuned photomultiplier tube.

The device can operate under a choice of five full-scale ranges from 0.25 to 10.0 ppm, and is an US EPA reference method for SO_2 in the ranges 0 to 0.5 and 1.0 ppm. It has a lower detectable limit of 1.0 ppb with a minimum rise-and-fall time of four minutes (Monitor Labs, 1984).

4.3.2.4 Ozone (O_3)

Ambient ozone was continuously monitored using a Monitor Labs, Model 8810 analyser, whose operation is based on the absorption of UV light by ozone at a wavelength of 254 *n*m. Sample air entering this rack mounted instrument at a flow rate of between 0.5 to 1.0 l/min is routed to the optical chamber directly or via an O_3 scrubber which completely removes all traces of O_3. Photomultiplier tubes are used to monitor the amount of light absorption in the optical chamber. The ratio of the light intensity transmitted through O_3 free air to that transmitted through ambient air (containing O_3) is then expressed as a voltage output which relates to the amount of O_3 present in the sample by the Beer-Lambert Law (Monitor Labs, 1983).

The analyser has three selectable full-scale ranges from 0.5 to 10 ppm, and is an US EPA reference method in the ranges 0 to 0.5 and 1.0 ppm. It has a lower detectable limit of 2.0 ppb and a rise-and-fall time of less than two minutes (Monitor Labs, 1983).

4.3.2.5 Hydrocarbons (HCs)

Gaseous hydrocarbons were monitored using an Analysis Automation Ltd, Model 526, flame ionisation hydrocarbon analyser. This rack mounted device operates continuously, providing outputs for methane, non-methane (reactive) and total hydrocarbons. The value for non-methane hydrocarbons is not measured directly, but is calculated internally by subtracting the methane value from the value for total hydrocarbons. The instrument detects and measures hydrocarbons using the principle of flame ionisation detection. A continuous flow of sample gas with a flow rate of between 10 to 60 cm^3/min is burnt in a polarised hydrogen flame. Compounds containing carbon-hydrogen bonds form ions during combustion, and these ions migrate to a collector electrode when a potential difference is applied between the flame and the electrode. The resulting ion current is proportional to the concentration of hydrocarbons, expressed as methane equivalents, in the gas sample. Although the instrument is called a hydrocarbon analyser, it actually responds to compounds containing carbon-hydrogen bonds, with the result that it really measures total organic compounds (Analysis Automation Ltd, 1986).

For methane analysis, all hydrocarbons other than methane have to be removed from the sample air. This is achieved by periodically switching a scrubber, in the form of an activated carbon pre-column, into the sample stream prior to combustion. In order to prolong the life of the pre-column, the scrubber is backflushed when the instrument is measuring in the total hydrocarbon mode. Breakthrough of the scrubber has been experienced when using very light hydrocarbon mixtures and this is therefore a potential source of error. The respective times the unit spends in the methane and total hydrocarbon modes can be pre-set using internal switches, and were set to four minutes in each mode during this research.

The hydrogen and the pure air supply to the flame of the analyser are both produced within the mobile laboratory. Air generated by a compressor passes through a series of Spirax-Sarco gas and particulate filters and additional water traps before being scrubbed by a Signal AS80 high temperature, catalytic air purifier. In Mobile Laboratory 1, hydrogen was produced by a Milton Roy Mark 4 hydrogen generator, while in Mobile Laboratory 2 it was produced by a STEC Inc Model OPGU-1500A hydrogen generator. Both generators use a version of the solid polymer electrolyte (SPE) water electrolysis method.

The instrument may be operated in seven selectable ranges from 10 to 10,000 ppm and has a lower detectable limit of 0.1 ppm (Analysis Automation Ltd, 1986).

4.3.2.6 Instrument calibration

Prior to and upon completion of each air quality survey, the equipment within the mobile laboratory was carefully checked, and where necessary apparatus was replaced. The gaseous analysers are plumbed into the gas calibration system and through a system of toggle valves either calibration or sample gas can be measured. The sample and calibration pipelines were examined for damage, leaks and possible sources of contamination, and their condition was monitored throughout the survey. The in-line filters to the analysers were replaced and in-line scrubbers and convertors were checked for operating efficiency. The in-line filters were often replaced during the surveys, depending on pollutant concentrations. The gaseous pollutant analysers were calibrated before, during and upon completion of each survey. The analysers require calibration for range linearity, zero and span (a gas concentration of approximately 80% full scale range). During this research, the gaseous analysers were calibrated approximately once a week.

Two Signal Model AS80 catalytic air purifiers connected in series were used to provide pure air for instrument zero adjustment and gas dilution purposes. Air for the purifiers was supplied by a single compressor with an outlet pressure of 2.5 bar. The purifiers oxidise all combustible compounds (including carbon monoxide and methane) to carbon dioxide and water vapour using a high temperature catalyst of platinum coated alumina pellets. Water vapour is subsequently removed using an in-built molecular sieve. Nitrogen oxides are not removed by this process and so the NO_x analyser had to be carefully calibrated to accommodate this background NO_x concentration. This was achieved by setting the zero points on both the NO and NO_x channels with the internal O_3 generator switched off, and then recording the 'new' zero value with the O_3 generator on. These zero offset values were then used to offset the span point voltages.

A number of single concentration certified calibration gases (nitric oxide, nitrogen dioxide, sulphur dioxide, carbon monoxide and a hydrocarbon mixture) were stored in Spectra-seal cylinders within the mobile laboratory. The cylinder gases used during this research project were provided and certified by British Oxygen Company (BOC) to standards set by the US National Institute of Standards and Technology (NIST). These gases were used in conjunction with a five stream Signal gas blender to produce an accurate range of lower concentrations, creating a mixed gas standard which may be delivered to each analyser for calibration purposes. The gas blender operation is based on a constant differential pressure across a given orifice determining a given gas flow, at a set temperature. The flow rates of the five gas streams were set by adjusting the instrument's front mounted dials which regulate the size of the orifice. The dial settings are obtained from calibration graphs supplied by the manufacturer, with fine adjustments made to each channel in order to compensate for the differing specific gravities of the calibration gases.

Calibration information was entered into the computer in order to correct data for span and zero drift. In addition, a logbook was kept at each sample site, to record calibration data, weather and traffic conditions, maintenance and equipment behaviour.

4.3.2.7 Data acquisition

The instruments within the mobile laboratory were linked to a data logger via shielded cables. The voltage output from each of the gaseous analysers and the meteorological instrumentation was recorded every second on an Odessa Engineering DSM 3260 Data Acquisition and Control Unit. A logging command file, which stores details of each instrument, converts the voltage outputs from them to the appropriate units. The data was stored in battery backed up internal memory and also on a solid state data cartridge that provides for failsafe data storage. With this particular setup, the data cartridge can store up to approximately 25 days logging data before information retrieval is required.

Communication to the logger was via a portable personal computer, running a software package called ENVICOM. Fifteen minute averages were calculated and stored on personal disc as an ASCII file before being transferred into spreadsheets for ease of data manipulation, handling and storage. This minimum storage period was selected to accommodate the longest instrument sampling period, which within the mobile laboratory is eight minutes for the hydrocarbon analyser. This instrument monitors in the methane, and subsequently within the total hydrocarbon, mode for four minutes each. In order to identify correlations between selected pollutant concentrations and traffic flows, sampling periods were kept to a minimum. Longer sampling periods would not be so sensitive to fluctuations in traffic volumes.

To facilitate easy data viewing, and to provide an additional data storage facility, hourly average values of each measured parameter were recorded on a printer. In addition, a set of tabulated data was printed at the end of each 24 hour period to display the average concentrations over the 00:00-24:00 hour sampling period.

4.3.4 The monitoring and analysis of carbonyl compounds

The concentrations of selected carbonyl compounds in ambient air were estimated using US EPA Method TO5 (1984). Ambient air was drawn through a midget impinger containing an acidified solution of *2,4*-dinitrophenylhydrazine (henceforth known as DNPH reagent) by a peristaltic pump. Carbonyl compounds present in the sampled air react readily with the DNPH reagent to form stable *2,4*-dinitrophenylhydrazones (henceforth known as DNPH derivatives), the concentrations of which may be determined using reversed phase High Performance Liquid Chromatography (HPLC) with an UV diode array absorption detector. A brief summary of the method is outlined in Sections 4.3.4.1-4.3.4.4.

4.3.4.1 Preparation of reagents and standards

The DNPH reagent was prepared by adding 250 mg of solid *2,4*-dinitrophenylhydrazine to 90 cm^3 of concentrated hydrochloric acid in a clean 500 cm^3 volumetric flask and made up to the mark with double distilled, de-ionised water. After sonification (to dissolve the solid material), approximately 400 cm^3 of the DNPH reagent was transferred to a screw-capped bottle with a teflon-lined cap, to which was added 50 cm^3 of a 70/30 (v/v) hexane/methylene chloride mixture. The capped bottle was then shaken for 15 minutes on a reciprocating shaker before the organic layer was removed using a separating funnel. The DNPH reagent was extracted a further two times before storage of the organic extract in metal can containing 2 inches of granulated charcoal to remove potential organic impurities from its immediate environment. This is particularly important since formaldehyde contamination of the DNPH reagent is a frequently encountered problem. All the glassware utilised during the preparation, storage and sampling stages was carefully washed, rinsed in methanol and oven dried to minimise the risk of contamination.

A portion of the freshly-made DNPH reagent was retained for analysis of background levels of carbonyl compounds. The US EPA Method TO5 suggests that each batch of DNPH reagent should be prepared and purified within 48 hours of sampling, but as this would be a very time-consuming and expensive procedure, reagents were retained for longer periods. The reagent blanks were therefore further monitored by taking a second blank sample at the end of the reagent's sampling lifetime.

The DNPH derivatives, for the preparation of calibration standard solutions, were synthesised from solid *2,4*-dinitrophenylhydrazine and AnalaR aldehydes according to the method outlined by Shriner, Fuson and Curtin (1964). A solution of *2,4*-dinitrophenylhydrazine was prepared by carefully adding concentrated AnalaR sulphuric acid (2 cm^3) to approximately 0.4 g of AnalaR *2,4*-dinitrophenylhydrazine (accurately weighed to 4 decimal places) in a 25 cm^3 Erlenmeyer flask. Double distilled, de-ionised water (3 cm^3) was introduced dropwise to the flask with constant swirling until the solution was complete, and then 10 cm^3 of 99.5% (w/w) AnalaR ethanol was added. A solution of the carbonyl compound was prepared by dissolving 0.5 g (accurately weighed to 4 decimal places) in 20 cm^3 of 99.5% (w/w) AnalaR ethanol. The DNPH derivative was then prepared by adding the fresh solution of *2,4*-dinitrophenylhydrazine to the solution of the carbonyl compound and allowing the resulting mixture to stand at room temperature. Crystallisation of the *2,4*-dinitrophenylhydrazone usually occurred within 5-15 minutes, but if no precipitate was formed the mixture was allowed to stand overnight.

The derivative was filtered under pressure and then recrystallised on a steam bath with 30 cm^3 of AnalaR ethanol. The hot solution was filtered through a fluted filter and allowed to stand at room temperature until crystallisation was complete (usually overnight). The purity of each derivative was checked using melting point determinations and chromatographic techniques.

Calibration standards were prepared in AnalaR methanol from the synthesised DNPH derivatives. Individual stock solutions with derivative concentrations of approximately 100 mg/l were prepared by dissolving 10 mg (accurately weighed to 4 decimal places) of solid derivative in 100 cm^3 of methanol. These individual stock solutions were used to make individual and mixed calibration standards at concentrations of 0.1-50 mg/l.

4.3.4.2 Sampling, preparation and storage of carbonyl compounds

The apparatus used for the sampling of ambient carbonyl compounds is illustrated in Figure 4.15. Two 25 cm^3 jet inlet midget impingers were each loaded with 10 cm^3 of DNPH reagent and 10 cm^3 of *iso*-octane. The loaded impingers were placed inside an insulated ice bath and connected in series with a third midget impinger containing silica gel (for drying purposes). Ambient air was drawn through the apparatus at a flow rate of approximately 0.5 l/min by a Masterflex Model 7554-50 peristaltic pump and the total sampled air volume was recorded by a gas meter. The sampler was allowed to operate for the desired interval, typically 2-3 hours, with a maximum sampled volume of 80 l. It is essential that at least 2-3 cm^3 of *iso*-octane remains in the first impinger (Impinger A) at the end of the sampling period, for extraction purposes. During the four air quality surveys, the carbonyl sampler was situated on the floor of the mobile laboratory and usually operated in peak morning and afternoon traffic periods.

Immediately after sampling the impingers were removed from the ice bath and the contents of Impinger A were carefully emptied into a 50 cm^3 glass vial with a teflon-lined screw cap. Impinger A was then rinsed with the contents of Impinger B (the backup impinger); the two impingers were further rinsed with approximately 1 cm^3 of *iso*-octane, and both the rinse solutions were added to the glass vial. The vial was capped, stored in a metal can containing 1-2 inches of granulated charcoal and refrigerated until extraction.

The DNPH derivatives need to be recovered from the sampled solutions within a few days of sampling in order to avoid possible contamination of the solution. The vials were shaken in a horizontal position for 10-15 minutes on a reciprocating shaker before the contents were allowed to settle. The *iso*-octane layer was removed using a disposable pipette and placed into a second clean screw capped glass vial. The remaining aqueous layer was further extracted (as described above) with 10 cm^3 of 70/30 (v/v) hexane/methylene chloride before the organic layer was removed and combined with the *iso*-octane extract. The glass vial containing the combined extracts was then placed in a water bath at approximately 40°C and concentrated to dryness under a stream of pure nitrogen. The vial was removed from the nitrogen stream when the sample just reached dryness and methanol (2 cm^3) was added to the vial to dissolve the derivatives. Finally, the vial was tightly capped and stored under refrigeration until analysis.

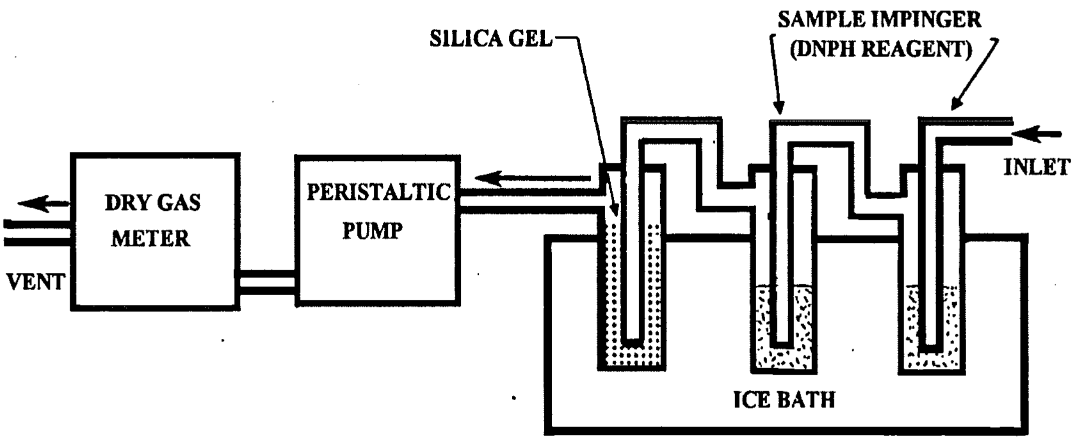


Figure 4.15
Sampling system for airborne carbonyl compounds.

4.3.4.3 Description of the HPLC system

The technique of HPLC was originally derived from the application of the theories and instrumentation developed for gas chromatography to liquid chromatography. In HPLC a solid adsorbent (stationary phase), typically alumina or silica, is packed into a column and eluted with a suitable liquid (mobile phase). The small size of the adsorbent particles often creates a considerable resistance to solvent flow, and so the mobile phase is pumped through the column at a controlled flow rate. The mixture of solutes to be separated is introduced (injected) at the head of the column and is washed through the column by the mobile phase. A solute that is weakly adsorbed to the stationary phase will travel down the column faster and be eluted before a solute that is more strongly attracted to the stationary phase. It therefore becomes possible to separate a mixture of solutes if there are differences in their attraction to the adsorbent stationary phase. If the stationary phase is more polar than the mobile phase the technique is referred to as *normal phase chromatography*, whereas if the stationary phase is less polar than the mobile phase the technique is called *reverse phase chromatography*.

An HPLC system requires a supply of mobile phase, a high pressure pump, a column packed with stationary phase, an injection unit, an in-line detector and a method of displaying the detector signal. The HPLC system utilised in this research is outlined in Table 4.3 and displayed in Plate 4.6.

Table 4.3
HPLC assembly for the determination of DNPH derivatives.

System unit	Description of system unit	Specifications
Columns	Guard: 5 μm ODS[1]	1 cm x 4.6 mm ID[2]
	Chromatography: LDC Analytical Spherisorb 5 μm ODS[1]	25 cm x 4.6 mm ID[2]
Pump	LDC Analytical Constametric Metering Pump Model III	Flow rate 1 cm^3/min
Detector	UV absorption Spectromonitor 5000 Photo Diode Array Detector	Wavelength (λ) 360 *nm*
Data Processor	LA 500 Chromatography Integrator	
Chart Recorder	Tekman Potentiometric Pen Chart Recorder TE220 Series	2 mV full scale sensitivity Chart speed 10 mm/min

[1] Octa-decyl silane
[2] Internal diameter

The HPLC method utilised for the detection and determination of the DNPH derivatives is outlined in Table 4.4. The method requires the use of a filtered 80/20 (v/v) methanol (HPLC grade)/reagent water mobile phase. Filtration was performed using a 5.0 μm polycarbonate membrane filter (Nuclepore Corporation, 47 mm) held in a Millipore suction filtration apparatus.

4.3.4.4 Calibration and operation of the HPLC system

Prior to analysis, the filtered mobile phase was placed in the mobile phase reservoir and degassed for 15-20 minutes using pure nitrogen gas. The degassed mobile phase was allowed to pump through the system for at least one hour at a flow rate of 1 cm^3/min, during which time the detector was switched on to warm up. The system was calibrated once a stable baseline had been achieved.

The analysis procedure was the same for each standard/sample. An aliquot of the sample was loaded into a 20 μl sample loop via a clean 100 μl HPLC injection syringe. The sample

Plate 4.6
HPLC system.

Table 4.4
HPLC method for the detection and determination of DNPH derivatives.

Application	Parameter	Parameter description	Specification
Data collection	Run time	Specifies run time.	6400 secs
	Peak width	Peak width is half the height of the narrowest peak to be analysed. 5 data points are collected within peak width time.	5.0 secs
	Input voltage	Specifies input analogue voltage.	10000 mV
Peak detection	Start time End time	Specifies start and end time for peak detection.	0 6400 secs
	Sensitivity	Sensitivity is the difference in 2 successive data points equal to or greater than the specified value.	5
	Minimum baseline time	Specifies minimum time for section of data containing no peaks before it is accepted as baseline.	3.0 secs
	Peak end slope	Difference between 2 successive data points equal to or less than this value - indicates end of peak.	1
	Minimum width	Test to allow or reject a peak (removal of background noise).	1.0 secs
	Minimum height	Test to allow or reject a peak (removal of background noise).	100
	Maximum height	Test to allow or reject a peak (rejection of solvent front).	10000000
	Area total	% of integrated area.	100 %

injection was made simultaneously with the activation of the data system and the chart recorder. The injection valve was returned to the 'load' position after the sample had been eluted from the loop (at least 1 minute) and both the syringe and valve were thoroughly flushed with methanol prior to the next sample analysis. The data acquisition was terminated after the last component of interest had eluted from the column and the peak areas were calculated by the integrator. Further sample analysis were performed as described above once the baseline becomes stable. A series of calibration standards spanning the concentration range of interest were injected into the system in order to document linear response, as illustrated in Figure 4.16.

4.3.5 The monitoring and analysis of airborne particulate matter

The most common method of sampling airborne particulates is to draw a sample of contaminated air through a filter medium. The filter media are generally required to have a low resistance to flow and a high collection efficiency. The collection period has to be carefully selected in order to prevent filter clogging, and is a function of ambient concentration, pump

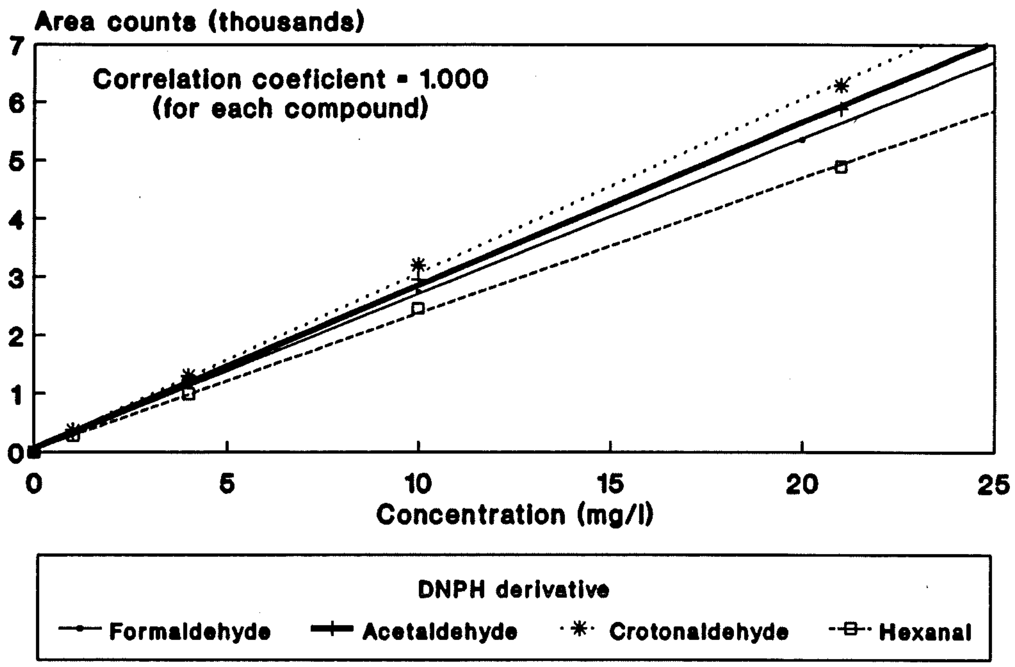


Figure 4.16
Typical plots of derivative concentration vs area counts for carbonyl compounds.

flow rate, filter area and collection efficiency (McCrae, 1991). The total volume of sampled air may be determined using flow meters or rotameters.

Flow meters allow a direct reading of the sampled air volume and may be accurately calibrated using certified wet type gas flow meters. In contrast, rotameters enable a direct reading of the sample flow rate, therefore allowing the total sampled air volume to be calculated using the collection period together with the average of the initial and final flow rates. The use of rotameters in this way assumes a uniform decrease in flow rate as the filter loading increases, an assumption which is probably unrealistic at roadside locations, particularly in wet weather conditions. Flow meters are thus generally regarded as more reliable and accurate estimators of sample volume than rotameters.

4.3.5.1 Smoke

The British suspended particulate or 8-port smoke sampler has been extensively used in the United Kingdom National Survey of Air Pollution and the method is the subject of a British Standard (BS 1747:Part 2, 1964). The device may also be used as a means of simultaneously measuring ambient sulphur dioxide concentrations.

The 8-port smoke sampler was situated inside the TRL mobile laboratory and was connected to the inlet via a short length of plastic tubing. The inlet was positioned at a height of approximately 1.5 m above ground and consisted of an inverted funnel which has been shown to prevent particles with an aerodynamic diameter greater than 10 μm from entering the system. Ambient air was drawn through the funnel by a low volume suction pump (Charles Austin Ltd, 1.5 l/min), and then through a valve changeover device, a bubbler and filter assembly before the total volume of air sampled was recorded by a gas meter. The sampling period was controlled by a timing device which allowed automatic sampling for 8 periods of 3 or 24 hours. For this research project, sampling periods of 24 hours were selected for use at all sites.

After sampling, the filter papers were removed and the blackness of the smoke stain was assessed by means of a photoelectric reflectometer (Evans Electroselenium Ltd, (EEL)). The smoke concentration in the ambient air was calculated by means of a calibration graph which relates the stain density to the weight of the smoke per unit area of stain (so-called 'standard smoke'). The calibration graph used was the British Standards Smoke Calibration curve (BS 1747:Part 2, 1964), and not the Organisation for Economic Cooperation and Development (OECD) calibration curve of 1964. In order to compare and convert BSI to OECD smoke measurements, the following relationship may be used:

$$0.85 \times C_{OECD} = C_{BSI}$$

4.3.5.2 Total suspended particulates (TSP)

Total suspended particulates were collected on 60 mm diameter glass fibre (Whatman GF/A) filter papers using Rotheroe and Mitchell medium and high volume sampling pumps controlled by electric timers. Whatman GF/A filters have a collection efficiency of greater than 99% for particles of between 0.1 and 1.0 μm (Hwang, 1972), although care is necessary when handling glass fibre filters since fibres readily break away from the filter matrix (Harrison, 1986). The Rotheroe and Mitchell L30 and L100 sampling pumps had operational flow rates of approximately 25-30 and 90-95 l/min respectively. The L30 pumps were used to allow a sampling period of 24 hours, while the L100 pumps were used for periods of 4 hours covering the morning and afternoon rush hours.

The filter papers were initially equilibrated to a constant weight in a controlled temperature and humidity chamber before being weighed on an electronic balance. On-site, the weighed filter papers were clamped into open-faced filter holders and suspended outside the mobile laboratory via a protective particulate collection canopy. This canopy was suspended between the caravan and the cab at a height of 1.5 m above ground in Mobile Laboratory 1 to enable sampling in

Plate 4.7
Filter holder canopy, displaying open faced filters (Mobile Laboratory 1).

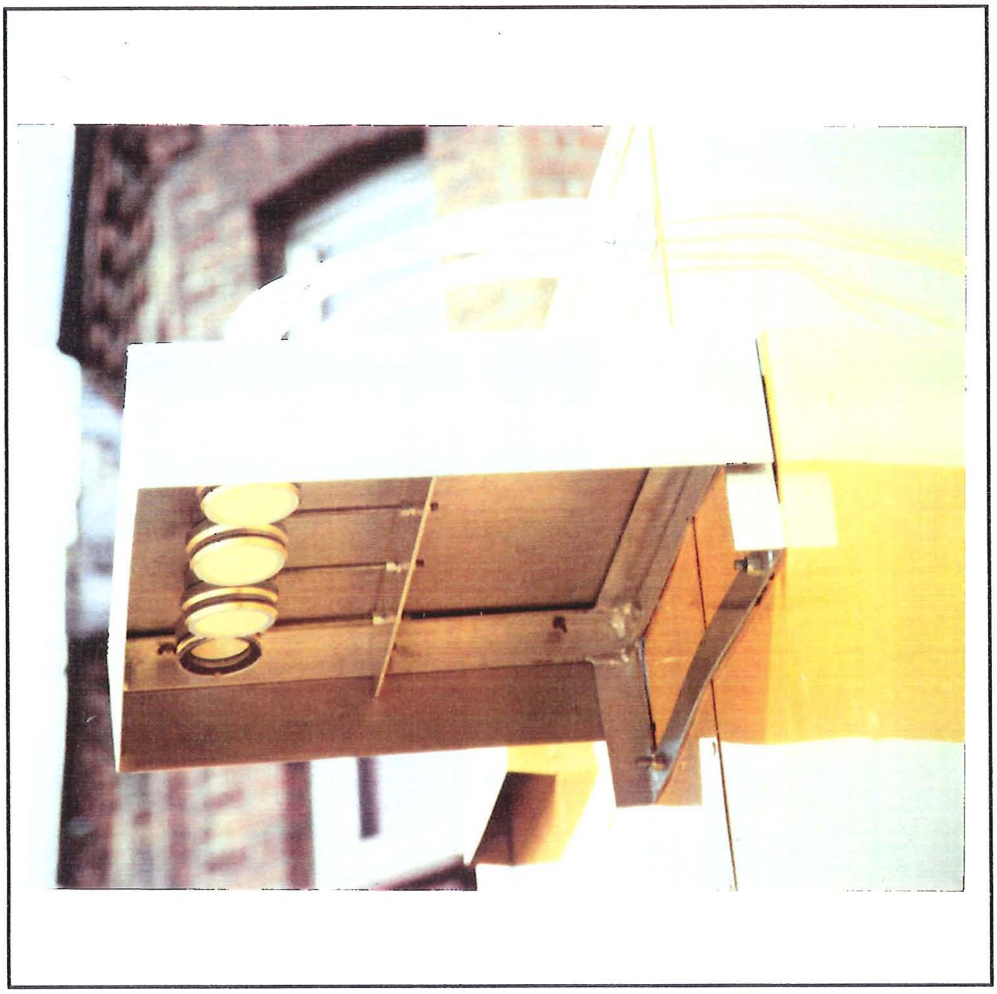


Plate 4.8
Filter holder canopy, displaying open faced filters (Mobile Laboratory 2).

the region of an adult's breathing zone, as shown in Plate 4.7. Unfortunately, the canopy had to be raised above the cab to a height of 3 m in Mobile Laboratory 2, as shown in Plate 4.8. After sampling, the filters were again dried in the environmental chamber and the gain in weight (due to the particulates) was measured.

4.3.6 Meteorological data

The TRL mobile laboratory is equipped to monitor certain local meterological parameters, including wind speed and direction, relative humidity and air temperature. This facility was only available for use at the Wood Green sites, and so additional meteorological information was obtained from the meteorological office weather station closest to the study locations.

At the mobile laboratory, wind direction is monitored using a Vector Instruments, Porton Model W200P Windvane, mounted on a mast 4.5 m above ground level. For calibration purposes, the axis of the windvane is orientated to the north at each site. The windvane is connected to a shaft which upon rotation operates a surrounding set of reed switches which select a voltage output proportional to the wind direction from a potentiometric chain of resistors. The instrument is accurate to 2° in steady winds over 5 m/s.

Wind speed is measured at the mobile laboratory by a Vector Instruments, Porton Anemometer mounted adjacent to the windvane. The instrument operates satisfactorily for wind speeds in a range of between 25 cm/s and 54.4 m/s, and has a response time of 1 second at a wind speed of 5 m/s.

Relative humidity and air temperature are monitored using a Skye Instruments Ltd, Model SKH 2013 Humidity/Temperature probe mounted on the side of the mobile laboratory at a height of 3 m above ground level. Relative humidity may be defined as the relative measure of the amount of moisture in the air to the amount required to saturate the air at the same temperature. The relative humidity probe operates by calculating electronically the capacitance of a metal plate capacitor with a permeable top plate and dielectric. The top plate consists of a very thin evaporated layer of stretched and cracked chromium, allowing the dielectric to absorb water according to the relative humidity of the air. Direct water penetration into the dielectric is prevented by the small width of the cracks in the chromium (100 *n*m or less) (Skye Instruments Ltd, 1992).

4.3.7 Traffic flow characteristics

Traffic volumes were monitored on a continuous basis at both the Ealing and Wood Green locations through the use of temporary road surface mounted pressure loops. At both the Ealing sites, directional axle numbers were counted by the London Research Centre, while TRL performed the counts at Site WG-R. Haringey Council performed the traffic counts at Site WG-C.

Traffic classification surveys were performed at sites E-C, E-R and WG-C through manual counting. The road vehicles were divided into 8 classes; petrol/diesel cars, vans, motorbikes/mopeds, dustcarts, buses/coaches, heavy goods vehicles (HGV), light-duty lorries and milk floats. The vehicles were counted over 3 or 4 days at each site, with a daily monitoring period of approximately 12 hours (0600-1800). It is recognised that these surveys provide only an estimation of the proportion of vehicles in each class at each site.

4.4 The monitoring of public attitudes to road vehicle derived pollution

The research work to develop a questionnaire that could measure public nuisance from road vehicle pollutants was divided into several stages. The aims of the study were closely defined (see Chapter 1), and the previous literature relating to this work was studied (see Chapters 2 & 3). The subsequent stages of the research are described in Sections 4.4.1-4.4.2.

4.4.1 Familiarisation with questionnaire design and interview techniques

Familiarisation with social survey techniques and methodology was achieved through several methods. The initial literature surveys and background reading (*eg* Payne (1951); Youngman (1978); Moser and Kalton (1971); Rossi, Wright & Anderson (1983); Bradburn *et al* (1979); Oppenheim (1966); Reynolds (1990)) provided a solid base upon which more specialised knowledge could be built. An understanding of the methods and techniques utilised in question formulation, questionnaire design and interviewing was obtained by attending specialised training courses organised by the Survey Research Centre (Survey Research Centre, 1990). This methodological knowledge was further supplemented and extended through meetings and discussions with other social researchers from the government, academia and market research organisations.

4.4.2 Questionnaire design and development

A questionnaire is a highly structured data collection technique where each respondent is asked a similar set of questions. Questionnaires are the most widely used method of collecting survey data, mainly because they provide an extremely efficient way of creating a variable by case matrix for large samples (de Vaus, 1986). They are usually constructed in several stages; the information to be collected is defined; the questions are devised, written and organised into a meaningful order and format before the whole questionnaire is revised, evaluated and rewritten. This procedure is repeated until a satisfactory text and layout is created. The flowchart shown in Figure 4.17 summarises the various stages of the development of a questionnaire to monitor public attitudes to vehicle-derived pollution.

The phrasing of questions is one of the most important aspects of questionnaire design. The literature pertaining to social survey techniques contains a vast number of guidelines for question wording, including suggestions about language, length, format (open or closed; direct or indirect), bias, clarity, saliency, detail and tone. The reader is referred to the literature detailed in Section 4.4.1 for an in-depth analysis of generic question wording. With these guidelines and the survey objectives in mind, a large number of draft questions were prepared, tested and revised. This stage of the research overlapped with the next stage which was the preparation of draft questionnaires.

As with question phrasing, there is a large body of literature pertaining to questionnaire construction and the reader is again referred to the literature outlined in Section 4.4.1 for further reading. Draft questionnaires were prepared for use with three distinct categories of respondent - pedestrians, householders and business people. Specific questionnaires were designed for each target group to take into account factors such as the interview location, the (assumed) special interests of each group and the time available for the interview. To allow the responses of the different target groups to be compared, each questionnaire contained a number of common questions. A brief explanation of why each question was included on the questionnaires is presented with the survey results in Chapter 5.

The questionnaires utilized both multiple-choice (fully structured) and free-response (open-ended) questions. In a multiple-choice situation, the interviewer reads out the question and offers the respondent a choice of reply from a specific set of possible answers, while in an open-ended situation, the interviewer reads out the question and the respondent formulates their own reply. Both these situations have some structure, as opposed to a free situation where the interviewer formulates his/her own questions and the respondent formulates his/her own replies. The use of multiple-choice questions allows a fully structured exchange between interviewer and respondent, permitting the collected data to be readily tabulated. Multiple-choice questions are also used to filter respondents before asking an open-ended question. Open-ended questions are more difficult to interpret than multiple-choice questions, since a wider variety of responses

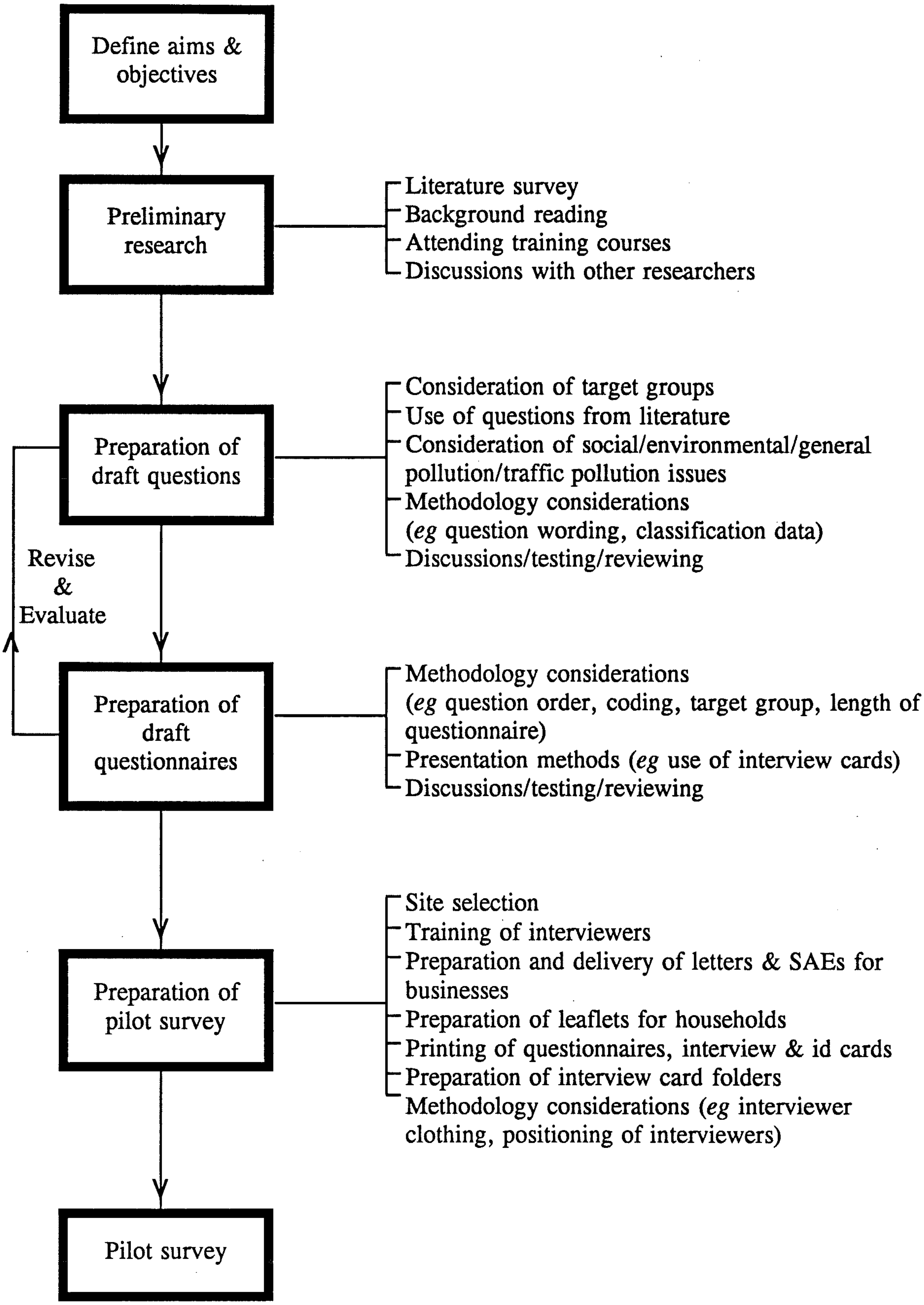


Figure 4.17
Summary flowchart outlining the development stages of a questionnaire to monitor public attitudes to vehicle-derived pollution.

are possible. They thus tend to be used for exploratory purposes *eg* discovering what sorts of environmental problems are experienced by people.

The use of multiple-choice questions introduces the possibility of so-called 'order effects'. A selection of interview cards listing the various alternative answers to a particular multiple-choice question were used as visual aids. When people are shown a card listing a variety of possible answers to a multiple-choice question, there is a tendency to select answers at the extreme positions of the list rather than at the middle, and also an inclination to favour those answers at the top of the list over those at the bottom. This phenomenon is termed an order effect, and in an attempt to cancel the effects of position, four types of pilot questionnaire (and hence four types of interview card) were designed for each respondent group (types A, B, C and D), presenting the answer statements in different orders. To illustrate this strategy, cards A-D for question 1 of the pilot pedestrian questionnaire are shown in Figure 4.18. Each possible answer *eg* housing, is situated:

- near the top of the list (Card A);
- near the bottom of the list (Card B);
- upper centre of the list (Card D);
- lower centre of the list (Card C).

Any order effects would hopefully be cancelled out by using this strategy together with approximately equal numbers of questionnaires A-D. Classification data, such as gender, age, and occupational class, were collected so that the responses of specific groups to a particular question or set of questions could be compared. The interviewees' responses were coded to allow the data to be stored, retrieved and analysed by computer.

As the pilot survey progressed, it became apparent that the majority of business people did not have sufficient free time available to answer the fairly lengthy business questionnaire. Therefore, a self-completion postal questionnaire was designed specifically for businesses in an attempt to improve the response rate. An example of this 'Ticklist', together with examples of questionnaires for the three target groups and a set of interview cards, are shown in Appendix A.

On completion of the pilot survey, the methodology was evaluated, resulting in the social survey techniques being improved and modified. This updated methodology was used in the follow-up survey at Wood Green, and in the five subsequent surveys. The modifications to the three types of questionnaire are outlined and explained in the relevant parts of Chapter 5.

Card A	Card B
Unemployment 1	Education 8
Housing 2	Rising prices 9
Health/social services 3	Rising population 10
Law and order 4	Local environment 6
Old age pensions 5	Global environment 7
Local environment 6	Law and order 4
Global environment 7	Old age pensions 5
Education 8	Unemployment 1
Rising prices 9	Housing 2
Rising population 10	Health/social services 3
Card C	**Card D**
Law and order 4	Local environment 6
Global environment 7	Old age pensions 5
Education 8	Rising prices 9
Unemployment 1	Housing 2
Rising population 10	Education 8
Rising prices 9	Health/social services 3
Housing 2	Rising population 10
Health/social services 3	Law and order 4
Local environment 6	Unemployment 1
Old age pensions 5	Global environment 7

Figure 4.18
Interview cards A-D for pedestrian question 1 (pilot survey).

Chapter 5
Surveys of Traffic Nuisance in Residential and Commercial Areas

5.1 Introduction

In this Chapter, the main results from the social surveys of traffic nuisance in residential and commercial areas are presented and interpreted. The data from the pilot survey is usually presented at the beginning of each Section, followed by the information collected during the follow-up surveys. A brief explanation of why each question was included on the questionnaires is provided, and where necessary, an explanation of the modification(s) made to a particular question for the follow-up surveys is included. In addition, a summary of the social survey findings is presented in Section 5.13.

5.2 Sampling procedure

The sampling procedure utilised during each survey depended upon the type of respondent under consideration. A different sampling regime was designed for each respondent group to take into account factors such as the interview location, the time required for the interview and respondent availability.

Potential household respondents were selected on the basis of the proximity of their home to the location of the air pollution monitoring equipment. Residences within two or three streets of the monitoring equipment were usually included in the study area, depending on their geography. At the Ealing and Wood Green locations, a letter was sent to each household in the selected study area introducing the survey and asking for the householders' assistance in its completion. The letter was designed to prepare the householder(s) for a visit from a researcher and to encourage their participation, thereby improving the response rate. The letter <u>did not detail the aims of the study or include any information that might prejudice the respondent's views</u>. The text of the letter sent to household respondents is shown in Figure 5.1. The households were visited by a researcher within a few days of the letter's despatch and an interview was requested if the householder was at home. Households were not revisited if the respondent declined to be interviewed, but were (usually) revisited if the researcher was unable to obtain a reply.

Surveys at the Birmingham, Cardiff, Coventry, Edinburgh and Sheffield locations were conducted by Public Attitude Surveys Ltd (PAS) using the questionnaires and sampling procedure utilised at Ealing and Wood Green. However, during these surveys, letters were not sent to the householders in advance of the researcher's visit since PAS had a pre-set quota of

Dear Resident(s),

1992 Urban Household Survey

The Urban Research Centre is carrying out a large urban survey in the Wood Green area. We need your help to make this project successful.

Urban planning is a complicated task. The needs of householders, pedestrians, business people and road users must be considered. To help us with with this task, we need to obtain information from householders living in urban areas. Everybody's opinion is important.

We are hoping to carry out an interview with every household in this area. Within the next month you will be contacted by an interviewer from The Urban Research Centre. Any information given to the interviewer will be treated in the strictest confidence and will not be released to anyone in a way which would allow it to be identified with your name and address.

It is important to the success of this project that everyone chosen takes part. Your help will be very much appreciated.

Yours faithfully

I D Williams

Figure 5.1
Text of letter sent to Wood Green Households prior to interview.

75 interviews to perform at each location.

Business people were selected for interview by a similar process to that outlined for householders. A letter (similar to that for householders) was sent to businesses in the vicinity of all the commercial centres under study. As described in Section 4.4.2, it became necessary to utilise a self-completion questionnaire during the business surveys to improve the response rate. The questionnaire and a pre-paid return envelope were therefore also sent to the potential respondents together with the letter of introduction. The completed questionnaires were usually returned within a month of the initial contact.

Pedestrian respondents were interviewed at specific locations within the selected commercial and residential areas. The interview locations were determined by factors such as the number of pedestrians, restriction of pedestrian movement and access to shops, roads *etc*, availability of seating (for elderly respondents) and interviewer safety and shelter. No particular instructions were given regarding interviewee selection. The pedestrians were approached at random and an interview was requested. It is obviously desirable to obtain a sample population which is representative of the selected community, but this is particularly difficult in a busy shopping area where potential respondents are often in a hurry, carrying shopping and/or supervising children.

The number of interviews conducted at each location and a breakdown by respondent type is shown in Table 5.1. The response rates of business-people to the business questionnaire are displayed in Table 5.2, and vary from 23.1% at Ealing to 56.7% at Sheffield, with an overall average of 38%. These response rates are high for this type of survey, and suggest that the strategy of using self-completion postal questionnaires for the business respondents was very successful.

Table 5.1
Number of interviews at each location.

Location	Respondent type			Total
	Business	Household	Pedestrian	
Ealing - pilot survey	42	44	209	295
Birmingham	44	73	150	267
Cardiff	59	80	150	289
Coventry	81	79	150	310
Edinburgh	60	78	151	289
Sheffield	85	83	153	321
Wood Green	52	47	30	129
Overall	423	484	993	**1900**

5.3 Classification data

The classification data includes details such as gender, age and occupational class grouping. This information is collected so that the responses of specific groups to a particular question or set of questions can be compared. The classification data is presented here before the survey data to highlight any minor biases incurred during the sampling.

Table 5.2
Response rates to the business questionnaire.

Location of sampling site	Number of businesses contacted[1]/ questionnaires distributed[2]	Number of interviews	Response rate (%)
Ealing[1]	182	42	23.1
Birmingham[2]	150	44	29.3
Cardiff[2]	150	59	39.3
Coventry[2]	150	81	54.0
Edinburgh[2]	150	60	40.0
Sheffield[2]	150	85	56.7
Wood Green[1]	180	52	28.9
Overall	1112	423	38.0

As described in Section 4.4, the pilot questionnaires were divided into 5 types and Table 5.3 shows the percentage of each type of questionnaire used in the survey for each target group.

Table 5.3
Percentage responses to questionnaire types used in the pilot survey.

Questionnaire type	Pilot survey responses (%)		
	Business	Household	Pedestrian
Ticklist	88.1	Not applicable	Not applicable
Type A	2.4	22.7	38.3
Type B	7.1	22.7	26.8
Type C	2.4	27.3	20.6
Type D	0.0	27.3	14.3

The high percentage of ticklist respondents to the business questionnaire illustrates the difficulties of persuading business people to give up valuable time for this sort of survey. Ideally, the household and pedestrian surveys should have included equal numbers of Types A-D, and thus the data shown in Table 5.3 indicates that an excess of Type A questionnaires were used at the expense of Type D questionnaires in the pedestrian survey. However, analysis of the pedestrian questionnaire results indicates that there were no significant differences between the responses to the four questionnaire types. This suggests that no order effects were observed and therefore the greater use of Type A questionnaires compared to the other three types probably did not influence the overall results. As a result of the absence of order effects in the pedestrian pilot survey, only a single type of questionnaire was used in the subsequent surveys.

A breakdown of the respondents by gender is shown in Table 5.4, together with data for comparison from the 1981 or 1991 National Census for the local wards. The figures show that women are statistically slightly over-represented in the household surveys at Ealing, Coventry, Sheffield and Wood Green, and under-represented at Birmingham and Cardiff. The former is not surprising, since women are possibly more likely to be at home during normal daytime working hours than men. The data also suggest that men are slightly over-represented in the pedestrian surveys at commercial sites. Men may possibly be more 'available' to answer questionnaires than women in commercial areas as they are less likely to be escorting children or burdened with shopping. The overall figures indicate that the sample populations at all locations were broadly representative of the total populations in terms of gender.

A breakdown of the pilot survey respondents by age is shown in Table 5.5. The Ealing pedestrian respondents were selected at random and there is a good correlation between the ages of pedestrian respondents who are 25+ and the age data for the 1991 Ealing census. It was not intended to question people under the age of 18, but some people in this group were sampled. The 25-44 age group appears to be over-represented in the business and household surveys, as does the 65+ age group in the household survey, but these figures are probably not directly comparable with the 1991 census data since it is usually older people who run businesses and own houses. Unfortunately, no specific data (*ie* the ages and gender of home owners in Ealing) is available to allow a more accurate comparision of age structure to be performed.

The age data for the other six locations is illustrated in Tables 5.6 - 5.11, and follow the same trend as the pilot survey figures. Business respondents in the 25-44 age group, householders in the 65+ age group and pedestrians in the 18-24 age group may appear over-represented when compared to the census data for each area, but are probably representative of the specific respondent group considered.

Table 5.4
Respondent classification by gender at each location.

Gender	Statistical Breakdown (%)						
	Business	Household	Pedestrian		Overall	Borough/ city	Residential ward
			C*	R+			
Ealing Pilot Survey							
Female	59.5	59.1	46.7	-	50.2	51.5[1]	52.2[1]
Male	40.5	40.9	53.6	-	49.8	48.5[1]	47.8[1]
Birmingham Survey							
Female	47.7	48.0	49.3	50.7	49.1	51.6[2]	52.4[2]
Male	52.3	52.0	50.7	49.3	50.9	48.4[2]	47.6[2]
Cardiff Survey							
Female	50.9	47.5	46.7	54.7	51.3	51.7[3]	50.1[3]
Male	49.1	52.5	53.3	45.3	48.7	48.3[3]	49.9[3]
Coventry Survey							
Female	46.9	57.0	54.7	52.0	52.5	51.2[4]	50.2[4]
Male	53.1	43.0	45.3	48.0	47.5	48.8[4]	49.8[4]
Edinburgh Survey							
Female	47.5	50.0	49.3	52.6	50.0	53.0[5]	51.8[5]
Male	52.5	50.0	50.7	47.4	50.0	47.0[5]	48.2[5]
Sheffield Survey							
Female	57.6	55.4	52.0	54.0	54.8	51.7[6]	51.4[6]
Male	42.4	44.6	48.0	46.0	45.2	48.3[6]	48.6[6]
Wood Green Survey							
Female	45.1	57.4	43.3	-	49.6	51.7[7]	52.8[7]
Male	54.9	42.6	56.7	-	50.4	48.3[7]	47.2[7]

* Commercial site   + Residential site
[1] 1991 Census of Population for Ealing (1993) (Hanger Lane Ward shown).
[2] 1991 Census of Population for Birmingham (1993) (Selly Oak Ward shown).
[3] 1991 Census of Polulation for Cardiff (1993) (Mackintosh and Park Wards shown).
[4] 1991 Census of Population for Coventry (1993) (St Michael's Ward shown).
[5] 1981 Census of Population for Edinburgh (1983) (Telford Ward shown).
[6] 1991 Census of Population for Sheffield (1993) (Burngreave Ward shown).
[7] 1991 Census of Population for Wood Green (1993) (Noel Park Ward Shown).

Table 5.5
Respondent classification by age at Ealing (%).

Age group	Business	Household	Pedestrian	Ealing Borough[1]	Hanger Lane ward[1]
< 18	0.0	0.0	5.8	22.2	16.6
18 - 24	9.5	4.5	29.3	11.4	11.0
25 - 44	64.3	47.7	36.1	33.6	33.3
45 - 64	19.1	20.5	16.3	19.7	21.9
> 65	7.1	27.3	12.5	13.1	17.2

[1] 1991 Census of Population for Ealing (1993)

Table 5.6
Respondent classification by age at Birmingham (%).

Age group	Business	Household	Pedestrian		Commercial ward[2] (Sparkbrook)	Residential ward[2] (Selly Oak)
			C*	R+		
< 18	0.0	0.0	0.0	0.0	6.1	19.2
18 - 24	27.3	13.7	21.3	17.6	12.2	14.1
25 - 44	54.5	42.5	34.7	37.8	25.3	30.2
45 - 64	18.2	24.7	32.0	31.1	17.7	19.0
65+	0.0	19.1	12.0	13.5	8.7	17.5

[2] 1991 Census of Population for Birmingham (1993). * Commercial site + Residential site.

Table 5.7
Respondent classification by age at Cardiff (%).

Age group	Business	Household	Pedestrian		City[3]	Residential ward[3]
			C*	R+		
< 18	3.4	0.0	1.3	2.7	26.2 (<20)	21.0 (<20)
18 - 24	22.2	16.3	37.3	13.5	9.3 (20-24)	19.1 (20-24)
25 - 44	54.3	37.5	30.7	44.6	29.4	33.0
45 - 64	20.3	25.0	21.3	24.3	19.4	13.6
65+	0.0	21.2	9.3	14.9	15.7	13.3

[3] 1991 Census of Population for Cardiff (1993) (Mackintosh and Park Wards shown).
* Commercial site + Residential site.

Table 5.8
Respondent classification by age at Coventry (%).

Age group	Business	Household	Pedestrian		City[4]	Residential ward[4]
			C*	R+		
< 18	1.2	1.3	2.7	0.0	23.7	25.4
18 - 24	23.5	29.1	20.0	25.3	38.7	17.2
25 - 44	50.6	32.9	34.7	34.7		27.4
45 - pensionable age	23.5	24.0	30.7	21.3	18.5	16.8
over pensionable age	1.2	12.7	12.0	18.7	19.1	13.2

[4] 1991 Census of Population for Coventry (St Michael's Ward shown). * Commercial site + Residential site

Table 5.9
Respondent classification by age at Edinburgh (%).

Age group	Business	Household	Pedestrian		City[5]	Residential ward[5]
			C*	R+		
< 18	3.4	1.3	0.0	1.3	19.2	26.4 (<20)
18 - 24	22.0	2.6	22.7	11.8	11.1	7.6 (20-24)
25 - 44	50.8	33.3	30.7	39.5	31.2	21.1
45 - 64	20.4	44.9	30.7	26.3	21.6	32.3
65+	3.4	17.9	16	21.0	16.9	12.6

[5] 1981 Census of Population for Edinburgh (1983) (Telford Ward shown). * Commercial site + Residential site

Table 5.10
Respondent classification by age at Sheffield (%).

Age group	Business	Household	Pedestrian		City[6]	Residential ward[6]
			C*	R+		
< 18	0.0	1.2	0.0	1.3	23.3 (<20)	27.5 (<20)
18 - 24	18.6	15.7	19.5	14.5	9.5 (20-24)	9.7 (20-24)
25 - 44	52.3	30.1	35.1	48.7	28.5	27.2
45 - 64	29.1	32.5	27.3	19.7	21.4	20.3
65+	0.0	20.5	18.2	15.8	17.3	15.3

[6] 1991 Census of Population for Sheffield (Burngreave Ward shown). * Commercial site + Residential site

Table 5.11
Respondent classification by age at Wood Green (%).

Age group	Business	Household	Pedestrian Commercial	Haringey Borough[7]	Residential ward[7]
< 18	0.0	0.0	0.0	21.8	22.5
18 - 24	5.8	0.0	16.7	12.2	13.4
25 - 44	76.9	30.0	36.7	35.7	31.0
45 - 64	17.3	30.0	23.3	18.8	19.4
65+	0.0	40.0	23.3	11.5	13.7

[7] 1991 Census of Population for Haringey (1993) (Noel Park Ward shown).

The classification of respondents by occupation was performed according to the criteria laid down by the Market Research Society (MRS) (Reynolds, 1991). A respondent's occupational class is obtained by reference to the job title of the main wage earner in his/her household. A guide to the occupational class groupings is given in Table 5.12. Retired people are classified according to their previous job.

Table 5.12
Guide to occupational class groupings.

Occupational class	Description
A	Professional people, or very senior in business or commerce or top level civil servants.
B	Middle management executives in large organisations, with appropriate qualifications. Principal officers in local government and civil service. Top management or owners of small business concerns, educational and service establishments.
C1	Junior management; owners of small establishments; and all others in non-manual positions.
C2	All skilled manual workers, and those manual workers with responsibility for other people.
D	All semi-skilled and unskilled manual workers, and apprentices and trainees to skilled workers.
E	All those entirely dependent on state long term, through sickness, unemployment, old age or other reasons. Casual workers and those without a regular income.

The occupational classes of respondents in each target group are shown in Table 5.13.

Table 5.13
Occupational class of respondents.

Occupational class	Ealing - pilot survey (%)			Birmingham (%)				Cardiff (%)			
	B[1]	H[2]	P-C[3]	B[1]	H[2]	P-C[3]	P-R[4]	B[1]	H[2]	P-C[3]	P-R[4]
A	4.8	13.6	4.8	0.0	0.0	0.0	1.3	3.4	1.2	2.7	1.3
B	14.3	38.6	17.8	4.6	6.8	0.0	16.0	8.5	13.8	12.0	6.7
C1	47.6	25.0	35.6	68.2	28.8	33.3	16.0	40.7	27.5	37.3	32.0
C2	2.4	2.3	20.2	11.4	15.1	22.7	18.7	25.4	21.2	22.7	24.0
D	2.4	0.0	10.1	9.1	17.8	21.3	25.3	6.8	12.5	9.3	13.3
E	0.0	11.4	7.7	0.0	15.1	17.3	22.7	0.0	23.8	12.0	17.3
Unable to classify	28.3	9.1	3.8	6.7	16.4	5.3	0.0	15.2	0.0	4.0	5.3
Occupational class ratio*	14.00	5.67	1.53	3.56	0.74	0.54	0.5	1.63	0.74	1.18	0.73

* Occupational class ratio = (A+B+C1)/(C2+D+E).
[1] Business respondents.
[2] Household respondents.
[3] Pedestrian respondents in commercial area.
[4] Pedestrian respondents in residential area.

Table 5.13 cont.
Occupational class of respondents.

Occupational class	Coventry (%)				Edinburgh (%)				Sheffield (%)				Wood Green (%)		
	B[1]	H[2]	P-C[3]	P-R[4]	B[1]	H[2]	P-C[3]	P-R[4]	B[1]	H[2]	P-C[3]	P-R[4]	B[1]	H[2]	P-C[3]
A	4.9	0.0	1.3	0.0	0.0	3.8	2.7	1.3	4.7	0.0	5.2	0.0	1.9	0.0	0.0
B	11.1	1.3	10.7	8.0	13.3	25.6	29.3	0.0	11.6	2.4	7.8	0.0	15.4	8.5	3.3
C1	48.1	27.8	30.7	41.3	46.7	34.6	37.3	4.0	53.5	10.8	40.3	19.7	59.6	36.2	43.3
C2	16.0	17.7	22.7	17.3	16.7	15.4	5.3	29.3	15.1	16.9	22.1	29.0	13.5	25.5	16.7
D	1.2	13.9	14.7	14.7	6.7	10.3	10.7	26.3	4.6	15.7	6.5	14.5	0.0	14.9	10.0
E	0.0	39.2	20.0	18.7	0.0	9.0	13.3	36.8	0.0	43.4	18.2	29.0	0.0	14.9	26.7
Unable to classify	18.5	0.0	0.0	0.0	16.7	1.3	1.3	2.6	10.4	10.8	0.0	7.9	9.6	0.0	0.0
Occupational class ratio*	3.71	0.41	0.74	0.97	2.57	1.85	2.32	0.06	3.53	0.17	1.14	0.27	5.71	0.81	0.47

* Occupational class ratio = (A+B+C1)/(C2+D+E).
[1] Business respondents.
[2] Household respondents.
[3] Pedestrian respondents in commercial area.
[4] Pedestrian respondents in residential area.

The occupational class ratios (OCR) (defined in Table 5.13) were calculated in order to provide an approximate guide of the ratio of professional to non-professional classes for each respondent type at each location. Figures provided by Nielson Consumer Research (1991) suggest that a typical UK OCR is approximately 0.6-0.7. The OCRs listed in Table 5.13 are in broad agreement with this range for the household and pedestrian surveys at Birmingham, Cardiff, Coventry, Sheffield and Wood Green. More people from occupational classes A, B and C1 were interviewed at Ealing and Edinburgh than at the other sites, although the OCR for the pedestrian survey at the residential site in Edinburgh is unusually low. At all seven locations, professional people were much better represented than non-professional people in the business surveys, with the Ealing business respondents having a particularly high OCR.

5.4 Relative importance of environmental issues

The first question on any questionnaire is vitally important since it sets the scene for the questions to come. For this study, the opening question served a number of purposes:

- it acted as a 'scene-setting' question to 'introduce' the respondent to the questionnaire;
- it asked the respondent for their *personal opinion* on an issue in an attempt to arouse interest in the questionnaire;
- it was designed to compare the public's concern about environmental issues with other issues that may worry them, so that concern generated by nuisance effects could be put into perspective (this assumes that the public perceive nuisance effects as environmental issues).

The response to the pilot question 'can you please tell me which three issues are the most important to you?', which was used on all three target groups, is shown in Table 5.14. Over 40% of respondents from each target group felt that education, health and social services and law and order were among the three most important issues. Almost 50% of pedestrians felt that unemployment was one of the three most important issues, which may be a reflection of the fact that nearly 40% of pedestrian respondents were in occupational classes C2, D or E. Between 20-30% of respondents stated that global environment, housing, local environment and rising prices were one of the three most important issues to them, with old age pensions and rising population being regarded as the least important.

The issues raised in the pilot survey were ranked in order of importance to each respondent group (Table 5.14). Ranking the issues is useful since it indicates the order of importance of the listed issues, enabling the respondents' concerns to be prioritised. The rankings listed in Table 5.14 indicate that there was broad agreement between the respondent groups about the relative importance of the 10 specified issues.

Table 5.14
Response to the pilot question 'Can you please tell me which three issues are the most important to you?' *Figures in brackets refer to the relative rankings of the listed issues.*

Issues	Pilot Survey Responses (%)		
	Business	Household	Pedestrian
Health\social services	52 (1)	50 (1)	43 (3)
Law & order	45 (2)	45 (2)	41 (4)
Education	40 (3)	45 (2)	49 (1)
Unemployment	33 (4)	18 (7)	46 (2)
Local environment	31 (5)	32 (5)	22 (7)
Rising prices	29 (6)	23 (6)	18 (8)
Global environment	26 (7)	43 (4)	27 (6)
Housing	24 (8)	18 (7)	28 (5)
Rising population	12 (9)	9 (10)	12 (9)
Old age pensions	7 (10)	11 (9)	12 (9)

It was felt that the pilot survey question simply ranked the issues in order of priority, and did not provide information about the magnitude of concern felt by the public about these issues. The question was therefore modified for the subsequent surveys so that the extent of the public's concern about each issue could be monitored. It was also felt that any concern generated by vehicle-derived pollution needed to be specifically measured, and therefore an eleventh category, *air pollution from road traffic*, was added to the list shown in Table 5.14.

The results are illustrated in Tables 5.15-5.20, and indicate a high level of concern by each respondent group at each location about many of the listed issues. Over 62% of all respondents stated that they were 'very' or 'extremely' worried about unemployment, clearly making it the number one issue at each location. In addition, at least one third of all respondents were 'very' or 'extremely' worried about law and order, education, rising prices, unemployment, air pollution from road traffic and the global environment (with the exception of the pedestrian respondents at the residential site in Edinburgh). These results are surprisingly consistent, and

Table 5.15

Response to the question '...would you please tell me how worried you personally feel about each of these issues?' (**Birmingham**).

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely worried.

	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
Issues	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Unemployment	16	80 (1)	10	77 (1)	8	91 (1)	15	80 (1)
Law & order	23	70 (2)	30	59 (2)	28	68 (2)	21	65 (4)
Education	30	67 (3)	29	47 (6)	35	57 (3)	36	52 (9)
Air pollution from road traffic	36	59 (4)	29	48 (3)	29	52 (5)	13	79 (2)
Rising prices	43	50 (6)	25	48 (3)	21	65 (3)	20	68 (3)
Health/social services	36	50 (6)	21	37 (8)	37	31 (11)	33	53 (8)
Global environment	35	49 (8)	32	48 (3)	29	48 (7)	28	61 (5)
Local environment	36	52 (5)	40	34 (9)	47	33 (9)	32	56 (6)
Old age pensions	51	32 (10)	16	45 (7)	28	51 (6)	23	56 (6)
Housing	45	32 (10)	30	29 (10)	29	44 (8)	31	40 (10)
Rising population	23	33 (9)	18	22 (11)	25	33 (9)	28	33 (11)

[1] Moderately worried.
[2] Very/extremely worried.

Table 5.16

Response to the question '...would you please tell me how worried you personally feel about each of these issues?' **(Cardiff)**.

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely worried.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Unemployment	24	63 (2)	22	68 (1)	18	78 (1)	17	83 (1)
Law & order	19	75 (1)	24	68 (1)	28	55 (5)	24	65 (2)
Education	39	34 (8)	21	42 (8)	33	47 (7)	32	57 (6)
Air pollution from road traffic	29	56 (3)	32	60 (5)	21	67 (2)	32	63 (3)
Rising prices	33	45 (5)	20	64 (4)	30	58 (4)	27	58 (5)
Health/social services	33	43 (6)	34	35 (10)	31	35 (10)	33	49 (8)
Global environment	41	47 (4)	30	66 (3)	24	67 (2)	25	59 (4)
Local environment	51	32 (9)	32	40 (9)	37	36 (9)	48	40 (10)
Old age pensions	30	36 (7)	22	56 (6)	33	54 (6)	28	53 (7)
Housing	38	31 (10)	30	44 (7)	28	46 (8)	39	44 (9)
Rising population	19	21 (11)	26	22 (11)	32	18 (11)	19	16 (11)

[1] Moderately worried.
[2] Very/extremely worried.

Table 5.17

Response to the question '...would you please tell me how worried you personally feel about each of these issues?' (**Coventry**).

Figures in brackets refer to the relat*ive rankings of the listed issues, based on the number of respondents who were very/extremely worried.*

	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
Issues	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Unemployment	25	70 (1)	18	73 (1)	9	88 (1)	15	83 (1)
Law & order	30	62 (2)	25	58 (3)	25	65 (2)	21	68 (2)
Education	40	44 (3)	32	46 (6)	37	39 (10)	28	52 (8)
Air pollution from road traffic	40	43 (5)	39	49 (5)	28	65 (3)	33	59 (4)
Rising prices	30	40 (6)	27	58 (3)	35	47 (6)	28	54 (7)
Health/social services	40	36 (7)	33	33 (10)	39	40 (9)	28	48 (9)
Global environment	42	44 (3)	28	66 (2)	29	56 (5)	20	64 (3)
Local environment	44	26 (9)	35	38 (8)	37	41 (7)	45	33 (10)
Old age pensions	37	22 (10)	25	40 (7)	26	61 (4)	25	55 (6)
Housing	30	33 (8)	33	38 (8)	23	41 (7)	19	56 (5)
Rising population	27	21 (11)	36	15 (11)	25	20 (11)	27	23 (11)

[1] Moderately worried.
[2] Very/extremely worried.

Table 5.18

Response to the question '...would you please tell me how worried you personally feel about each of these issues?' (**Edinburgh**).

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely worried.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Unemployment	13	85 (1)	14	85 (1)	17	72 (1)	20	71 (1)
Law & order	33	52 (4)	36	51 (3)	35	57 (2)	28	47 (3)
Education	38	35 (9)	32	42 (7)	41	41 (7)	41	22 (8)
Air pollution from road traffic	28	57 (2)	26	65 (2)	32	53 (3)	34	29 (6)
Rising prices	32	57 (2)	36	47 (4)	31	49 (5)	36	53 (2)
Health/social services	43	38 (7)	33	46 (5)	43	35 (8)	36	36 (5)
Global environment	37	52 (4)	40	46 (5)	37	47 (6)	38	20 (9)
Local environment	48	36 (8)	38	31 (9)	41	31 (10)	47	14 (10)
Old age pensions	23	45 (6)	33	40 (8)	24	51 (4)	32	44 (4)
Housing	37	27 (10)	38	22 (10)	31	32 (9)	24	26 (7)
Rising population	40	17 (11)	23	13 (11)	23	15 (11)		9 (11)

[1] Moderately worried.
[2] Very/extremely worried.

Table 5.19

Response to the question '...would you please tell me how worried you personally feel about each of these issues?' (**Sheffield**).

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely worried.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Unemployment	10	86 (1)	16	77 (1)	22	67 (1)	4	87 (1)
Law & order	24	67 (2)	30	55 (3)	38	49 (2)	26	59 (4)
Education	40	45 (3)	24	36 (8)	40	48 (3)	41	39 (8)
Air pollution from road traffic	32	50 (4)	30	49 (4)	44	46 (4)	17	66 (3)
Rising prices	33	50 (4)	20	74 (2)	45	42 (6)	16	76 (2)
Health/social services	37	44 (7)	23	38 (7)	53	26 (11)	41	32 (10)
Global environment	29	55 (3)	32	40 (6)	45	38 (7)	22	43 (7)
Local environment	46	42 (8)	39	32 (10)	53	27 (10)	38	39 (8)
Old age pensions	28	38 (9)	20	47 (5)	48	46 (4)	29	50 (5)
Housing	33	33 (10)	31	35 (9)	40	34 (8)	26	47 (6)
Rising population	37	14 (11)	26	26 (11)	40	30 (9)	13	14 (11)

[1] Moderately worried.
[2] Very/extremely worried.

Table 5.20

Response to the question '...would you please tell me how worried you personally feel about each of these issues?' (**Wood Green**).

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely worried.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Unemployment	28	62 (1)	13	72 (2)	20	70 (1)
Law & order	38	58 (2)	33	34 (8)	33	57 (5)
Education	33	49 (3)	28	45 (7)	20	67 (3)
Air pollution from road traffic	44	48 (4)	15	68 (3)	27	70 (1)
Rising prices	31	41 (5)	15	77 (1)	47	46 (9)
Health/social services	38	40 (6)	19	32 (10)	27	43 (10)
Global environment	50	40 (6)	28	53 (4)	27	60 (4)
Local environment	48	38 (8)	40	34 (9)	40	47 (8)
Old age pensions	27	38 (8)	17	46 (5)	17	50 (6)
Housing	31	35 (10)	26	46 (5)	30	50 (6)
Rising population	33	25 (11)	26	31 (11)	17	40 (11)

[1] Moderately worried.
[2] Very/extremely worried.

although the magnitude of concern about each issue varies from location to location, the relative ranking of each issue changes little (rankings also listed in Tables 5.15-5.20).

Comparisons between the rankings obtained in each survey need to be treated with caution. The responses to the opening question of the pilot and follow-up surveys are not strictly comparable, since the questions used were different. The surveys were performed in different years; Ealing in 1991, Wood Green in 1992 and the remainder in 1993, and it should be remembered that public opinion is likely to be influenced greatly by the media and the social, political and economic climate of that time. However, with these reservations in mind, it is possible to draw some tentative conclusions from the data presented in Tables 5.14-5.20.

The results suggest that the public have a generally high level of concern about the listed range of social issues. This high level of concern means that the issues have to be ranked in order of importance/concern so that their relative priority may be assessed. The rankings shown in Tables 5.14-5.20 indicate that certain issues (primary issues) are regularly ranked highly in terms of importance or concern by each respondent group at each location. The data suggests that unemployment was the most important primary social issue of those listed, with other primary issues including law and order, air pollution from road traffic, rising prices and the global environment. Issues such as education, health/social services, local environment, old age pensions and housing generate a considerable amount of concern, but are currently relatively less important than the primary issues. Rising population was consistently ranked last of the 11 listed issues.

5.5 Local environmental issues

Having established the relative importance of local environmental issues compared to other public concerns, the second question was designed to prioritise local environmental issues. During the pilot survey, all three target groups were asked, 'can you please tell me which three from this list cause the greatest nuisance to you when you are out walking in Ealing?'. The responses are shown in Table 5.21.

For each target group, litter and rubbish, the amount of road traffic and smoke, fumes or odour from road traffic were the three greatest nuisances to the public when they were out walking in Ealing, although the relative importance of each nuisance to the target groups differs. Over 70% of business people complained about nuisance from litter and rubbish, while the amount of road traffic was the greatest nuisance to householders. Approximately 50% of people from all target groups stated that smoke, fumes or odour from road traffic was one of their three

Table 5.21
Response to the question '...can you please tell me which three from this list cause the greatest nuisance to you when you are out walking in Ealing?'

Figures in brackets refer to the relative rankings of the listed issues.

Local environmental issue	Pilot Survey Responses (%)		
	Business	Household	Pedestrian
Litter & rubbish	71 (1)	59 (2)	57 (1)
Amount of road traffic	52 (2)	75 (1)	41 (3)
Smoke, fumes or odour from road traffic	48 (3)	52 (3)	52 (2)
Noise from road traffic	38 (4)	23 (5)	27 (5)
Dog mess	29 (5)	32 (4)	38 (4)
Dust & dirt	21 (6)	14 (6)	16 (6)
Ugly\disused buildings	19 (7)	11 (7)	12 (9)
Noise from sources other than road traffic	10 (8)	2 (9)	8 (10)
Graffiti	5 (9)	7 (8)	13 (8)
Smoke, fumes or odour from industrial plants	0 (10)	2 (9)	15 (7)
2.3% of household respondents said that none of the above caused them any nuisance. 2.9% of pedestrian respondents said that none of the above caused them any nuisance.			

greatest nuisances when they were out walking in Ealing. Fewer respondents were concerned about a group of problems including dust and dirt, ugly/disused buildings, noise from sources other than road traffic, graffiti and smoke, fumes or odour from industrial plants, with less than one-fifth of respondents stating that they were among their three greatest nuisances. The local environmental issues raised in the pilot survey were also ranked in order of importance to each respondent group, as shown in Table 5.21. The rankings indicate that there was good agreement between the respondent groups about the relative importance of the 10 specified issues.

As for the opening question, the second question was modified for the follow-up surveys to take into account the magnitude of the respondents' concern. Some of the local environmental issues listed in Table 5.21 were also changed. The results are illustrated in Tables 5.22-5.27, and indicate a high level of concern by each respondent group at each location about certain of the listed issues. In general, over 40% of all business and household respondents stated that they were 'very' or 'extremely' bothered about litter and rubbish; smoke, fumes and odour; the amount of road traffic and dog mess. The magnitude of pedestrian concern about these issues was more variable, although high levels of concern are evident at pedestrian sites in all locations. However, there is more concern about these issues at the commercial site in Edinburgh than at the residential site, with the opposite occurring in Sheffield. Dust/dirt also caused considerable annoyance, with at least one third of all respondents being 'very' or 'extremely' bothered in Birmingham, Cardiff and Wood Green. Fewer respondents were 'very' or 'extremely' bothered about graffiti, ugly/disused buildings and noise, although high levels of concern are evident at certain sites. Smog and the blackening of building walls caused least concern, with at least 30% of all respondents at each site being 'not at all' or 'not very' bothered about these issues.

The results illustrated in Tables 5.22-5.27 show the same type of consistency as the data for question 1 (see Section 5.4). The magnitude of concern about each issue again varies from location to location, but the relative ranking of each issue changes little. Comparisons between the rankings obtained in each survey should be treated with caution for the same reasons as those outlined in Section 5.4, although local environmental issues are possibly less prominent in the public's mind than national social issues. In the pilot survey, two of the top three nuisances were traffic generated, with dog mess, noise and dust/dirt also being identified as important nuisances to the public. The rankings for the other sites are very similar, with litter and rubbish, the amount of road traffic and smoke, fumes and odour once more being identified as the most annoying ahead of dog mess and dust/dirt. These data suggest that the physical

Table 5.22

Response to the question '...would you please tell me how much these issues bother you when you are out walking in **Birmingham**'?

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely worried.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Graffiti	43	39 (6)	16	16 (10)	20	28 (8)	27	36 (7)
Litter & rubbish	36	54 (2)	40	36 (3)	24	40 (2)	31	49 (4)
Smoke, fumes & odour	36	59 (1)	19	47 (2)	40	37 (3)	24	59 (2)
Amount of road traffic	39	45 (4)	23	58 (1)	25	56 (1)	13	67 (1)
Dog mess	34	48 (3)	22	30 (5)	15	33 (4)	28	51 (3)
Ugly/disused buildings	34	41 (5)	27	23 (7)	28	28 (7)	31	36 (7)
Noise	30	39 (6)	29	29 (6)	32	32 (5)	32	39 (6)
Dust & dirt	50	36 (9)	30	32 (4)	37	32 (5)	32	47 (5)
Smog	30	37 (8)	14	23 (7)	19	24 (10)	20	28 (9)
Blackening of building walls	40	30 (10)	23	19 (9)	27	26 (9)	32	25 (10)

[1] Moderately bothered.
[2] Very/extremely bothered.

Table 5.23

Response to the question '...would you please tell me how much these issues bother you when you are out walking in **Cardiff**'?

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely bothered.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Graffiti	34	24 (8)	32	20 (9)	28	24 (9)	28	29 (7)
Litter & rubbish	34	58 (2)	29	51 (3)	36	48 (1)	28	60 (3)
Smoke, fumes & odour	22	63 (1)	16	44 (4)	32	44 (3)	35	56 (4)
Amount of road traffic	27	44 (4)	21	69 (1)	27	48 (1)	29	63 (1)
Dog mess	32	49 (3)	25	59 (2)	28	43 (4)	20	61 (2)
Ugly/disused buildings	33	29 (7)	31	27 (7)	26	38 (5)	41	31 (6)
Noise	47	21 (9)	26	34 (6)	29	31 (7)	47	23 (9)
Dust & dirt	36	41 (5)	32	39 (5)	39	33 (6)	40	41 (5)
Smog	27	39 (6)	17	23 (8)	19	28 (8)	32	21 (10)
Blackening of building walls	46	17 (10)	26	17 (10)	23	25 (10)	28	27 (8)

[1] Moderately bothered.
[2] Very/extremely bothered.

Table 5.24

Response to the question '...would you please tell me how much these issues bother you when you are out walking in **Coventry**'?

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely bothered.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Graffiti	43	20 (7)	35	19 (9)	28	20 (8)	25	24 (9)
Litter & rubbish	38	48 (2)	30	46 (1)	37	36 (3)	31	48 (2)
Smoke, fumes & odour	42	49 (1)	29	43 (3)	20	39 (2)	28	55 (1)
Amount of road traffic	47	35 (4)	32	41 (4)	25	33 (4)	33	45 (4)
Dog mess	27	46 (3)	23	44 (2)	11	48 (1)	21	48 (2)
Ugly/disused buildings	36	35 (4)	41	33 (5)	35	29 (5)	41	28 (7)
Noise	45	20 (7)	36	26 (6)	25	19 (9)	31	32 (5)
Dust & dirt	51	17 (10)	45	24 (7)	29	29 (5)	48	32 (5)
Smog	36	22 (6)	32	19 (9)	19	21 (7)	33	25 (8)
Blackening of building walls	38	18 (9)	32	22 (8)	36	16 (10)	48	19 (10)

[1] Moderately bothered.
[2] Very/extremely bothered.

Table 5.25

Response to the question '...would you please tell me how much these issues bother you when you are out walking in **Edinburgh**'?

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely bothered.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Graffiti	48	22 (8)	26	17 (7)	17	19 (8)	18	11 (7)
Litter & rubbish	46	49 (30	33	35 (4)	23	33 (3)	41	13 (6)
Smoke, fumes & odour	27	64 (1)	30	47 (2)	31	45 (2)	24	18 (4)
Amount of road traffic	37	50 (2)	31	59 (1)	23	56 (1)	24	36 (1)
Dog mess	23	45 (4)	23	41 (3)	29	33 (3)	13	26 (2)
Ugly/disused buildings	40	23 (7)	22	15 (8)	31	25 (7)	9	3 (10)
Noise	47	18 (9)	33	20 (6)	25	28 (5)	9	18 (4)
Dust & dirt	46	32 (6)	35	26 (5)	47	27 (6)	13	23 (3)
Smog	19	36 (5)	25	14 (9)	21	12 (10)	4	9 (8)
Blackening of building walls	30	18 (9)	30	14 (9)	35	15 (9)	7	5 (9)

[1] Moderately bothered.
[2] Very/extremely bothered.

Table 5.26

Response to the question '...would you please tell me how much these issues bother you when you are out walking in **Sheffield**'?

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely bothered.

Issues	Business (%)		Household (%)		Pedestrian Commercial (%)		Pedestrian Residential (%)	
	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Graffiti	41	48 (5)	26	40 (4)	13	17 (4)	37	28 (7)
Litter & rubbish	29	66 (1)	23	65 (1)	32	26 (2)	32	62 (1)
Smoke, fumes & odour	25	61 (2)	30	39 (5)	34	18 (3)	25	50 (4)
Amount of road traffic	35	51 (3)	29	48 (3)	31	27 (1)	25	53 (2)
Dog mess	25	46 (6)	20	63 (2)	21	12 (8)	28	51 (3)
Ugly/disused buildings	40	46 (6)	23	35 (6)	19	14 (6)	21	32 (6)
Noise	33	29 (9)	29	26 (8)	23	13 (7)	28	26 (8)
Dust & dirt	32	49 (4)	41	31 (7)	30	16 (5)	24	50 (4)
Smog	30	35 (8)	22	25 (9)	16	9 (9)	17	24 (9)
Blackening of building walls	37	19 (10)	19	25 (9)	25	8 (10)	18	18 (10)

[1] Moderately bothered.
[2] Very/extremely bothered.

Table 5.27

Response to the question '...would you please tell me how much these issues bother you when you are out walking in **Wood Green**'?

Figures in brackets refer to the relative rankings of the listed issues, based on the number of respondents who were very/extremely bothered.

	Business (%)		Household (%)		Pedestrian Commercial (%)	
Issues	M[1]	V/E[2]	M[1]	V/E[2]	M[1]	V/E[2]
Graffiti	27	31 (8)	26	34 (6)	23	40 (6)
Litter & rubbish	21	77 (1)	19	73 (2)	13	77 (1)
Smoke, fumes & odour	38	52 (2)	19	55 (4)	30	60 (2)
Amount of road traffic	31	46 (5)	17	59 (3)	37	57 (4)
Dog mess	25	49 (3)	15	79 (1)	23	60 (2)
Ugly/disused buildings	45	35 (6)	36	30 (7)	30	27 (9)
Noise	56	23 (9)	34	30 (7)	27	37 (7)
Dust & dirt	40	49 (3)	28	42 (5)	34	43 (5)
Smog	31	34 (7)	21	18 (10)	17	33 (8)
Blackening of building walls	39	16 (10)	23	23 (9)	26	14 (10)

[1] Moderately bothered.
[2] Very/extremely bothered.

presence of road traffic and its associated air pollution are probably the largest contributors to outdoor public environmental nuisance.

5.6 Indoor nuisance effects

The questions outlined in this section, and discussed in sections 5.6-5.9 were designed to:

- establish the specific environmental problems and health effects that bother or cause distress to the public;
- discover if the public attributes these problems and effects to vehicular sources.

Since this research is only really concerned with vehicle-generated air pollution, only problems which may be linked to road traffic emissions were considered. For comparative purposes, both indoor and outdoor environmental and health problems were included.

5.6.1 Pilot survey

In the pilot survey, householders and business people were asked 'when you are inside (the shop/your home), can you please tell me if you are ever bothered or disturbed by any of these effects?'. The results indicated a very high level of indoor disturbance from noise and dust/dirt, as illustrated in Table 5.28. Householders were also asked what they thought was the main cause of the effects listed in Table 5.28. Road traffic was blamed by at least 38% of total household respondents for the noise inside their homes, by 36% for the dust/dirt on furniture or indoor walls and by 50% for dust/dirt on the inside of curtains or inside window sills.

Table 5.28

Response to the question 'when you are inside (the shop/your home), can you please tell me if you are ever bothered or disturbed by any of these effects?'.

Effect	% bothered or disturbed	
	Business	Household
Smoke, fumes or odour	71	25
Noise	86	63
Dust & dirt on the inside of the (shop windows/curtains or inside window sills)	88	63
Dust & dirt on (shelves or goods/furniture or walls)	86	44
Vibrations	52	50

The data in Table 5.28 also seem to indicate that more business people than householders were bothered indoors by the listed effects, particularly in the case of smoke, fumes or odour. Many of the business people questioned worked in shops immediately adjacent to the Broadway and High Street roads in Ealing, where traffic was frequently slow-moving or stationary, and this possibly contributed to their higher level of disturbance. There is also the possibility of a methodological effect since business respondents completed their questionnaires themselves.

Householders were asked to consider the magnitude of indoor disturbance from vehicle-induced pollution over a whole week. The magnitude of the nuisance was measured using the 5-point scale shown in Figure 5.2, and the results are summarised in Table 5.29.

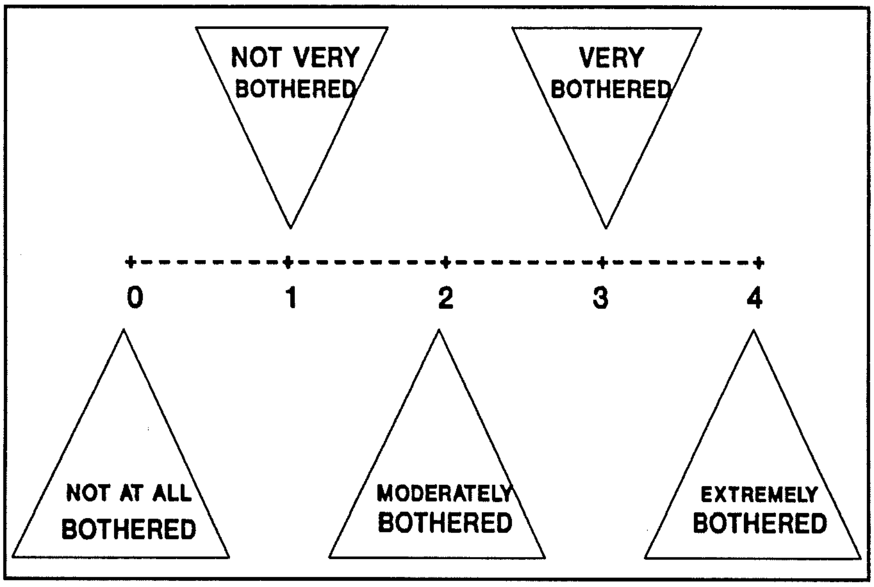


Figure 5.2
5-point scale used to measure magnitude of nuisance to household & pedestrian respondents.

The mean and median disturbance scores illustrated in Table 5.29 indicate that the average household respondent, and all of the different respondent groups, were 'not very'-'moderately' bothered by pollution from road traffic when they were inside their homes. The mean disturbance scores also seem to suggest that female respondents experience more indoor disturbance than males, current non-smokers more disturbance than current smokers and that the 45-64 age group experiences more disturbance than the other age groups. However, since the sampling distributions of each of the respondent groups are non-normal (they are all skewed right), the median is probably a better measure of central location. The data in Table 5.29 indicates that the median scores are almost all the same, and a more detailed statistical analysis of the data using non-parametric techniques (the Mann-Whitney test, non-parametric analysis of variance (ANOVA)) indicates that there are no significant differences between males/females, smokers/non-smokers and respondents from different age groups.

Table 5.29
Householder response to the pilot question '... when you are inside your home, how much are you bothered by pollution from road traffic?'

Respondent group	Number of respondents	Disturbance score	
		Mean	Median
All	44	1.7	2
Male respondents	18	1.3	1.5
Female respondents	26	1.9	2
Current smokers	13	1.4	2
Current non-smokers	31	1.8	2
Age group 25-44	21	1.5	2
Age group 45-64	9	2.1	2
Age group 65+	12	1.6	0

Householders were questioned in order to determine the magnitude of the indoor nuisance from road traffic pollution at different times of the day and night. The responses, shown in Table 5.30 together with the mean nuisance scores (N) determined using the 5-point scale, indicate that the highest disturbance was between 4.00-7.00 pm and 7.00-10.00 am, when the 'average respondent' was 'not very'-'moderately' bothered.

5.6.2 Main surveys

The pilot question (stated in Table 5.28) did not give any information about the frequency of indoor disturbance and was therefore modified for the main household and business surveys. These data, shown in Figures 5.3(a-h), indicate that respondents at commercial sites were generally more disturbed by the listed nuisance effects than the householders. Noise from road traffic generally caused the greatest frequency of indoor disturbance, with between 37-59% of business respondents and 25-48% of householders being disturbed 'frequently' or 'all the time'. The highest frequency of disturbance from vibrations was noted at Wood Green, where the presence of the Underground Tube trains may have contributed to the overall annoyance. Smoke, fumes and odour usually caused the lowest frequency of indoor disturbance, particularly to householders.

The revised questionnaires included questions designed to measure the magnitude of the indoor nuisance from smoke, fumes and odour and dust/dirt from road traffic. The nuisance measurement scale was changed to a 7-point bi-polar semantic differential version, ranging

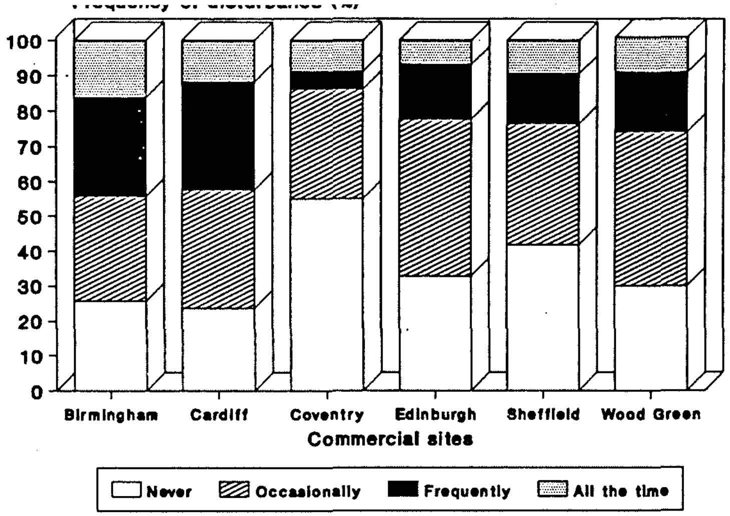
Table 5.30
Householder response to the pilot question, 'on Mondays to Fridays, when you are inside your home, how much are you bothered by pollution from the traffic on this road...(name time)?'

	Pilot survey householder responses (%)					N
	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered	
Before 7.00 *am*	50	32	20	0	0	0.7
Between 7.00 *am* & 10.00 *am*	18	23	31	15	13	1.8
Between 10.00 *am* & 1.00 *pm*	26	37	15	4	18	1.5
Between 1.00 *pm* & 4.00 *pm*	25	25	32	0	18	1.6
Between 4.00 *pm* & 7.00 *pm*	17	22	25	22	14	1.9
After 7.00 *pm*	38	23	35	0	4	1.1

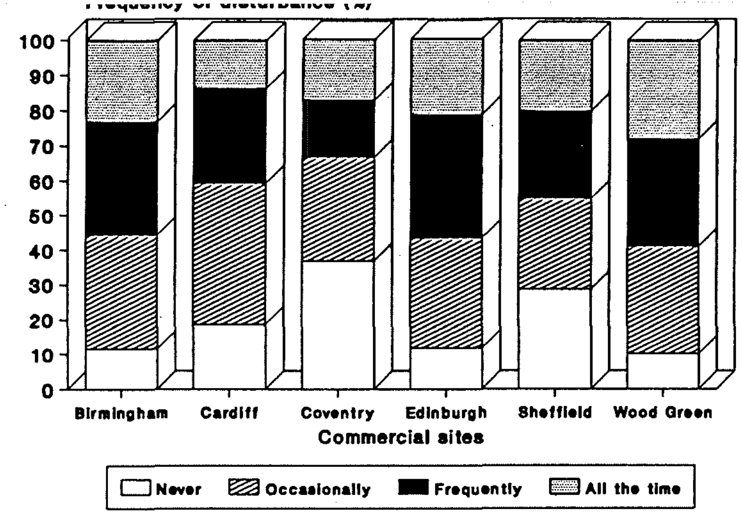
from 0 (not at all bothered) to 6 (extremely bothered) in integers, to allow the respondent a wider choice. This same scale was used to measure the overall indoor disturbance generated by air pollution from road traffic, and the results are summarised in Tables 5.31-5.35.

The data shown in Table 5.31 indicate that the average household respondent was not very bothered by indoor vehicle-generated smoke, fumes and odour, with the mean scores ranging from 1.2 at Edinburgh and Sheffield to 1.9 at Cardiff. The median scores, which are probably a better measure of central location than the mean scores, are more variable, ranging fom 0 at Coventry, Edinburgh and Sheffield to 2 at Cardiff and Wood Green. A more detailed investigation of these data using non-parametric ANOVA reveals that the household disturbance scores at Cardiff are statistically significantly higher than those at Edinburgh and Sheffield. With the exception of Cardiff, the mean disturbance scores for female respondents were higher than those for males, although only at Edinburgh was the difference statistically significant. In general, middle-aged respondents (*ie* those between 25-64 years) showed higher disturbance than younger or older respondents. This trend has statistical significance only at Birmingham, where the scores for the 45-64 age group were much greater than those of the 65+ age group.

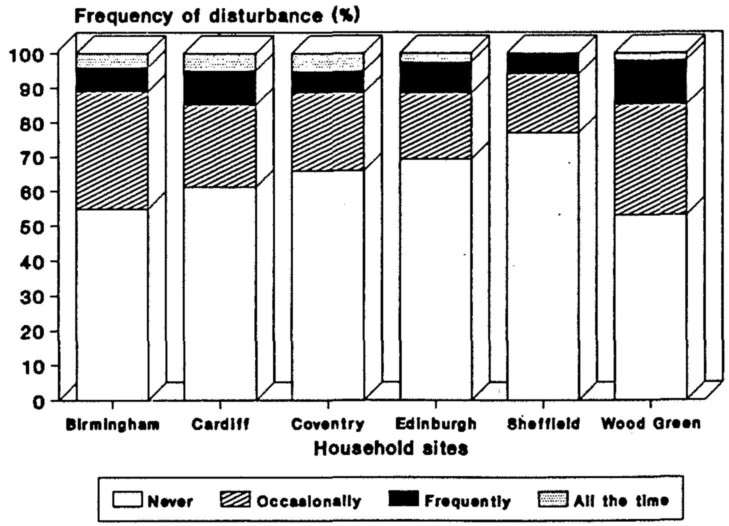
The mean indoor disturbance scores from vehicle-generated smoke, fumes and odour at the commercial sites (illustrated in Table 5.32) ranged from 1.5 at Coventry to 3.3 at Birmingham,



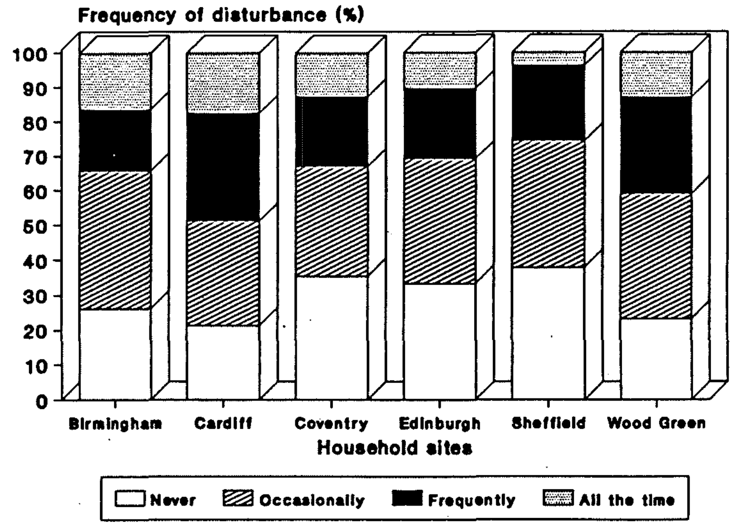
a) smoke, fumes & odour



b) noise



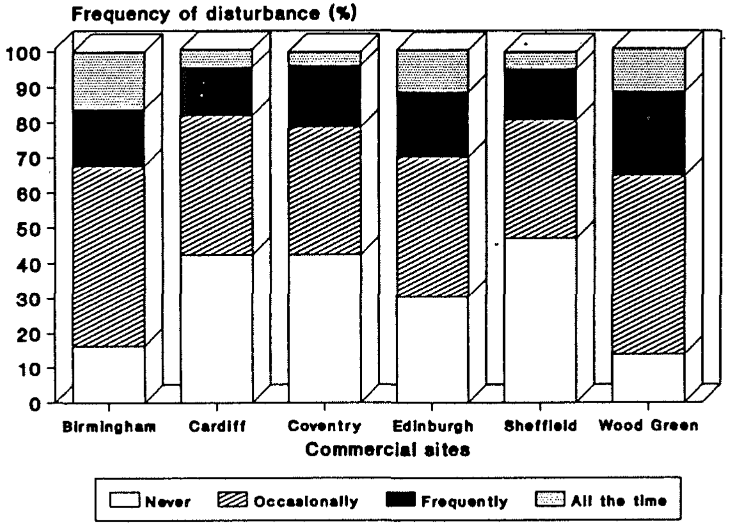
c) smoke, fumes & odour



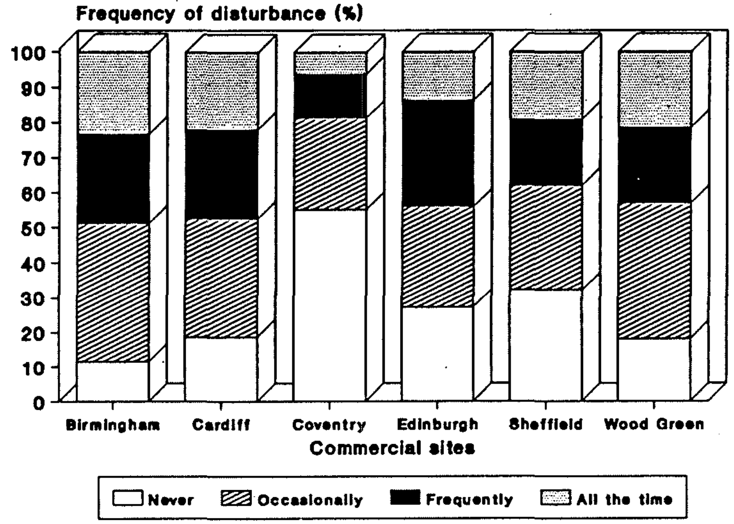
d) noise

Figure 5.3(a-d)

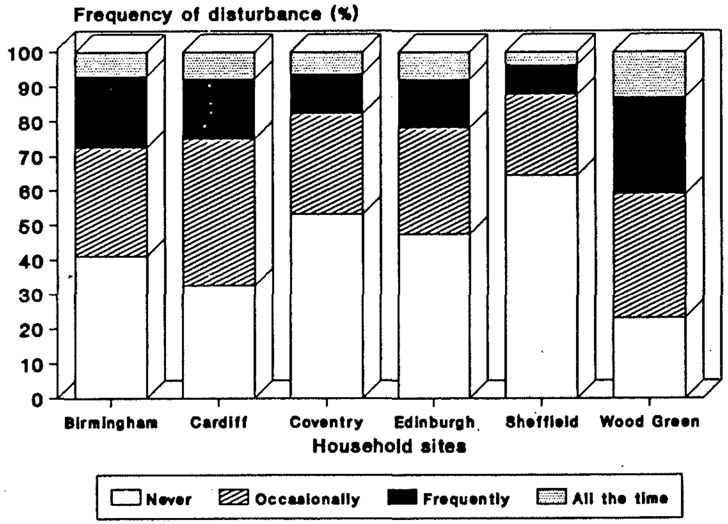
Frequency of indoor disturbance from road traffic.



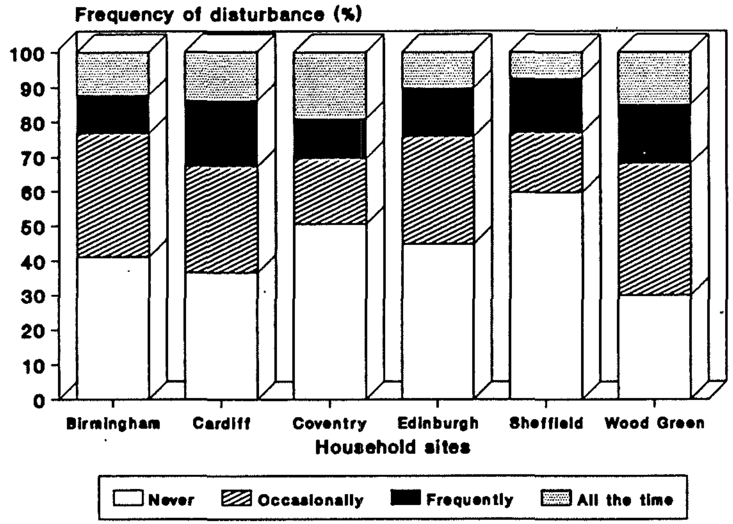
e) vibrations



f) dust/dirt



g) vibrations



h) dust/dirt

Figure 5.3(e-h)
Frequency of indoor disturbance from road traffic.

with the median scores varying from 1 at Coventry to 3 at Birmingham, Cardiff, Edinburgh and Wood Green. The scores at these latter 4 locations are statistically significantly higher than the disturbance score at Coventry. The mean and median disturbance scores at the commercial sites were higher than those at the residential sites at all locations except at Coventry, which is an exceptional location since the residential and commercial areas overlap. The figures indicate that the average commercial respondent was not very - moderately bothered by indoor dust/dirt from road traffic, with middle-aged respondents again showing generally higher disturbance than younger respondents.

The disturbance scores shown in Table 5.33 suggest that the average household respondent was not very bothered by indoor dust/dirt from road traffic. The mean scores varied from 1.3 at Sheffield to 2.2 at Cardiff, with the median scores ranging from 0 at Coventry and Sheffield to 2 at Birmingham and Cardiff. Further investigation of the data using non-parametric ANOVA shows that the household disturbance scores at Cardiff were significantly higher than those at Sheffield. Female respondents had higher disturbance scores than males at each location except Cardiff, although only at Birmingham and Edinburgh were the scores statistically significantly higher. As with indoor smoke, fumes and odour, middle-aged respondents generally displayed the highest disturbance, with the 45-64 age group at Birmingham having statistically higher scores than respondents who were 65+. At each location, the residential respondents showed more concern about indoor dust/dirt than indoor smoke, fumes and odour, with statistically significant data occuring at Birmingham, Cardiff and Coventry.

At the commercial sites, the mean indoor disturbance scores from vehicle-derived dust/dirt ranged from 1.4 at Coventry to 3.5 at Birmingham, with the median scores ranging from 1 to 3 (see Table 5.34). The Coventry score was statistically significantly lower than the scores at the other 5 locations, with Sheffield also having a significantly lower score than Birmingham. Overall, these figures indicate that the average commercial respondent was not very - moderately disturbed by indoor dust/dirt from road traffic. The mean and median disturbance scores at the commercial sites were higher than at the residential sites at all locations, with younger respondents generally showing less concern than those in middle-age. The commercial respondents showed higher concern indoors about dust/dirt than smoke, fumes and odour at each location.

The overall indoor disturbance scores from vehicle-generated air pollution for householders are shown in Table 5.35. The mean disturbance scores vary from 1.3 in Sheffield to 2.2 in

Table 5.31
Householder disturbance scores - indoor smoke, fumes and odour from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	73	1.8	1	80	1.9	2	79	1.7	0	78	1.2	0	83	1.2	0	47	1.9	2
Male	38	1.5	0	38	2.0	2	34	1.6	0.5	39	0.8	0	37	1.1	0	20	1.8	2
Female	35	2.1	2	42	1.9	1.5	45	1.8	0	39	1.6	0	46	1.3	0	27	1.9	2
Current smokers	21	1.4	0	24	2.3	2	43	2.1	1	20	1.4	0	33	1.1	0	17	1.8	2
Current non-smokers	51	2.0	2	56	1.8	1.5	36	1.3	0	58	1.1	0	50	1.3	0	30	1.9	2
Age group 18-24	10	0.8	0	13	2.2	2	23	1.2	0	-	-	-	13	0.8	0	-	-	-
Age group 25-44	31	2.0	2	30	1.9	2	26	2.2	1.5	26	1.2	1	25	1.0	0	14	2.4	2
Age group 45-64	18	2.8	3.5	20	1.8	1	19	2.1	1	35	1.3	0	27	1.4	0	14	1.9	2
Age group 65+	14	0.8	0	17	2.1	2	10	1.1	0	14	0.9	0	17	1.5	0	19	1.5	0

Table 5.32
Commercial disturbance scores - indoor smoke, fumes and odour from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	42	3.3	3	56	2.9	3	80	1.5	1	60	2.7	3	87	2.3	2	51	2.7	3
Male	22	3.2	3	28	2.8	3	43	1.6	1	31	2.7	3	36	2.1	1	28	3.0	3
Female	20	3.3	3	28	2.9	3	37	1.4	1	28	2.6	3	49	2.4	2	22	2.4	2
Age group 18-24	12	2.8	3	12	2.7	2.5	19	1.4	1	13	2.5	3	16	3.2	3.5	-	-	-
Age group 25-44	23	3.4	3	31	2.6	3	40	1.6	1	30	2.8	3	45	2.1	2	39	2.6	2
Age group 45-64	7	3.6	3	11	3.4	4	19	1.5	1	12	2.8	3	25	1.9	1	9	3.6	3

Table 5.33
Householder disturbance scores - indoor dust/dirt from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	73	2.1	2	80	2.2	2	79	1.9	0	78	1.5	0.5	83	1.3	0	47	2.0	1
Male	38	1.6	0	38	2.4	2	34	1.5	0	39	1.0	0	37	1.1	0	20	1.9	1
Female	35	2.7	3	42	2.1	1	45	2.2	1	39	2.0	2	46	1.5	0	27	2.1	2
Current smokers	21	2.0	0	24	2.5	2.5	43	2.3	2	20	2.0	2	33	1.2	0	17	1.7	1
Current non-smokers	51	2.2	2	56	2.1	1	36	1.4	0	58	1.4	0	50	1.4	0	30	2.2	1.5
Age group 18-24	10	1.4	0.5	13	2.5	3	23	1.0	0	-	-	-	13	0.8	0	-	-	-
Age group 25-44	31	2.0	2	30	2.4	2.5	26	2.6	2	26	1.6	1.5	25	1.1	0	14	2.3	2
Age group 45-64	18	3.4	4	20	1.8	1	19	2.5	1	35	1.7	0	27	1.5	0	14	2.1	1.5
Age group 65+	14	1.2	0	17	2.2	2	10	1.5	0	14	1.1	0	17	1.8	0	19	1.7	1

Table 5.34
Commercial disturbance scores - indoor dust/dirt from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	43	3.5	3	57	2.8	3	79	1.4	1	58	2.9	3	85	2.4	2	50	3.2	3
Male	23	3.6	3	28	2.5	2.5	42	1.4	1	30	2.6	3	34	2.5	2	28	3.4	3
Female	20	3.4	3.5	29	3.0	3	37	1.4	1	27	3.1	3	49	2.4	2	21	3.0	3
Age group 18-24	12	3.1	3.5	13	2.1	2	19	1.4	1	13	3.0	3	15	3.3	3	-	-	-
Age group 25-44	23	3.7	3	32	2.9	3	39	1.4	1	29	2.8	3	44	2.2	2	39	3.3	3
Age group 45-64	8	3.8	3.5	10	2.7	2.5	19	1.3	1	12	3.0	3	25	2.2	2	9	3.3	3

Table 5.35

Householder disturbance scores from indoor air pollution from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	72	2.2	2	80	2.2	2	78	1.9	1	78	1.7	1	83	1.4	0	47	2.0	1
Male	38	2.0	1	38	2.4	2	33	1.6	1	39	1.0	0	37	1.1	0	20	1.9	1
Female	34	2.5	2	42	2.0	2	45	2.1	1	39	2.0	2	46	1.5	0	27	2.1	2
Current smokers	21	2.0	2	24	2.6	2	42	2.1	1	20	2.0	2	33	1.2	0	17	1.7	1
Current non-smokers	50	2.4	2	56	2.0	2	36	1.6	0	58	1.4	0	50	1.4	0	30	2.2	1.5
Age group 18-24	10	1.4	1	13	2.5	2	22	1.5	1	-	-	-	13	0.8	0	-	-	-
Age group 25-44	31	2.4	2	30	2.4	2	26	2.3	2	26	1.6	1.5	25	1.1	0	14	2.3	2
Age group 45-64	18	3.3	4	20	2.1	2	19	2.3	0	35	1.7	0	27	1.5	0	14	2.1	1.5
Age group 65+	13	1.2	0	17	1.6	2	10	1	0	14	1.1	0	17	1.8	0	19	1.7	1

Birmingham and Cardiff, with median scores varying from 0 to 2. These figures are consistent with the indoor disturbance scores for dust/dirt and smoke, fumes and odour in suggesting that the average respondent was not very disturbed by indoor air pollution from road traffic. Once again, female respondents and those in the 25-64 age group generally show the greatest disturbance, with the 45-64 group at Birmingham showing statistically higher scores than respondents who were 65+.

At each survey site, the disturbance scores may be slightly biased by factors such as the age, gender and socio-economic class of the respondent. However, with these considerations in mind, it is possible to see some general trends emerge from the figures in Tables 5.31-5.35. Respondents showed more concern about indoor dust/dirt than smoke, fumes and odour, which is consistent with the data shown in Figures 5.3(a, b, g & h). The disturbance scores for indoor dust/dirt were statistically significantly higher than the indoor disturbance scores from smoke, fumes and odour at the household sites in Birmingham, Cardiff and Edinburgh. Female respondents generally showed greater disturbance than males for each nuisance, and middle-aged respondents, particularly those in the 45-64 age group, often displayed higher disturbance than younger or older respondents. The mean disturbance scores for all respondents at each location are usually below the mid-points of the scales utilized, which probably indicates that the majority of respondents experience only minor-moderate indoor disturbances from vehicle-derived air pollution.

Householders who registered indoor disturbance from smoke, fumes and odour and dust\dirt from road traffic on the 7-point scale were asked to state specifically what it was about the pollutants that bothered or disturbed them. The actual smell of the traffic fumes caused the most annoyance, with 3-25% of the respondents complaining specifically about an unpleasant odour. Other responses included:

- complaints about the soiling effects of traffic fumes on indoor surfaces
- concern about the effects of the fumes on people's health
- annoyance at not being able to open windows because of the fumes
- general non-specfic concern for the environment
- complaints about the fumes causing irritation effects such as eye, nose and throat aggravation

Most of the householders who were disturbed by indoor dust/dirt (22-49% of the total respondents, depending on site location) complained about indoor soiling of items such as furniture, carpets, windows, curtains and nets.

Household respondents were asked about household jobs that were affected by air pollution from road traffic. Between 27-53% of the total respondents stated that there were some household jobs affected by air pollution from road traffic, and all of them complained about extra work caused by soiling. Specific responses included complaints about soiling of windows, window sills, curtains, washing, exterior paintwork, car bodies and vegetation.

The relative importance of indoor traffic-induced nuisances was investigated by asking commercial and household respondents to rank five traffic-induced nuisances in order of disturbance when they were inside their homes. The relative rankings shown in Table 5.36-5.37 consistently indicate that noise caused the greatest indoor traffic-induced disturbance, with dust and dirt second and smoke, fumes and odour third. Vibrations and danger from road traffic were consistently ranked fourth and fifth respectively as indoor traffic-related disturbances, although householders at Birmingham and Wood Green were suffiently disturbed by vibrations to rank them second overall.

5.7 Indoor health/irritant effects

To identify the precise nature of the nuisances effecting the public, household and business respondents were asked whether they were ever disturbed by a range of health/nuisance effects inside their homes/businesses. The pilot survey results are shown in Table 5.38. They again indicate that dust/dirt is the major contributor to indoor nuisance effects, with approximately two thirds of business people and one quarter of householders complaining about dirt on their clothes, skin, nails or hair. The lower percentage of householders stating that they are bothered by the listed problems is possibly due to the methodological effect discussed in Section 5.5. When the respondents were asked what they thought caused the nuisance effects, less than 10% of the sample population felt that road traffic/pollution from road traffic was to blame for any of the problems listed in Table 5.38. Forty percent of those household respondents who said that they were disturbed by sneezing (48% of the total respondents) thought that this was caused by dust/dirt, and 80% of householders bothered by dust/dirt blamed its presence on road traffic.

The question was modified for the main household and commercial surveys to assess the magnitude of the respondents' concern about each health/nuisance effect. Some of the effects used in the pilot survey were also dropped from the question. The results are discussed in greater detail in Sections 5.7.1-5.7.5.

Table 5.36
Relative rankings of indoor traffic related disturbances - **household respondents.**

Indoor disturbance	Birmingham		Cardiff		Coventry		Edinburgh		Sheffield		Wood Green	
	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank
Noise from road traffic	1.8	1	1.6	1	1.8	1	2.0	1	1.5	1	2.1	1
Dust & dirt from road traffic	3.0	3	3.0	2	2.6	2	2.9	2	3.0	2	3.2	3
Smoke, fumes & odour from road traffic	3.0	3	3.0	2	2.7	3	3.0	3	3.1	3	3.4	4
Vibrations from road traffic	2.6	2	3.1	4	3.1	4	3.2	4	3.1	3	2.5	2
Danger from road traffic	4.5	5	4.1	5	4.7	5	3.8	5	4.1	5	4.5	5

* Mean Ranking Score

Table 5.37
Relative rankings of indoor traffic related disturbances - **commercial respondents.**

Indoor disturbance	Birmingham		Cardiff		Coventry		Edinburgh		Sheffield		Wood Green	
	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank
Noise from road traffic	2.3	1	2.6	3	1.9	1	1.8	1	2.2	1	2.1	1
Dust & dirt from road traffic	2.5	3	2.4	2	3.2	4	2.6	2	2.4	2	2.5	2
Smoke, fumes & odour from road traffic	2.4	2	2.1	1	2.8	2	2.9	3	2.5	3	3.1	3
Vibrations from road traffic	3.5	4	3.9	4	2.9	3	3.3	4	3.6	4	3.2	4
Danger from road traffic	4.3	5	4.0	5	4.0	5	4.3	5	4.3	5	4.1	5

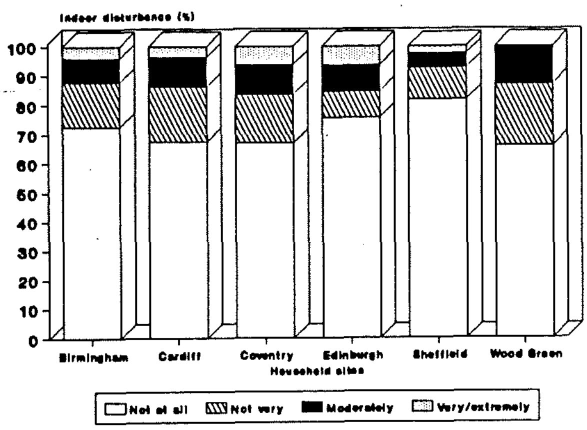
* Mean Ranking Score

Table 5.38
Response to the pilot question 'when you are inside (the shop/your home), are you ever bothered or disturbed by any of the following problems?'.

Health/nuisance effect	% bothered or disturbed	
	Business	Household
Sore or runny eyes	48	16
Sneezing	54	48
Irritated throat	39	23
Unpleasant taste in your mouth	36	9
Dirt on your clothes	69	23
Dirt on your skin, nails or hair	67	27
Headaches	62	25
Difficulty in breathing	20	23

5.7.1 Sore or runny eyes

Indoor disturbance from sore or runny eyes was generally very low, as illustrated in Figure 5.4(a-b). Disturbance indoors from sore or runny eyes at the commercial sites was approximately 20% higher than at the household sites, with 38-57% of commercial respondents claiming some degree of annoyance. In contrast, between 66-82% of householders at each location were not bothered at all by sore or runny eyes.



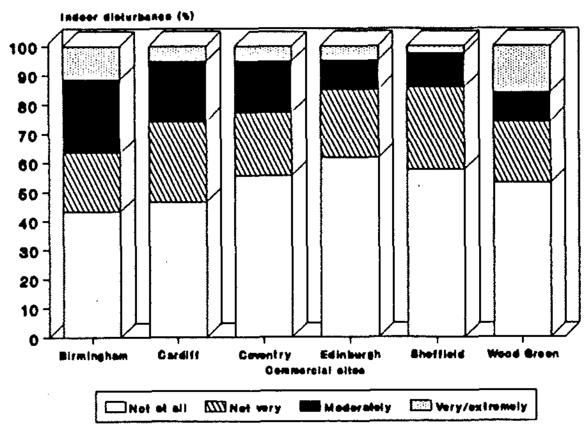


Figure 5.4 (a-b)
Indoor disturbance from sore or runny eyes at household and commercial sites.

5.7.2 Sneezing

The level of indoor disturbance from sneezing is illustrated in Figure 5.5(a-b). Disturbance was generally low at the household sites, with 65-70% of respondents showing no disturbance (except at Cardiff, where over 50% of residents showed some degree of annoyance). At the commercial sites, the figures were higher, with 49-69% of respondents reporting indoor disturbance from sneezing.

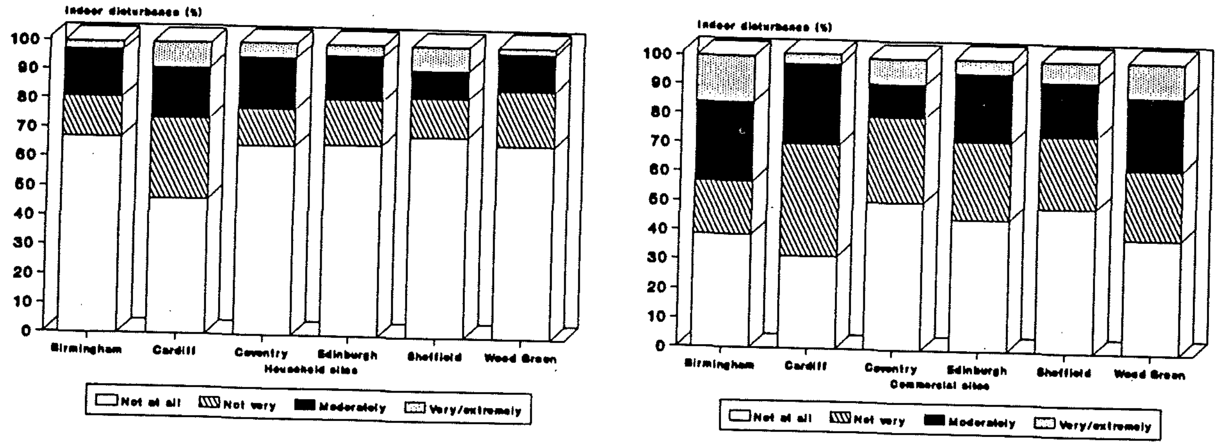


Figure 5.5 (a-b)
Indoor disturbance from sneezing at household and commercial sites.

5.7.3 Soiling

Two types of indoor disturbance from soiling were investigated; dirt on clothing and on skin, nails or hair. The highest level of disturbance was observed at the commercial sites, with 46-67% and 49-71% being irritated to some degree by dirt on clothing and skin, nails or hair respectively, as illustrated in Figures 5.6(a-b) and 5.7(a-b). However, the data indicates that 24-35% of those disturbed by bodily soiling and 26-34% of those disturbed by soiled clothes were not very bothered by these nuisances. At the residential sites, disturbance from soiling was generally very low.

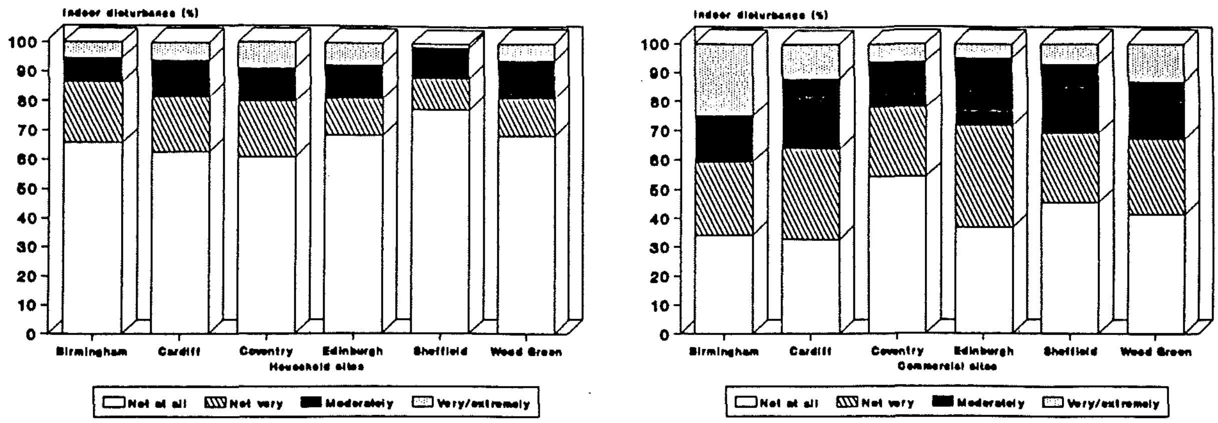


Figure 5.6 (a-b)
Indoor disturbance from dirt on clothes at household and commercial sites.

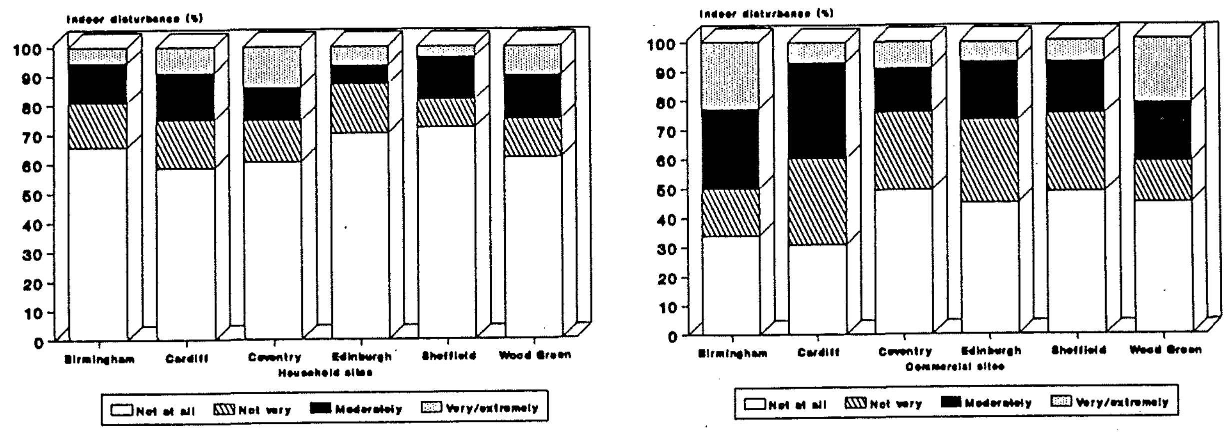


Figure 5.7 (a-b)
Indoor disturbance from dirt on skin, nails or hair at household and commercial sites.

5.7.4 Irritation of the throat

The level of indoor disturbance from irritation of the throat is shown in Figure 5.8(a-b). Disturbance at commercial sites was again higher than at residential sites, with 51-69% showing some degree of annoyance compared to 28-41% of householders.

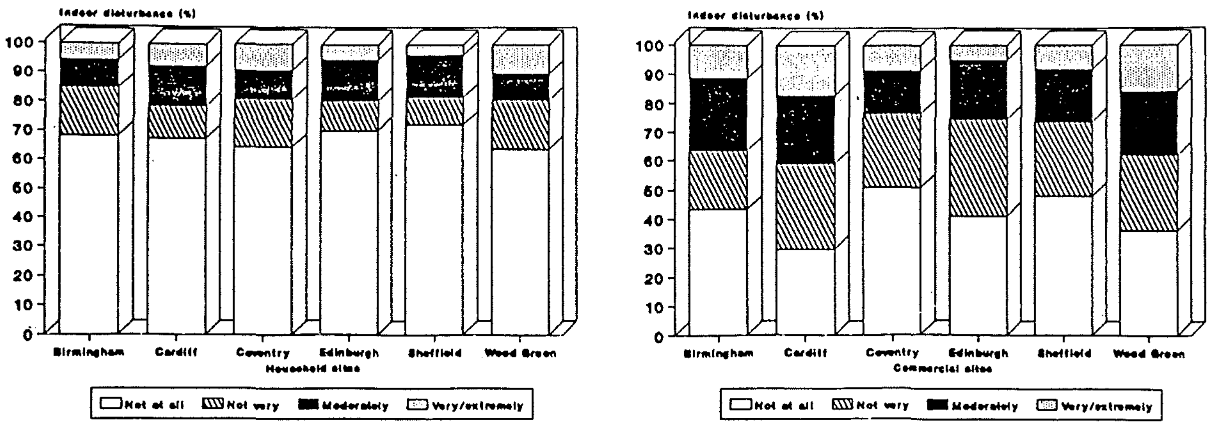


Figure 5.8 (a-b)
Indoor disturbance from throat irritation at household and commercial sites.

5.7.5 Causes of irritation

Those household respondents who indicated some degree of indoor disturbance from the health nuisance effects discussed in Sections 5.6.1-5.6.4 were asked to state what they thought was the main cause of that disturbance. A wide range of reasons were given, including gas fires, hayfever, general air pollution, atmospheric dryness, health reasons and smoking, house dust, bonfires and wind, with traffic pollution and dust/dirt being the two most popular answers.

5.8 Outdoor nuisance effects

5.8.1 Pilot survey

The level of outdoor disturbance in Ealing to all three target groups from a range of effects is listed in Table 5.39. Business people generally show more disturbance than both householders and pedestrians, which is consistent with the figures for indoor disturbance discussed in Section 5.6. This may reflect the different circumstances and/or the different occupational class ratios of the three target groups (see Table 5.13). The data suggests that the majority of business respondents and at least 50% of pedestrians and householders were disturbed by smoke, fumes or odour, dust/dirt and noise when they were out walking in Ealing. Smog and the blackening of building walls disturbed less people, although they still affected 20 - 40% of respondents.

Respondents were also asked what they thought caused the outdoor effects listed in Table 5.39. Fifty percent of the total pedestrian and household respondents thought that pollution from road traffic was primarily responsible for the smoke, fumes or odour and dust/dirt in Ealing, and between 20-30% thought that vehicle-generated pollution was the main cause of the blackening of building walls. The figures relating to road traffic for the household and pedestrian surveys are summarised in Table 5.40.

Table 5.39
Responses to the question 'when you are out walking in Ealing, can you please tell me if you are ever bothered or disturbed by any of these effects?'

Effect	% bothered or disturbed		
	Business	Household	Pedestrian
Smoke, fumes or odour	93	70	69
Dust & dirt	93	67	57
Noise	93	81	61
Smog	24	16	21
Blackening of building walls	38	42	33

Householders and respondents were asked to indicate how much they were bothered outdoors by exhaust fumes and dust/dirt from road traffic using the 5-point scale displayed in Figure 5.2. The results are illustrated in Table 5.41. The mean disturbance scores for household and pedestrian respondents are above the mid-point of the 5-point scale, suggesting that the outdoor disturbance from vehicle-derived exhaust fumes and dust/dirt to the average respondent was moderate-fairly high. For both respondent types, the mean disturbance scores for female respondents were higher than those for males and the 65+ age group had the lowest mean scores. In the household survey, non-smoking respondents had a higher disturbance score than smokers. These data are consistent with the data for indoor disturbance presented in Table 5.29. A comparison of the sampling distributions for male/female and smoking/non-smoking respondents using non-parametric statistics indicates that there are no significant differences between the median outdoor disturbance scores from vehicle-induced exhaust fumes and dust/dirt. However, non-parametric ANOVA of the scores for different age groups of both respondent types suggests that the lower disturbance scores of those people in the 65+ age group are statistically significant.

The time periods during which householders and pedestrians in Ealing were most bothered by vehicle-generated pollution are shown in Table 5.42. The disturbances are clearly not confined to any specific time of day, since over one third of household and pedestrian respondents chose more than one time period. The pedestrian responses were very evenly spread between 7.00

Table 5.40
Response to the pilot question 'In Ealing, what do you think is the main cause of the .... (name effect)?'

	Pilot survey responses (%)				
	Smoke, fumes or odour	Dust & dirt	Noise	Smog	Blackening of building walls
Household respondents					
Pollution from road traffic	56 (83)	33 (50)	51 (63)	12 (62)	30 (72)
Pollution from road traffic & other	9 (14)	19 (29)	21 (26)	5 (25)	9 (22)
Amount of road traffic	0	2 (4)	2 (3)	0	0
Pedestrian respondents					
Pollution from road traffic	57 (84)	24 (42)	48 (79)	13 (60)	20 (61)
Pollution from road traffic & other	6 (8)	10 (17)	9 (16)	1 (7)	5 (14)
Pollution/Air pollution	0	0	0	1 (5)	1 (4)
The figures without brackets represent data from all the respondents. The figures in brackets represent only respondents who answered 'yes' or 'sometimes' to the above question.					

am and 7.00 *pm*, although 45% of those who selected more than one time period (17% of the total pedestrian respondents) stated that they were most bothered between the peak traffic flow periods of 7.00-10.00 *am* and 4.00-7.00 *pm*. This question was not used in the follow-up survey.

5.8.2 Main surveys

The pilot question (stated in Table 5.39) did not give any information about the frequency of outdoor disturbance from different nuisance effects, and was therefore modified for the main survey. These data are illustrated in Figures 5.9-5.13. The frequency of outdoor disturbance from noise is shown in Figures 5.9(a-d). Commercial respondents and householders at each location reported a high frequency of outdoor disturbance, with at least 70% being bothered some of the time. The frequency of disturbance at pedestrian sites is more variable, with markedly lower disturbance at the commercial sites in Coventry and Sheffield and the residential site in Edinburgh. The frequency of outdoor disturbance from smoke, fumes and odour is generally high, as illustrated in Figures 5.10(a-d). Commercial respondents report the greatest frequency of irritation, with between 36-58% of respondents being disturbed frequently or all the time. Outdoor disturbance from dust and dirt is shown in Figures 5.11(a-d). Commercial respondents again show the highest frequency of annoyance, with at least 90%

being bothered some of the time and 40% being bothered frequently or all the time. Disturbance from smog and the blackening of building walls is clearly lower than from the other three nuisances, as illustrated in Figures 5.12-5.13(a-d).

Table 5.41
Response to the pilot question '... can you please choose a number which indicates overall, how much you are bothered by exhaust fumes and dust and dirt from road traffic when you are out walking?'

	Respondent group	Number of respondents	Disturbance score	
			Mean	Median
Household respondents	All	44	2.23	2
	Male respondents	18	1.94	2
	Female respondents	26	2.42	3
	Current smokers	13	1.8	2
	Current non-smokers	31	2.4	2
	Age group 25-44	21	2.50	2.5
	Age group 45-64	9	2.44	2
	Age group 65+	12	1.42	1.5
Pedestrian respondents	All	209	2.36	2
	Male respondents	112	2.25	2
	Female respondents	97	2.48	2
	Age group <18	12	2.25	2
	Age group 18-24	61	2.30	2
	Age group 25-44	75	2.60	2
	Age group 45-64	34	2.54	2.25
	Age group 65+	26	1.73	2

Table 5.42
Public response to the question "When you are outdoors in Ealing, at which time of day are you most bothered by exhaust fumes and dust and dirt from road traffic?".

	Pilot survey responses (%)	
	Household	Pedestrian
Before 7.00 *am*	0	0
Between 7.00 *am* & 10.00 *am*	23	14
Between 10.00 *am* & 1.00 *pm*	10	14
Between 1.00 *pm* & 4.00 *pm*	8	13
Between 4.00 *pm* & 7.00 *pm*	18	16
After 7.00 *pm*	0	1
More than 1 time period	41	37
Not bothered at any time	0	6

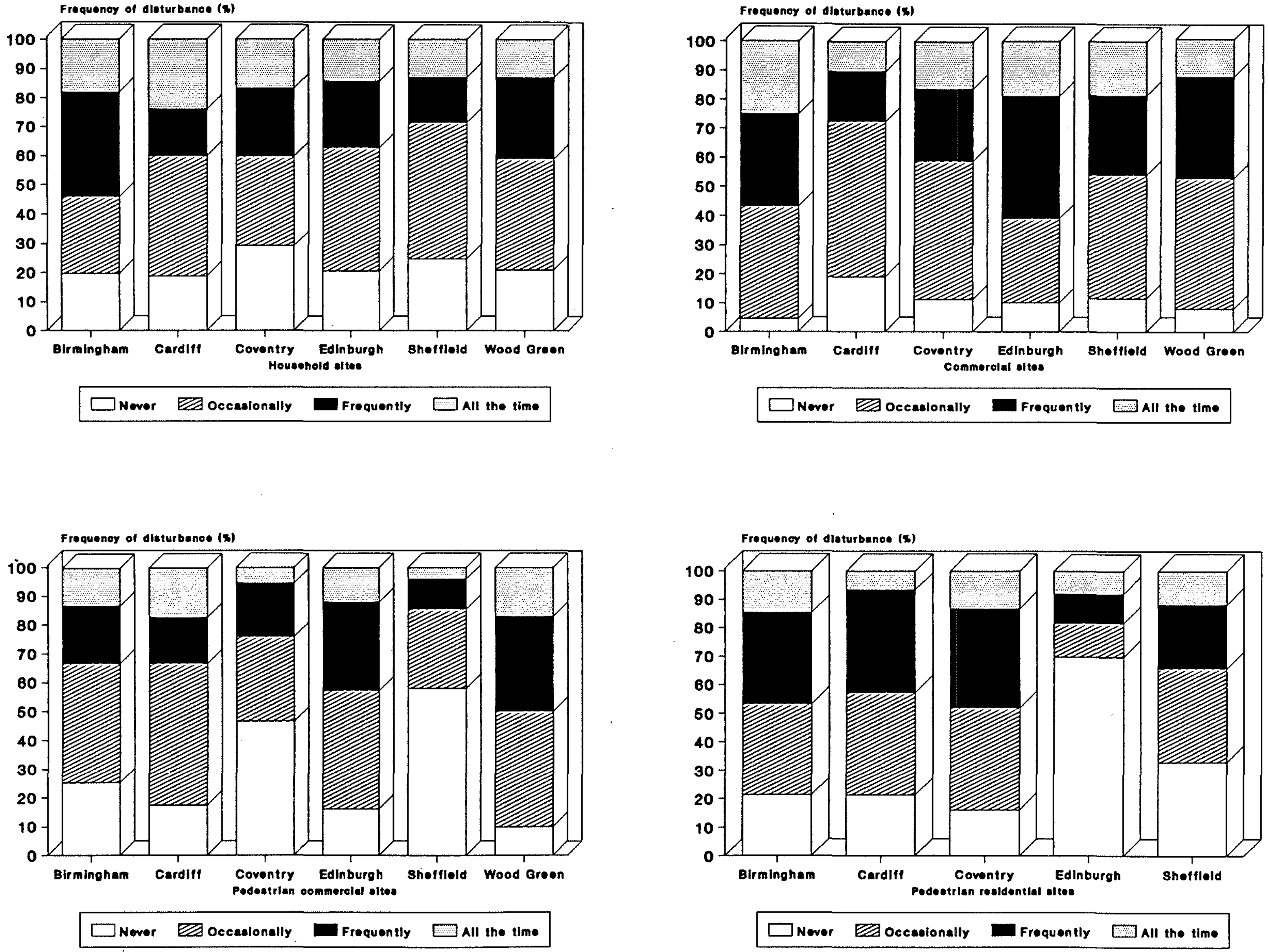


Figure 5.9(a-d)

Frequency of outdoor disturbance from noise.

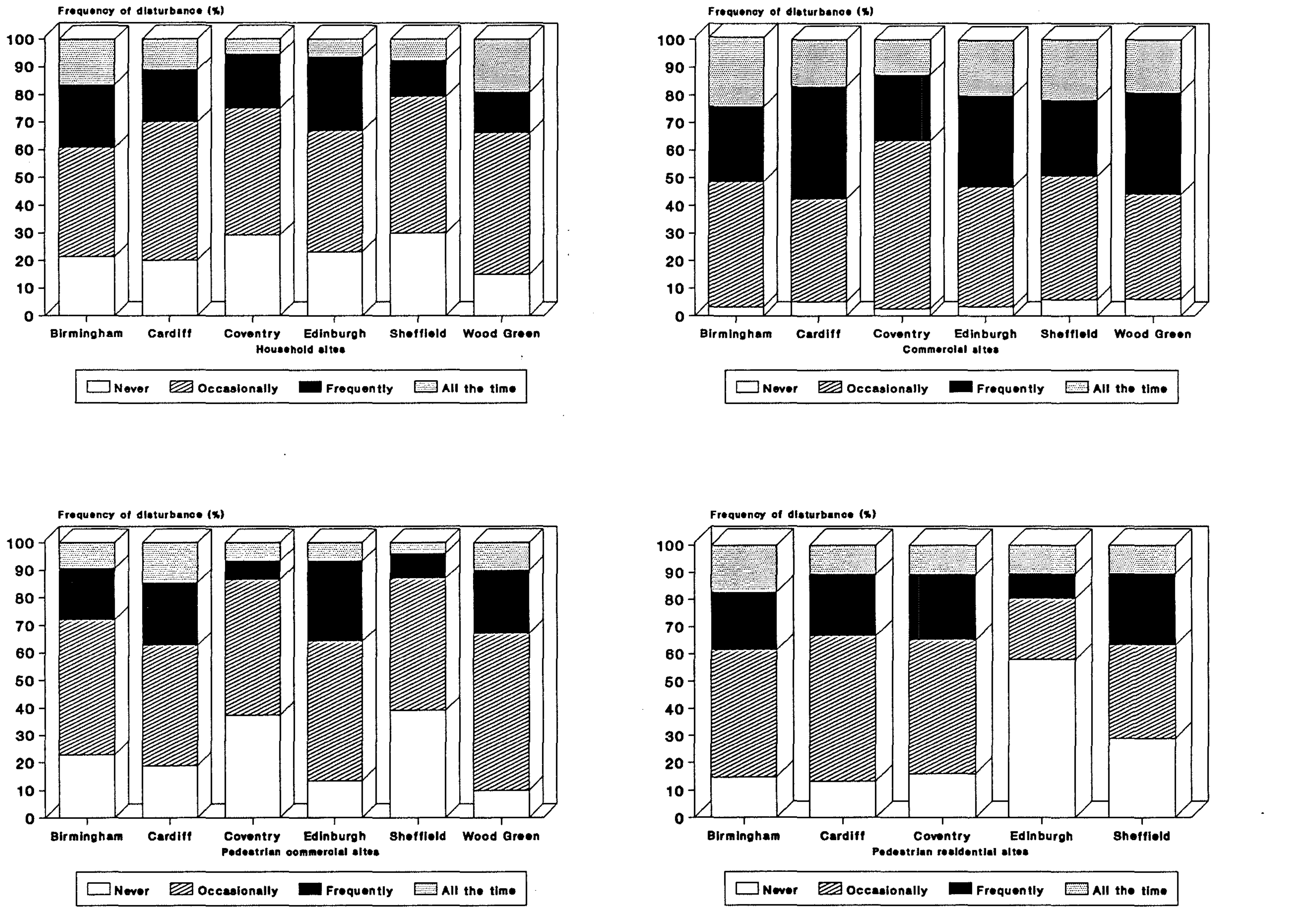


Figure 5.10(a-d)
Frequency of outdoor disturbance from smoke, fumes and odour.

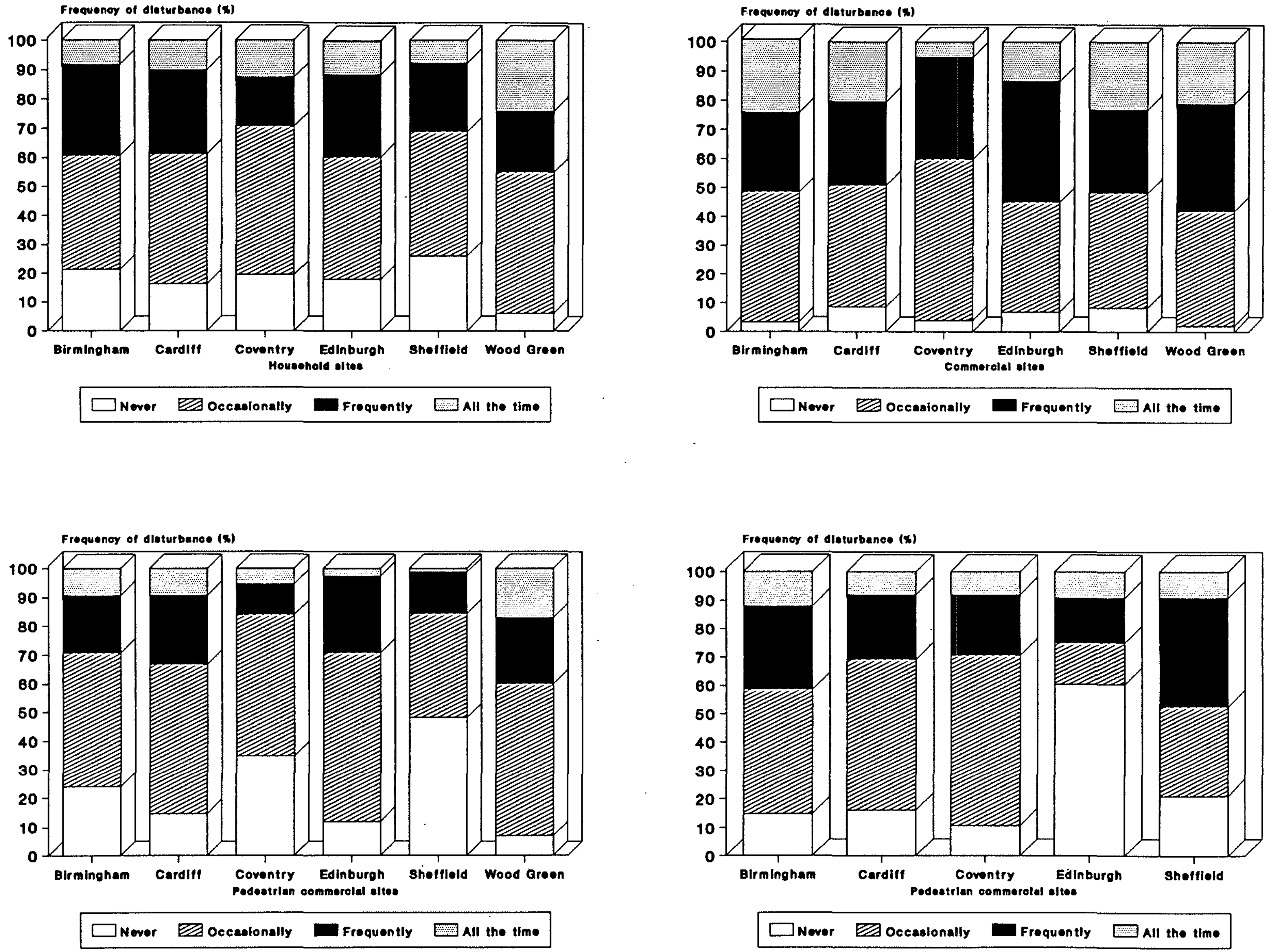


Figure 5.11(a-d)
Frequency of outdoor disturbance from dust/dirt.

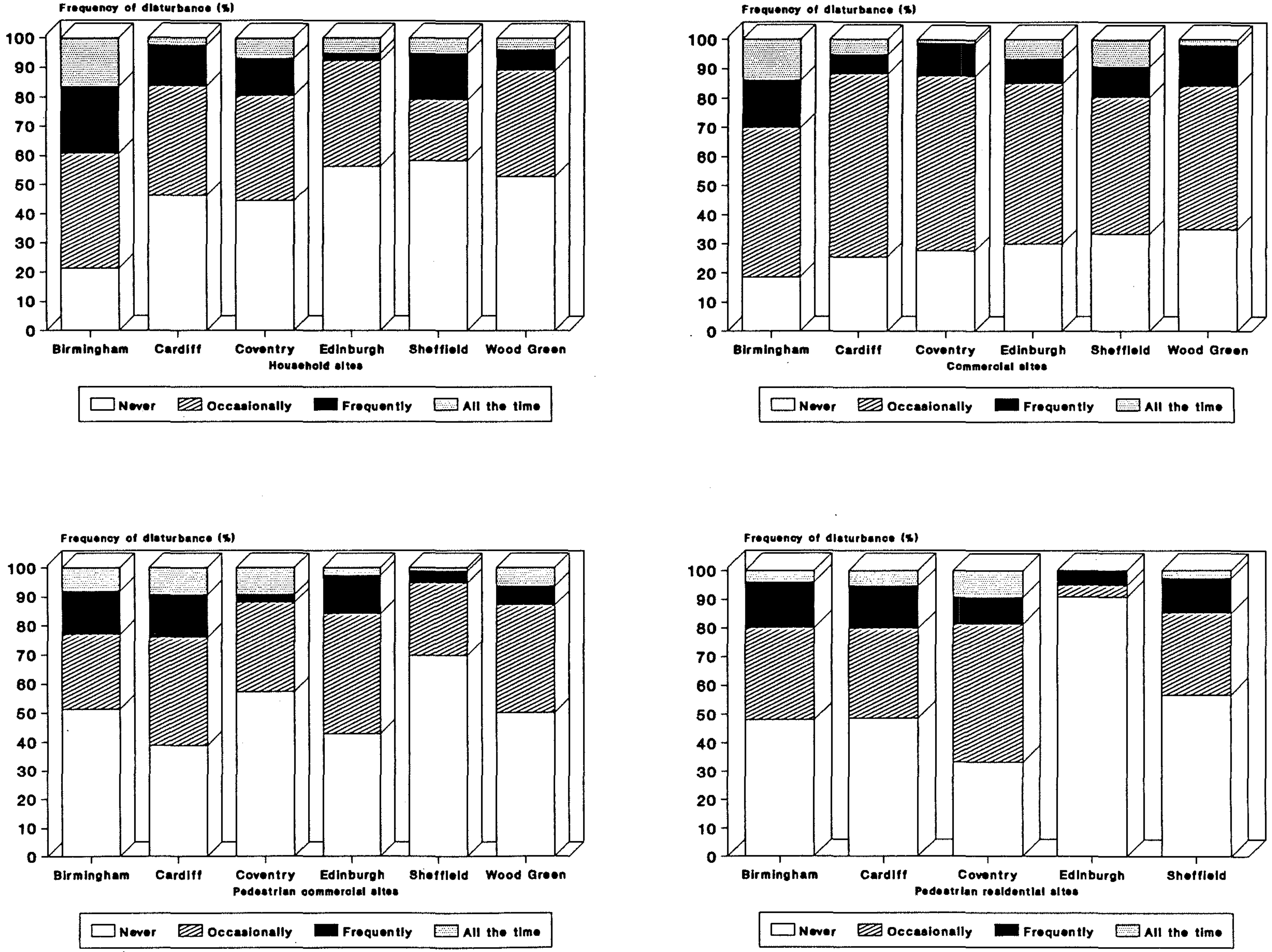


Figure 5.12(a-d)
Frequency of outdoor disturbance from the blackening of building walls.

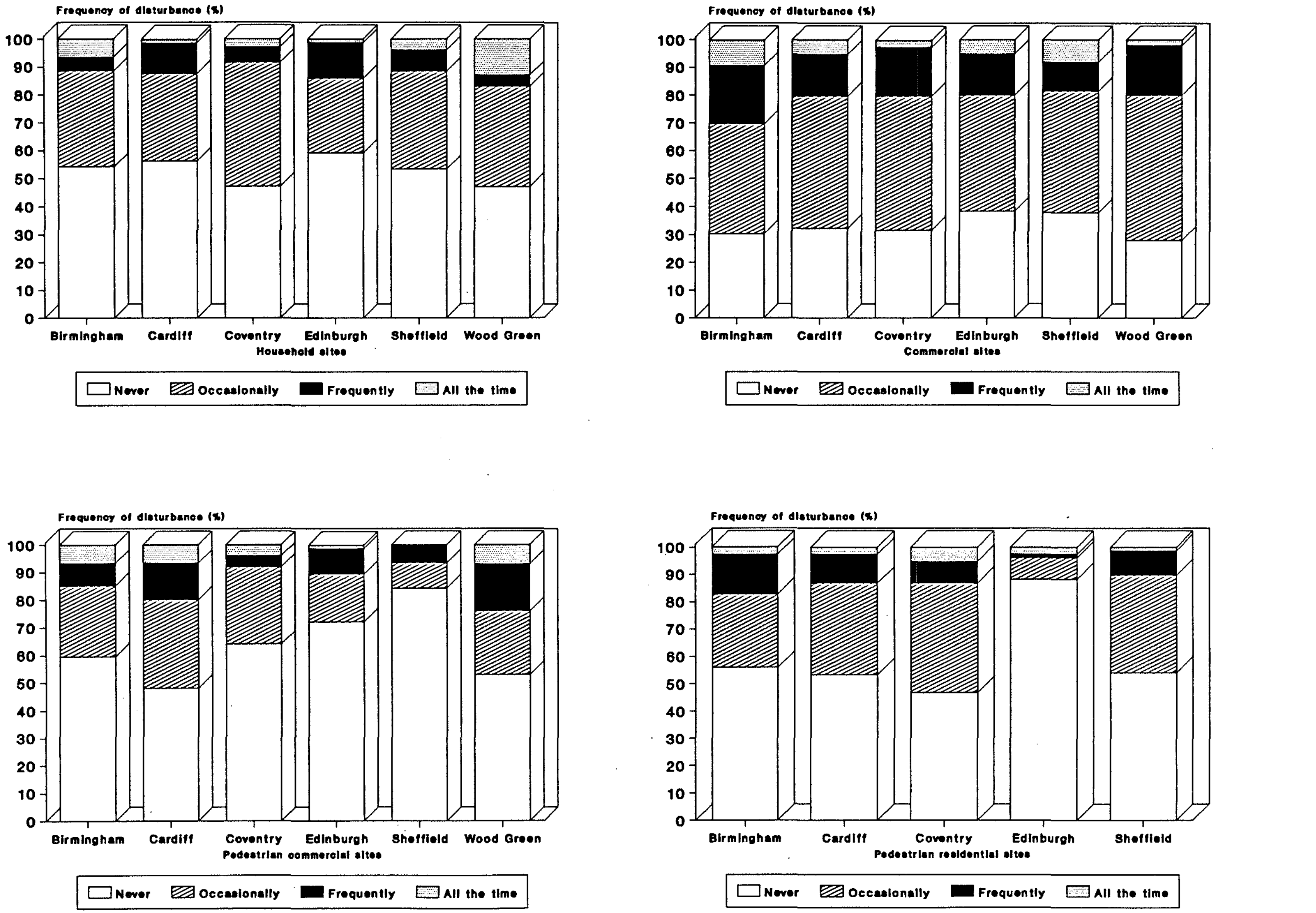


Figure 5.13(a-d)
Frequency of outdoor disturbance from smog.

Respondents were asked to consider the magnitude of outdoor disturbance from vehicle-induced smoke, fumes and odour using the scale described in Section 5.6.2. The results for the four different respondent groups at each location are displayed in Tables 5.43-5.46. With three exceptions (Coventry and Sheffield - pedestrian commercial, Edinburgh - pedestrian residential), the mean outdoor disturbance scores are above the mid-point, ranging from 1.9 to 4.1. The median outdoor disturbance scores are 3-4 at all sites except the pedestrian commercial site in Sheffield (2) and the pedestrian residential site in Edinburgh (0). A more detailed investigation of the data using non-parametric ANOVA reveals that the business disturbance scores at Cardiff are statistically significantly higher than those at Coventry, and that the Edinburgh pedestrian residential score was statistically significantly lower than those at Birmingham, Coventry, Sheffield and Cardiff. Wood Green, Edinburgh, Cardiff and Birmingham respondents had significantly higher disturbance scores than those at Sheffield at the pedestrian commercial sites. At these sites, Wood Green and Edinburgh respondents also had significantly higher scores than respondents from Coventry. <u>At all 10 household and commercial sites</u>, the outdoor figures are statistically significantly higher than those for indoor disturbance from traffic-produced smoke, fumes and odour (see Section 5.6.2). Overall, the data indicates that the average respondent is moderately-very bothered by outdoor smoke, fumes and odour from road traffic.

The data also suggests that the average commercial respondent is slightly more irritated by this nuisance than pedestrians and householders, which is consistent with the data described in Section 5.6.2. At all sites, female respondents generally showed higher disturbance than males, although only at the business sites in Cardiff and Coventry and the household site in Edinburgh were the female scores statistically significantly higher. Middle-aged respondents (25-64) generally showed more concern than younger or older respondents, with statistically significant data occuring at the pedestrian commercial sites in Cardiff and Sheffield, the pedestrian residential site at Cardiff, and the household sites in Birmingham and Coventry..

The magnitude of outdoor disturbance from vehicle-induced dust/dirt was measured using the scale described in Section 5.6.2. The results for the four different respondent groups at each location are displayed in Tables 5.47-5.50. The mean outdoor disturbance scores are generally around the mid-point, ranging from 1.4 to 4.0. The median outdoor disturbance scores are 3-4 at all sites except the pedestrian commercial sites in Coventry (2) and Sheffield (1), and the pedestrian residential site in Edinburgh (0). Analysis of the data using non-parametric ANOVA shows that the business and pedestrian residential disturbance scores at Coventry and Edinburgh were statistically significantly lower than those at Birmingham, Sheffield, Edinburgh and Wood

Table 5.43
Householder disturbance scores from outdoor smoke, fumes and odour from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	73	3.3	4	80	3.7	4	78	3.3	4	78	3.3	3	83	3.3	3	47	3.8	4
Male	38	2.8	3	38	3.6	4	34	3.3	3.5	39	2.9	3	37	3.1	3	20	3.7	3.5
Female	35	3.8	4	42	3.8	4	44	3.3	4	39	3.7	4	46	3.4	4	27	3.9	4
Current smokers	21	3.3	3	24	3.8	4	42	3.4	4	20	3.4	4	33	3.0	3	17	3.6	3.5
Current non-smokers	51	3.3	4	56	3.7	4	36	3.2	4	58	3.3	3	50	3.5	4	17	3.8	4
Age group 18-24	10	3.4	4	13	3.8	4	23	2.7	3	-	-	-	13	3.2	3	-	-	-
Age group 25-44	31	3.4	4	30	4.1	4	26	3.8	4	26	3.6	3	25	3.3	4	14	4.4	4.5
Age group 45-64	18	4.4	5	20	3.8	4	18	3.8	4	35	3.4	4	27	3.4	4	14	3.6	3.5
Age group 65+	14	1.6	1	17	2.9	3	10	2.5	2	14	2.7	3	17	3.2	4	19	3.6	4

Table 5.44
Commercial disturbance scores from outdoor smoke, fumes and odour from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	43	4.1	4	58	4.0	4	81	3.3	3	60	4.0	4	86	4.0	4	51	3.9	4
Male	23	4.0	4	28	3.4	4	43	3.0	3	31	3.6	4	36	3.6	3.5	28	3.9	4
Female	20	4.1	4.5	30	4.6	5	38	3.6	4	28	4.3	5	48	4.2	4	22	4.0	4
Age group 18-24	12	3.5	3.5	13	3.9	4	19	3.3	3	13	4.4	5	16	4.0	4	-	-	-
Age group 25-44	23	4.2	4	32	3.9	4	41	3.6	4	30	3.9	4	44	3.9	4	39	3.9	4
Age group 45-64	8	4.6	5	11	4.7	5	19	2.6	2	12	3.5	3.5	25	4.0	4	9	4.2	5

Table 5.45
Pedestrian commercial disturbance scores from outdoor smoke, fumes and odour from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	75	3.2	3	75	3.4	3	75	2.7	3	75	3.7	4	77	1.9	2	30	4.2	4
Male	38	2.7	3	40	3.1	3	34	2.7	3	38	3.5	4	37	1.9	2	17	3.6	4
Female	37	3.7	4	35	3.7	3	41	2.8	3	37	4.0	4	40	1.9	1	13	5.0	6
Age group 18-24	16	2.9	3.5	28	2.8	3	15	2.5	2	17	3.6	4	15	0.5	0			
Age group 25-44	26	3.1	3	23	4.3	4	26	2.7	3	23	4.1	4	27	2.4	2	11	4.5	4
Age group 45-64	24	3.5	4	16	3.2	3	23	3.3	4	23	3.6	4	21	2.1	2			
Age group 65+	9	3.3	3	7	3.1	3	9	1.9	1	12	3.3	3.5	14	2.1	1			

Table 5.46

Pedestrian residential disturbance scores from outdoor smoke, fumes and odour from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	75	4.0	4	74	3.4	3	75	3.6	4	76	2.0	0	76	3.4	4
Male	37	3.6	5	33	3.2	3	36	3.9	4	36	1.9	0	35	3.1	3
Female	38	4.2	4	41	3.5	4	39	3.4	4	40	2.1	0	41	3.5	4
Age group 18-24	13	3.0	4	10	3.4	3.5	19	3.5	4	9	2.0	0	11	3.5	4
Age group 25-44	28	4.1	5	32	3.5	4	26	3.8	4	30	2.5	2.5	37	3.0	3
Age group 45-64	23	4.4	5	18	3.8	4	16	3.4	4	20	2.0	0	15	3.7	5
Age group 65+	10	3.9	4	11	2.1	2	14	3.8	5	16	1.1	0	12	3.7	4

Table 5.47
Householder disturbance scores from outdoor dust/dirt from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	73	3.0	3	80	3.4	4	78	2.9	3	78	2.8	3	83	2.8	3	47	3.1	3
Male	38	2.6	2.5	38	3.3	4	34	2.7	3	39	2.3	3	37	2.7	3	20	3.0	3
Female	35	3.5	4	42	3.4	4	44	3.0	3	39	3.2	3	42	2.9	3	27	3.3	3
Current smokers	21	3.0	4	24	3.9	4	42	3.2	3	20	2.8	3	33	2.5	3	17	2.9	3
Current non-smokers	51	3.1	3	56	3.2	3	36	2.6	2.5	58	2.7	3	50	2.9	3	17	2.9	3
Age group 18-24	10	2.8	3.5	13	3.4	4	23	2.1	2	-	-	-	13	3.1	3	-	-	-
Age group 25-44	31	2.9	3.0	30	3.7	4	26	3.3	3	26	2.6	3	25	2.7	2	14	3.7	3.5
Age group 45-64	18	4.2	5	20	3.4	4	18	4.0	4	35	3	3	27	2.6	3	14	2.7	3
Age group 65+	14	1.8	1	17	2.8	3	10	1.9	0.5	14	2.4	3	17	2.9	4	19	3.0	3.0

Table 5.48
Commercial disturbance scores from outdoor dust/dirt from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	43	4.0	4	58	3.7	4	81	3.0	3	60	3.8	4	86	3.9	4	52	3.8	4
Male	23	4.0	4	28	3.3	3	43	2.9	3	31	3.4	4	36	3.4	3	28	3.8	3.5
Female	20	4.0	4	30	4.1	4	38	3.2	3	28	4.1	4	48	4.2	4	23	3.9	4
Age group 18-24	12	3.5	4	13	3.7	3	19	2.9	3	13	3.5	4	16	4.2	4	-	-	-
Age group 25-44	23	4.1	4	32	3.6	4	41	2.3	3	30	4.0	4	44	3.8	4	40	3.9	4
Age group 45-64	8	4.4	4.5	11	4.4	5	19	2.3	2	12	3.6	3.5	25	3.8	4	9	4.0	4

Table 5.49
Pedestrian commercial disturbance scores from outdoor dust/dirt from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	73	2.4	3	74	3.1	3	75	2.2	2	74	3.0	3	75	1.4	1	30	3.8	4
Male	36	2.2	1.5	39	2.6	2	34	2.0	2	38	2.9	3	36	1.5	1	17	3.0	3
Female	37	2.7	3	35	3.6	4	41	2.4	3	36	3.2	3.5	39	1.3	0	13	4.8	5
Age group 18-24	15	2.5	2	28	2.8	3	15	2.1	2	-	-	-	15	0.7	0			
Age group 25-44	25	2.0	2	22	3.6	3	26	2.2	2.5	23	3.2	3	26	1.2	1	11	4.1	4
Age group 45-64	24	2.8	3.5	16	3.1	3	23	2.6	3				20	1.8	1.5			
Age group 65+	9	2.6	3	-	-	-	9	1.9	2				14	1.7	1			

Table 5.50
Pedestrian residential disturbance scores from outdoor dust/dirt from road traffic.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	75	3.4	3	74	3.1	3	75	3.1	3	76	1.5	0	74	3.4	4
Male	37	3.1	3	33	3.0	3	36	3.3	3	36	1.2	0	35	3.1	4
Female	38	3.8	4	41	3.1	3	39	3.0	3	40	1.8	0	39	3.6	4
Age group 18-24	13	2.6	3	10	3.2	3.5	19	2.9	3	9	1.1	0	11	3.7	3
Age group 25-44	28	3.1	3	32	3.2	3	26	3.1	3	30	2.0	1	37	2.9	3
Age group 45-64	23	4.0	4	18	3.5	3	16	3.3	3.5	20	1.3	0	13	4.1	6
Age group 65+	10	3.8	4	11	1.7	2	14	3.4	4	16	1.1	0	12	3.6	4

Green and Birmingham, Sheffield, Coventry and Cardiff respectively. At the pedestrian commercial sites, respondents at Sheffield had a statistically significantly lower score than those at the other five locations. In addition, respondents at Wood Green, Edinburgh and Cardiff had significantly higher scores than respondents in Coventry and Sheffield, with Wood Green pedestrians also having significantly higher scores than pedestrians in Birmingham. Overall, the data indicates that the average respondent is moderately-very bothered by outdoor dust/dirt from road traffic.

<u>At all of the household and business sites</u>, the outdoor figures are statistically significantly higher than those for indoor disturbance from traffic-induced dust/dirt (see Section 5.6.2), and at every site bar four (Sheffield and Birmingham - business, Sheffield - pedestrian residential and Cardiff - pedestrian commercial), the disturbance scores from outdoor smoke, fumes andodour are statistically significantly higher than those from outdoor dust/dirt. As with the figures for indoor disturbance described in Section 5.6.2, the data suggests that the average commercial respondent shows slightly more irritation from outdoor dust/dirt than pedestrians and householders. Females again showed higher disturbance scores than males, with statistically significant data being obtained at the business sites in Edinburgh and Sheffield, the pedestrian commercial site at Cardiff and the household site in Edinburgh. Middle-aged respondents (25-64) usually showed more concern than younger or older respondents, with significant data occuring at the household sites in Coventry and Birmingham, and the business site in Coventry.

Pedestrian and household respondents gave a range of reasons when asked specifically what bothered them outdoors about smoke, fumes and odour from road traffic. At the household sites, 33-51% of respondents were worried about their health, with a further 10-22% complaining about the odour of the fumes. With the exception of the Edinburgh residential site, pedestrian responses generally showed a slightly higher level of concern about their health (37-71%) and the odour of the traffic fumes (10-37%). Other reasons given included difficulty in breathing, irritation of the throat, sneezing, visual disturbance from smoke, soiling of clothing, skin *etc*, concern for the environment, feelings of nausea and general irritation.Respondents were also asked what bothered them specifically about outdoor dust/dirt from road traffic. At the household sites, 18-32% of respondents complained of health worries and 15-38% of soiling (usually of clothes, skin, hair). Pedestrian responses were more variable, with 14-52% of respondents being worried about their health and 18-37% complaining about soiling. Other responses included irritation of the throat and eyes, sneezing, coughing, an unpleasant taste in the mouth, dizziness, concern for the environment, visual disturbance from smoke and general irritation.

To identify the relative importance of outdoor traffic-induced nuisances, respondents were asked to rank six traffic-induced nuisances in order of disturbance. The relative rankings shown in Tables 5.51-5.54 indicate that danger and smoke, fumes and odour from road traffic were consistently ranked above the other 4 outdoor disturbances.

5.9 Outdoor health/irritant effects

5.9.1 Pilot survey

The target groups were also asked to consider outdoor health/nuisance effects. This question is almost identical to that asked in Section 5.4.6 and hence the methodological problem discussed earlier is also relevant here. No significant increase in annoyance was observed when the pilot survey respondents were asked to consider these effects outdoors rather than indoors. The results for pedestrian respondents show the same pattern as for the other two groups, as shown in Table 5.55.

While over 25% of the pedestrian respondents felt that pollution from road traffic was responsible for the dirt on their clothes, skin, nails or hair, concern about health related effects was generally lower, with less than 12% of pedestrians blaming these effects exclusively on vehicle-derived pollution. If however, we make the assumption that all kerbside air pollution and dust/dirt is traffic generated (a 'worst-case senario'), it is possible to make an estimate of the **maximum percentage** of people who blamed the listed outdoor health/irritant effects on vehicle-generated air pollution, as illustrated in Column E of Table 5.56. Based on this assumption, the estimates indicate that a maximum 45% of pedestrians blamed pollution from road traffic for dirt on their clothes, skin, nails or hair, and 1 in 5 felt that road vehicle pollution was responsible for their sore or runny eyes, sneezing and irritated throat when they were outdoors.

The question was modified for the main household and pedestrian surveys to assess the magnitude of the respondents' concern about each health/nuisance effect, and the results are discussed in Section 5.9.2, with the 'worst-case scenario' discussed in Section 5.9.3.

Table 5.51
Relative rankings of outdoor traffic related disturbances - **household respondents.**

Indoor disturbance	Birmingham		Cardiff		Coventry		Edinburgh		Sheffield		Wood Green	
	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank
Noise from road traffic	3.3	3	3.5	4	3.5	4	3.6	4	3.9	5	3.6	3
Dust & dirt from road traffic	3.6	4	3.5	3	3.1	3	3.5	3	3.5	3	4.0	4
Smoke, fumes & odour from road traffic	2.7	2	2.1	1	2.4	2	2.6	2	2.5	2	2.5	2
Vibrations from road traffic	4.8	6	5.3	6	5.0	6	5.1	6	5.2	6	4.4	6
Danger from road traffic	2.3	1	2.2	2	2.3	1	2.2	1	2.2	1	2.4	1
Splash & spray from road traffic	4.3	5	4.3	5	4.5	5	4.1	5	3.7	4	4.2	5

* Mean Ranking Score

Table 5.52
Relative rankings of outdoor traffic related disturbances - **commercial respondents.**

Indoor disturbance	Birmingham		Cardiff		Coventry		Edinburgh		Sheffield		Wood Green	
	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank
Noise from road traffic	3.7	4	4.2	5	3.2	3	3.6	4	3.7	4	3.6	3
Dust & dirt from road traffic	3.2	3	3.2	3	3.4	4	3.4	3	3.1	3	4.0	4
Smoke, fumes & odour from road traffic	2.0	1	2.1	1	2.5	1	2.3	1	2.2	1	2.5	2
Vibrations from road traffic	5.0	6	5.3	6	5.1	6	5.4	6	5.3	6	4.4	6
Danger from road traffic	2.5	2	2.7	2	2.5	1	2.3	1	2.5	2	2.4	1
Splash & spray from road traffic	4.5	5	3.8	4	4.1	5	4.1	5	4.1	5	4.2	5

* Mean Ranking Score

Table 5.53
Relative rankings of outdoor traffic related disturbances - **pedestrian commercial respondents.**

Indoor disturbance	Birmingham		Cardiff		Coventry		Edinburgh		Sheffield		Wood Green	
	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank
Noise from road traffic	3.1	3	3.4	4	3.3	4	3.5	4	3.4	4	3.2	4
Dust & dirt from road traffic	3.5	4	3.3	3	3.1	3	3.5	3	3.2	3	3.0	3
Smoke, fumes & odour from road traffic	2.0	1	2.2	1	2.2	1	1.9	1	2.5	1	2.1	1
Vibrations from road traffic	5.3	6	5.1	6	5.0	6	5.3	6	4.9	6	5.1	6
Danger from road traffic	2.4	2	2.6	2	3.0	2	2.9	2	2.5	1	2.8	2
Splash & spray from road traffic	4.5	5	4.3	5	4.3	5	3.9	5	4.3	5	4.8	5

* Mean Ranking Score

Table 5.54
Relative rankings of outdoor traffic related disturbances - **pedestrian residential respondents.**

Indoor disturbance	Birmingham		Cardiff		Coventry		Edinburgh		Sheffield	
	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank	MRS*	Overall rank
Noise from road traffic	3.1	4	3.4	4	3.0	3	3.9	5	3.5	4
Dust & dirt from road traffic	3.0	3	3.3	3	3.5	4	3.3	4	2.9	3
Smoke, fumes & odour from road traffic	2.2	1	2.3	1	2.0	1	3.0	2	2.3	1
Vibrations from road traffic	5.0	6	5.0	6	4.9	6	4.9	6	5.3	6
Danger from road traffic	2.8	2	2.8	2	2.9	2	2.0	1	2.8	2
Splash & spray from road traffic	4.9	5	4.2	5	4.6	5	3.0	2	4.1	5

* Mean Ranking Score

Table 5.55
Response to the question 'when you are out walking in Ealing are you ever bothered or disturbed by any of the following problems?'

Health/nuisance effect	Pilot survey responses (%)		
	Business	Household	Pedestrian
Sore or runny eyes	50	19	44
Sneezing	50	46	33
Irritated throat	50	19	26
Unpleasant taste in your mouth	38	19	22
Dirt on your clothes	64	49	53
Dirt on your skin, nails or hair	63	38	47
Headaches	63	21	33
Difficulty in breathing	30	21	18

Table 5.56
Pedestrian response to the question 'In Ealing, what do you think is the main cause of your\the...(name effect)?' (Selected responses shown).

Health/nuisance effect	Pedestrian responses (pilot survey) (%)				
	A	B	C	D	E
	Pollution from road traffic	Pollution from road traffic & other	Pollution\air pollution	General dust & dirt	Sum of A-D
Sore or runny eyes	12	3	4	5	24
Sneezing	6	5	1	8	20
Irritated throat	10	6	4	1	21
Dirt on your clothes	28	8	4	6	46
Dirt on your skin, nails or hair	26	10	4	4	44

5.9.2 Main surveys

Outdoor disturbance from sore or runny eyes is displayed in Figures 5.14(a-d). It is evident that outdoor disturbance at the household and commercial sites was higher than indoor disturbance (see Figures 5.4(a-b)). Disturbance was highest at the commercial sites, with 53-84% claiming some degree of irritation, compared with 45-57% and 24-57% of householders and pedestrians respectively. When respondents were asked what they thought caused the irritation to their eyes, between 7 and 36% blamed pollution from road traffic, depending on site.

The level of outdoor disturbance from sneezing is illustrated in Figures 5.15(a-d). At the pedestrian sites, irritation was very variable, with large differences occuring between sites *eg* the Sheffield and Wood Green commercial locations. Overall, 20-69% of respondents claimed some degree of annoyance from sneezing, with 4-38% pinpointing vehicle-generated pollution as the main cause. Disturbance was higher amongst household and business respondents, with 46-67% and 67-84% respectively stating that they were disturbed by outdoor sneezing. Between 10-28% of householders blamed road traffic pollution for their sneezing.

Outdoor annoyance from irritation of the throat is shown in Figures 5.16 (a-d). Disturbance at the business sites was high, with 72-91% of respondents stating that they were bothered by an irritated throat. Lower levels of disturbance were recorded at the household and pedestrian sites, with 46-67% and 27-72% respectively claiming some degree of outdoor disturbance. Between 23 to 39% of householders and 23 to 56% of pedestrians felt that their irritated throat was caused by vehicle pollution.

Outdoor disturbance from soiling is displayed in Figures 5.17-5.18(a-d). The data reinforce the findings of the pilot survey that people are mainly concerned about dust/dirt, with at least 79% of business-people and 54% of householders being bothered by dust/dirt on their clothes, skin, nails or hair. At least 60% of pedestrians at the residential locations were irritated by outdoor soiling, with the exception of respondents at the Edinburgh site. Annoyance was more variable at the pedestrian commercial sites, ranging from 34 to 76%. Between 23 to 56% of household and pedestrian respondents blamed road traffic pollution for the soiling effects.

5.9.3 The 'worst-case scenario'

The values shown in Table 5.57 represent estimates of the maximum percentage of respondents who blamed vehicle-generated air pollution for the named health/irritant effects under the worst-case scenario described in Section 5.8.1. With the exception of the pedestrian residential location in Edinburgh, where disturbance was markedly lower than at the other sites, 23-51% of the household and pedestrian respondents felt that traffic pollution was at least partly to blame for their sore or runny eyes; 18-49% for sneezing; 23-69% for their irritated throat and 30-80% for soiling. These figures reinforce the findings of the pilot survey (described in Section 5.9.1).

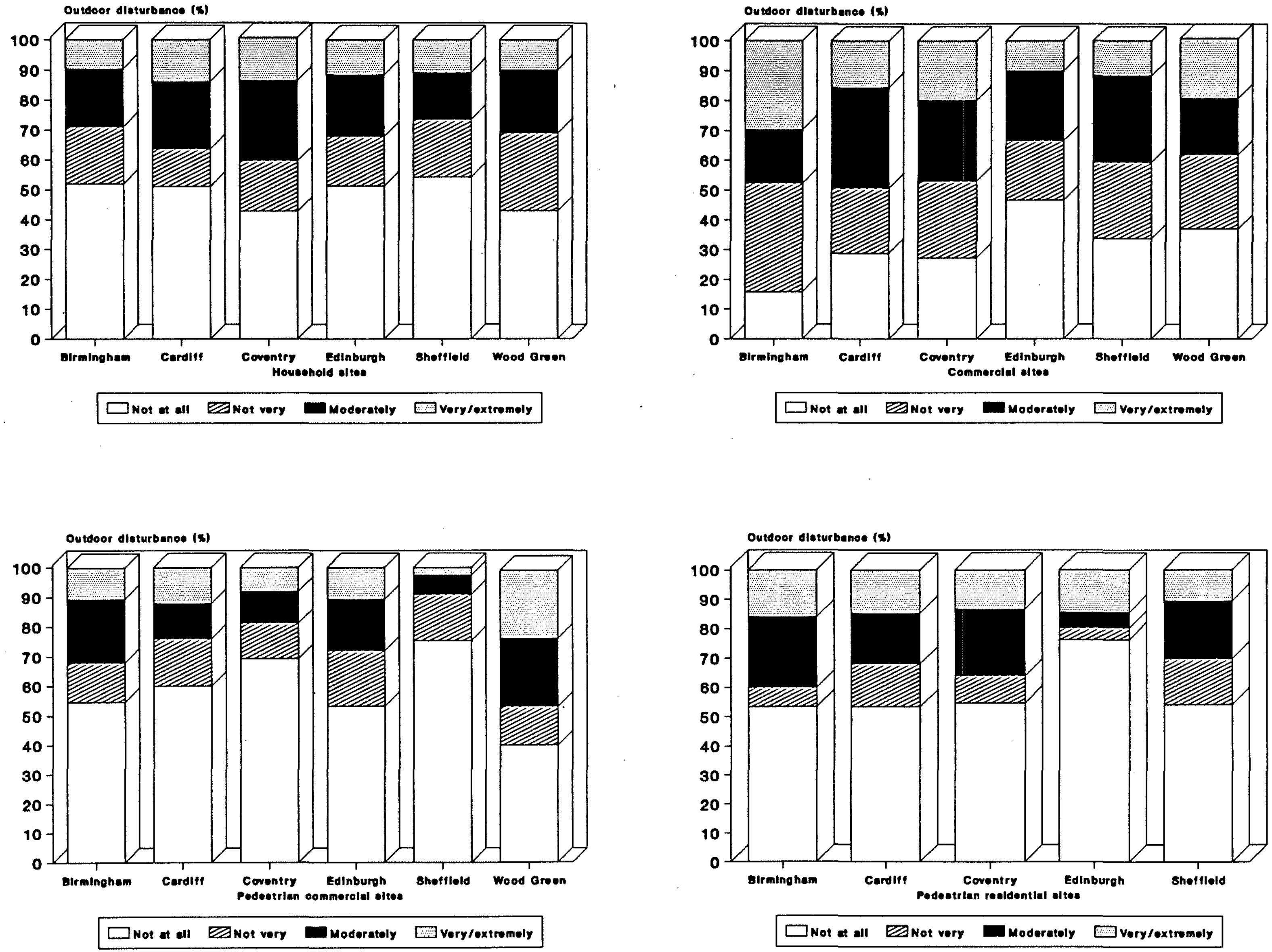


Figure 5.14(a-d).
Outdoor disturbance from sore or runny eyes.

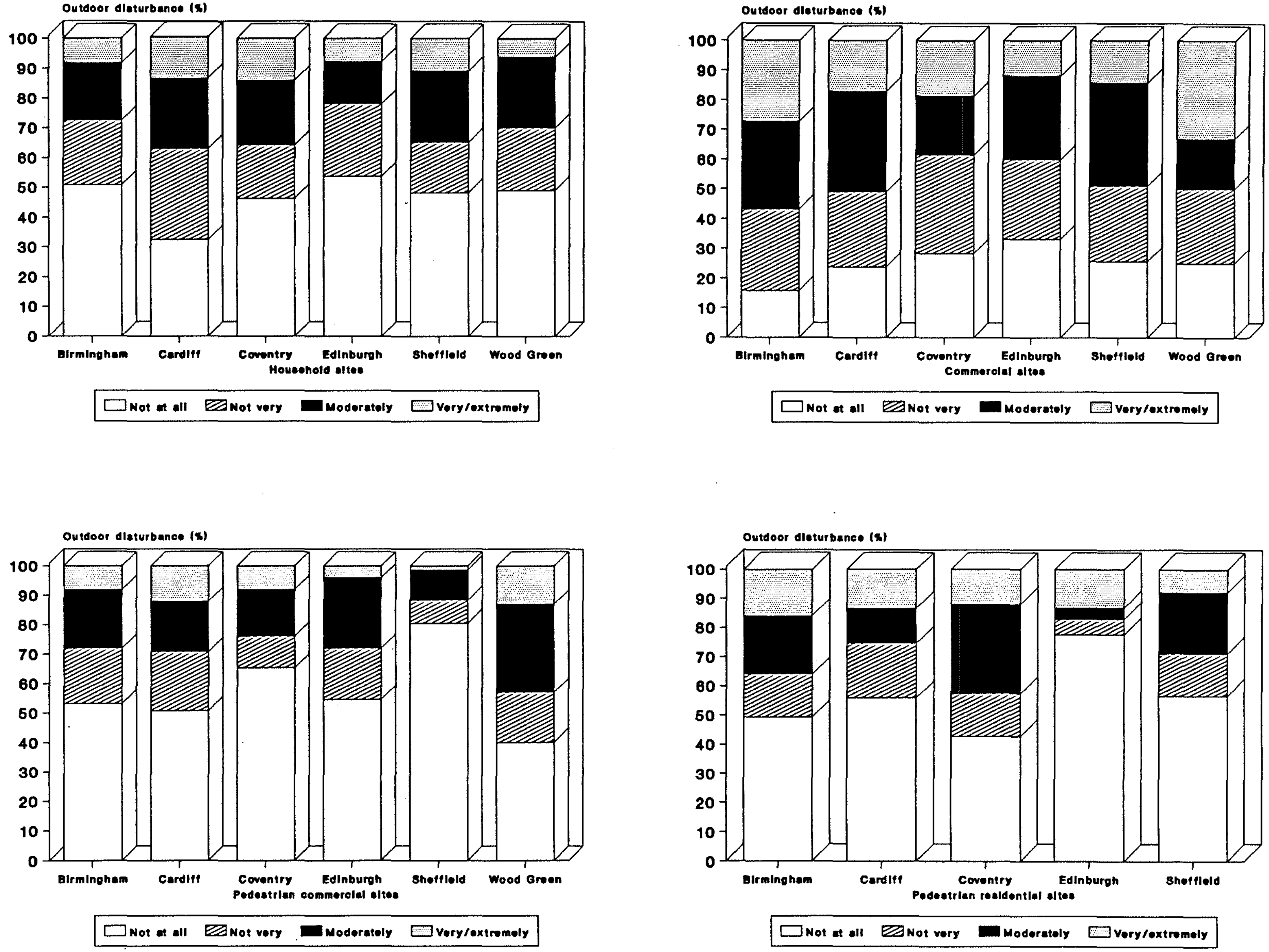


Figure 5.15(a-d).
Outdoor disturbance from sneezing.

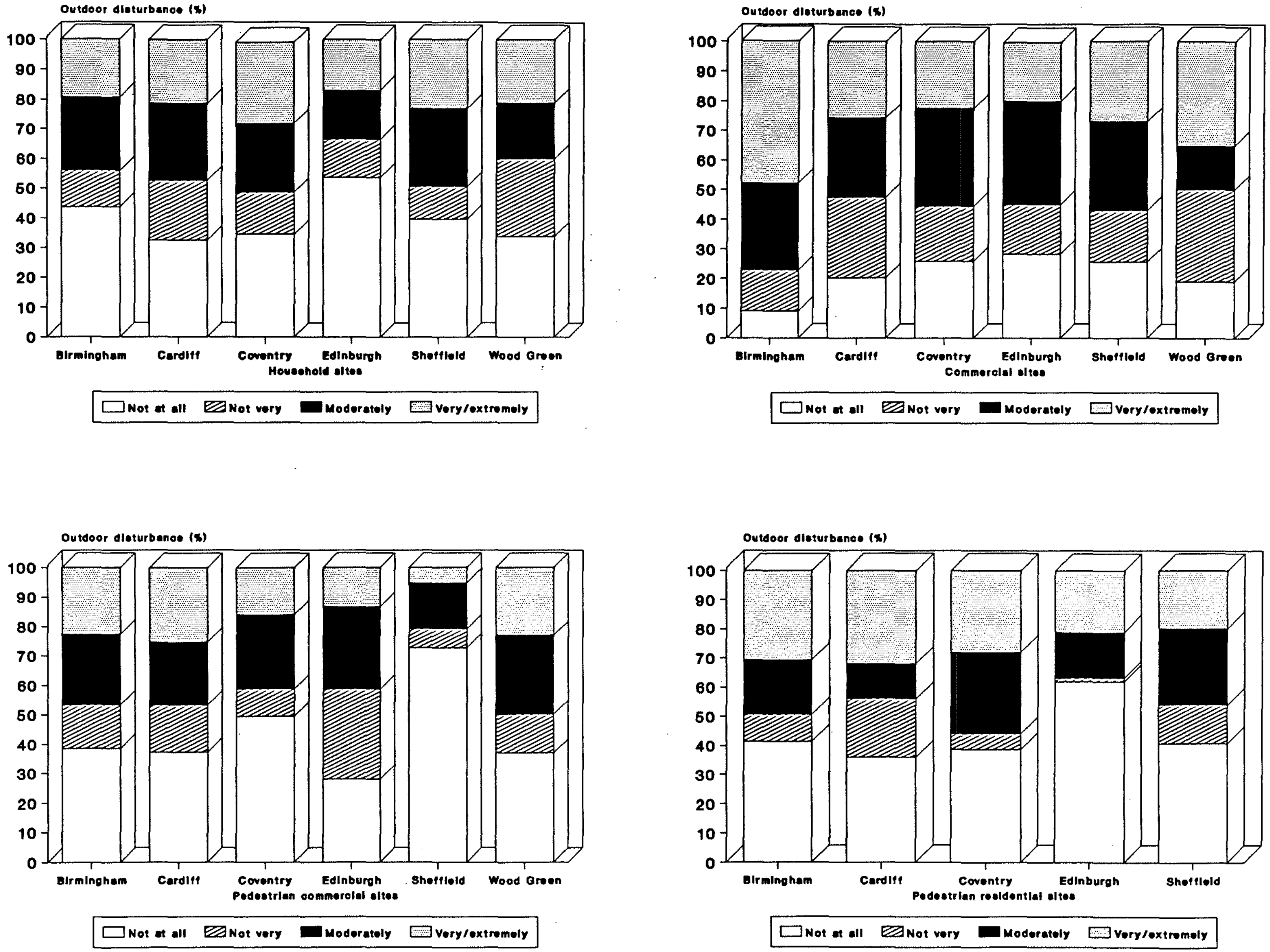


Figure 5.16(a-d)
Outdoor disturbance from an irritated throat.

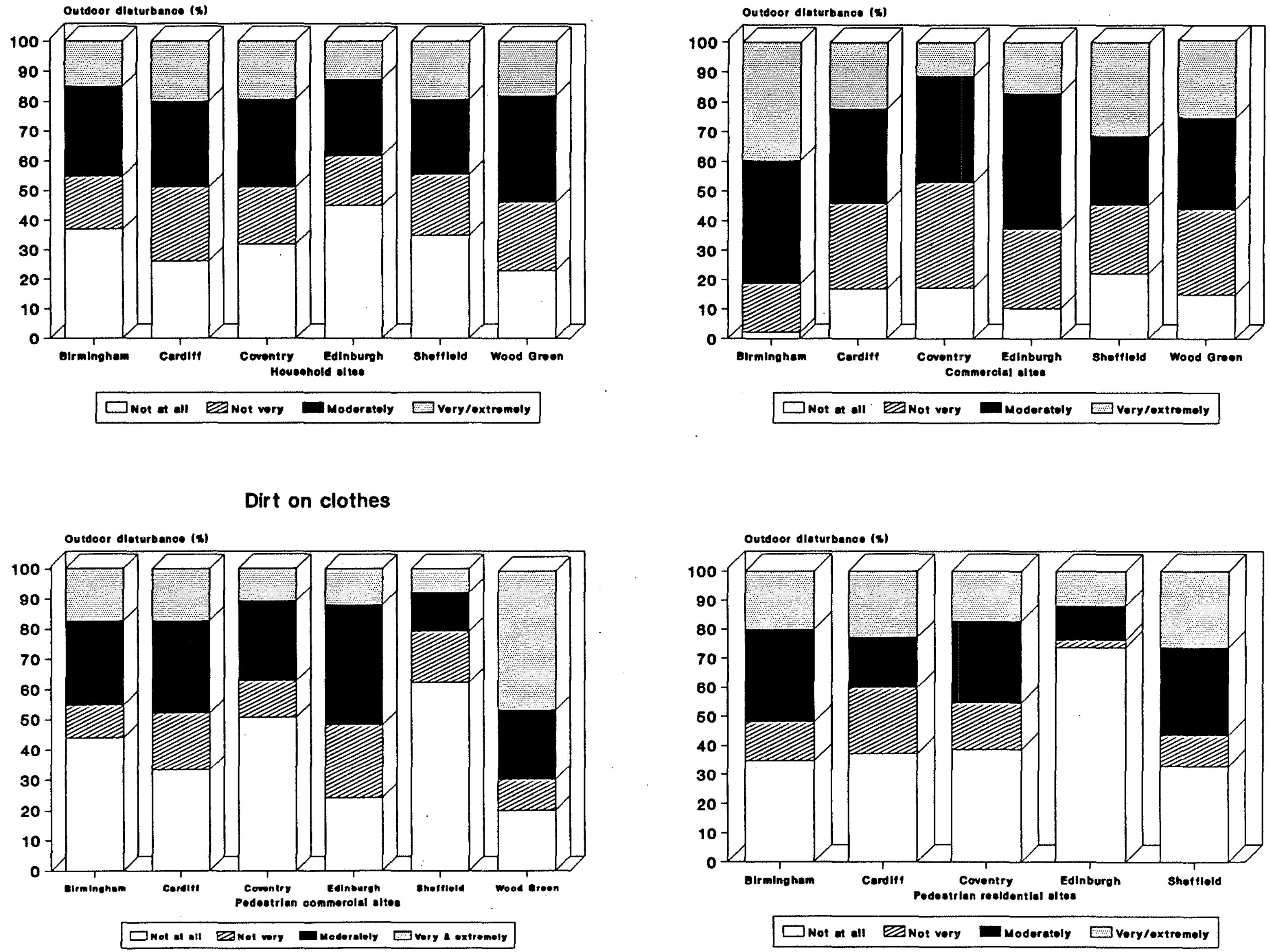


Figure 5.17(a-d)
Outdoor disturbance from dirt on clothing.

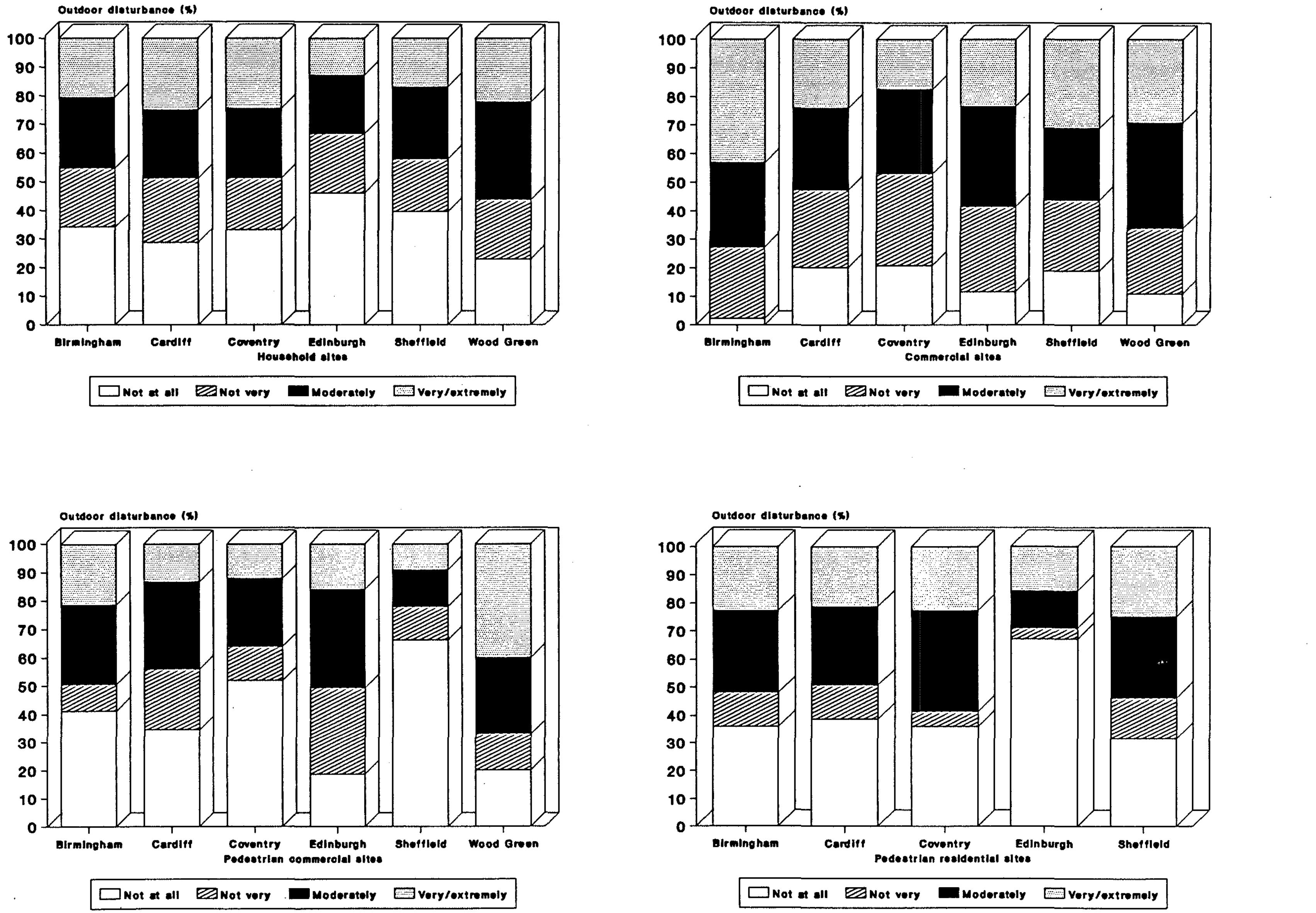


Figure 5.18(a-d)
Outdoor disturbance from dirt on skin, nails or hair.

Table 5.57
Maximum percentage of respondents blaming traffic-generated air pollution for the named health/irritant effect.

Location	% (maximum)				
	Sore or runny eyes	Sneezing	Irritated throat	Dirt on clothes	Dirt on skin, nails or hair
Household					
Birmingham	41	41	52	60	62
Cardiff	44	45	52	64	62
Coventry	51	44	55	62	54
Edinburgh	40	29	42	49	42
Sheffield	36	37	48	55	54
Wood Green	32	23	47	60	60
Pedestrian commercial					
Birmingham	47	43	59	55	55
Cardiff	35	44	56	60	59
Coventry	28	33	47	47	47
Edinburgh	43	41	69	67	69
Sheffield	23	18	23	34	30
Wood Green	40	43	53	80	80
Pedestrian residential					
Birmingham	43	48	52	53	56
Cardiff	37	33	57	55	53
Coventry	40	49	53	57	52
Edinburgh	9	5	16	23	29
Sheffield	41	37	50	57	58

5.10 Main causes of air pollution

All three target groups were asked 'in Ealing, do you think there is any air pollution?'. As can be seen in Table 5.58, the overwhelming majority of the public felt that Ealing suffered from air pollution.

Unfortunately, the respondents were not asked to describe their feelings on the magnitude of the air pollution in Ealing, which would have given more precise information.

The three respondent groups were asked 'In Ealing, which 3 from this list do you think are the main causes of air pollution?'. The results, shown in Table 5.59, show that over 80% of people felt that exhausts from road traffic were the main cause of air pollution in Ealing, with a large percentage also selecting dust and dirt. However, many respondents found great difficulty choosing three from the list of ten, possibly because of the obvious absence of *eg* power stations and farmers burning stubble in urban areas. With the benefit of hindsight, this question should probably have been a free response question.

Table 5.58
Public response to the question 'In Ealing, do you think there is any air pollution?'.

	Pilot survey responses (%)		
	Business (%)	Household (%)	Pedestrian (%)
Don't know	7	5	5
Yes	93	84	85
No	0.0	11	10

5.11 General sensitivity to air pollution

Respondents to the main surveys were asked to indicate their sensitivity to general air pollution using a 7-point bi-polar semantic differential scale ranging from 0 (not at all sensititve) to 6 (extremely sensitive). The mean sensitivity scores, shown in Tables 5.60-5.63, are generally around or above the mid-point of the 7-point scale, ranging from 1.3 at the pedestrian residential site in Edinburgh to 3.8 at sites in Cardiff, Birmingham and Sheffield. The median scores show a greater variability, ranging from 0 at the pedestrian residential site in Edinburgh to 4 at several sites. Detailed analysis of the data using non-parametric ANOVA indicates that business respondents in Cardiff had a statistically significantly higher sensitivity score than those in Coventry.

Table 5.59
Public response to the question 'In Ealing, which 3 from this list do you think are the main causes of air pollution?'.

Causes of air pollution	Pilot survey responses (%)		
	Business	Household	Pedestrian
Exhausts from road traffic	86	86	84
Dust & dirt	71	48	52
Cigarette smoke	36	27	35
Factories & industrial plants	29	20	29
Polluted air from other countries	10	9	10
Insecticides/fertilizers/chemical sprays	5	2	2
Power stations	2	2	4
Farmers burning stubble	2	0	0
Other	2	2	2
Coal fires	0	0	1

Overall, the figures indicate that the average respondent feels moderately - fairly highly

Table 5.60
Sensitivity to air pollution - **householders.**

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	72	2.9	2.5	80	3.2	3	79	2.9	3	76	3.1	3	82	3.1	3	47	3.1	3
Male	37	2.4	2	38	3.0	3	34	2.8	3	38	2.9	3	36	3.4	3	20	2.9	2.5
Female	35	3.4	4	42	3.4	4	45	3.0	3	38	3.3	3	46	2.9	3	27	3.3	3
Current smokers	21	3.0	3	24	3.2	3	43	2.6	3	19	2.9	3	32	2.9	3	17	3.2	3
Current non-smokers	50	2.9	2	56	3.2	3	36	3.3	3	57	3.1	3	50	3.2	3	17	3.0	3
Age group 18-24	10	2.5	2.5	13	3.7	4	23	2.6	3	-	-	-	13	3.1	3	-	-	-
Age group 25-44	31	2.9	2	30	3.5	4	26	3.1	3	26	3.1	3	25	2.2	3	14	4.2	4.5
Age group 45-64	17	4.1	5	20	3.2	3	19	3.4	3	34	3.4	3	26	3.2	3	14	3.2	3.5
Age group 65+	14	1.9	0.5	17	2.4	2	10	2.6	2	14	2.6	2	17	2.6	3	19	2.3	2

Table 5.61
Sensitivity to air pollution - commercial.

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	44	3.7	3	58	3.8	4	81	3.1	3	56	3.4	3	86	3.2	3	52	3.4	3.5
Male	23	3.8	3	29	3.6	4	43	2.8	3	29	3.1	3	36	3.1	3	28	3.5	4
Female	21	3.6	3	29	4.0	4	38	3.4	3	27	3.6	4	49	3.3	3	23	3.2	3
Age group 18-24	12	3.2	3	13	3.3	3	-	-	-	12	3.5	3	16	3.8	4	-	-	-
Age group 25-44	24	3.7	3	32	3.8	4	41	3.1	3	29	3.1	3	45	3.1	3	40	3.5	3.5
Age group 45-64	8	4.2	4.5	11	4.7	5	19	2.7	3	11	3.9	4	25	3.1	3	9	3.1	4

Table 5.62
Sensitivity to air pollution - **pedestrian commercial.**

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield			Wood Green		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	75	3.8	4	74	2.6	3	74	3.2	3	75	3.2	3	73	2.5	3	30	3.7	4
Male	38	3.7	4	39	2.0	2	34	3.2	3	38	3.3	3	34	2.3	2	17	3.6	4
Female	37	3.8	4	35	3.2	3	40	3.1	3	37	3.2	3	39	2.8	3	13	3.8	5
Age group 18-24	16	2.7	2	27	2.3	3	15	3.0	3	17	3.3	3	14	1.6	1	5	3.0	2
Age group 25-44	26	4.1	4	23	2.9	3	26	3.1	3	23	3.3	3	27	2.6	2	11	4.4	5
Age group 45-64	24	3.9	4	16	2.8	3.5	22	3.5	3.5	23	3.5	3	18	2.8	3	7	3.7	3
Age group 65+	9	4.4	4	7	2.1	2	9	2.8	3	12	2.8	3	14	3.0	3	7	3.1	5

Table 5.63

Sensitivity to air pollution - **pedestrian residential.**

Respondent group	Birmingham			Cardiff			Coventry			Edinburgh			Sheffield		
	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median	N	Mean	Median
All	75	3.7	4	75	3.0	3	75	3.2	3	76	1.3	0	75	3.8	4
Male	37	3.5	4	34	2.9	3	36	3.4	3	36	1.3	0	35	3.8	4
Female	38	3.8	4	41	3.0	3	39	3.0	3	40	1.2	0	40	3.8	4
Age group 18-24	13	2.7	3	10	3.1	3	19	2.8	3	9	1.9	2	11	4.0	4
Age group 25-44	28	4.1	4	33	3.3	4	26	3.2	3.5	30	2.2	2	37	3.6	4
Age group 45-64	23	3.9	4	18	3.1	3	16	3.5	3	20	0.4	0	14	4.3	4.5
Age group 65+	10	3.3	3.5	11	1.5	1	14	3.4	3.5	16	0.4	0	12	3.9	5

sensitive to general air pollution. The data in Tables 5.60-5.63 also indicate women generally claim higher sensitivity scores than men, with statistically significant data occuring at the business site in Coventry and the pedestrian commercial site in Cardiff.

Respondents in the 25-64 age category generally show higher sensitivity than younger/older respondents, with statistically significant data occuring at two pedestrian commercial sites (Birmingham and Cardiff) and the household site in Birmingham.

5.12 Volume of traffic

Householders at all survey locations were asked to describe the volume of traffic passing their homes on weekdays. The results from the Ealing pilot site (displayed in Table 5.64) show that overall 85% of respondents felt that the traffic flow was at least moderate in their street. The responses are further divided into individual streets in Table 5.64. Madeley Road is used by many drivers to by-pass Ealing town centre in order to reach the North Circular road, and as a result it is an extremely busy road considering that it runs through a residential area. This is reflected by three-quarters of respondents feeling that the traffic flow was 'extremely' or 'very' heavy. Although Haven Lane and Westbury Road are considerably quieter roads, nearly half of the respondents from Haven Lane thought that the traffic flow was 'extremely' or 'very' heavy outside their homes. However, most Haven Lane respondents qualified their answer by saying that the road was very busy considering that it is a narrow, one-way street in a residential area. This data suggests that the type of road under consideration may be an important factor in the respondent's mind when they are asked to evaluate nuisance from road traffic. The results from the main surveys are shown in Table 5.65.

Table 5.64

Householder response to the pilot question 'how would you describe the amount of traffic passing your home on Mondays to Fridays?'

Amount of traffic	Ealing householder responses (%)			
	All streets (44)*	Madeley Rd (21)*	Haven Lane (16)*	Westbury Rd (6)*
Extremely heavy	20	24	25	-
Very heavy	36	52	25	17
Fairly heavy	16	14	19	33
Moderate	13	5	19	42
Light	5	-	6	8
Very little	5	-	-	-
Don't know\varies	5	5	6	-

* Figures in brackets indicate the number of respondents questioned in each street.

Table 5.65
Householder response to the question 'how would you describe the amount of traffic passing your home on Mondays to Fridays' (%).

Amount of traffic	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green
Extremely heavy	21.9	23.8	39.2	24.4	3.6	19.2
Very heavy	31.5	22.5	11.4	21.8	12.0	19.2
Fairly heavy	21.9	27.5	8.9	24.4	27.7	27.7
Moderate	13.7	13.8	16.5	15.4	32.5	25.5
Light	8.2	7.5	8.9	9.0	8.4	6.4
Very little	2.7	-	13.9	5.1	14.5	-
Don't know/varies	-	-	1.3	-	1.2	2.1

The data is consistent with that from the pilot survey in that 75% of all respondents indicated that the traffic flow in their street was at least moderate. Except at the Sheffield site, where the traffic flow was extremely low, 38-54% of respondents described the amount of traffic passing their homes as very or extremely heavy. These data are consistent with that presented in Section 5.5, where the amount of road traffic was highly ranked as a local environmental issue at each residential site.

5.13 Sources of vehicular pollution

In the pilot survey, business and household respondents were asked to state which type of vehicle they felt contributed the most pollutants to the overall air pollution in their area. The results are illustrated in Table 5.66 and indicate that the respondent groups generally thought that cars were the main culprit, with lorries close behind. The respondents frequently named more than 1 type of vehicle at Ealing, but the interviewers were stricter in the follow-up survey and insisted that the respondents selected only a single group. The follow-up question was slightly modified to improve its clarity and to differentiate between petrol and diesel cars.

Table 5.66
Sources of vehicular pollution - **Ealing pilot survey.**

Type of vehicle	Pilot survey responses (%)	
	Business	Household
Cars	38	41
Buses/coaches	19	5
Lorries	24	27
Other	3	5
More than 1 type of vehicle named	16	22
Pilot survey question: 'In Ealing, which type of vehicle do you think contributes the most pollutants to the overall air pollution?'		

The responses displayed in Tables 5.67-5.70 illustrate that no particular type of vehicle is felt to be the dominant source of vehicular-derived air pollution. Petrol cars were considered to make the highest contribution to the overall air pollution at each household site except Edinburgh, where they came a close second to lorries. At commercial sites, buses/coaches were generally thought to be the main offenders, especially in Birmingham, Coventry and Sheffield. Generally, the data shows that the perception of sources of vehicular pollution varies according to location and site.

Table 5.67
Sources of vehicular pollution - **household respondents** (%).

Type of vehicle	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green
Petrol cars	36.1	40.0	41.8	37.2	33.7	34.0
Diesel cars	4.2	5.0	-	2.6	3.6	4.3
Buses/coaches	20.8	15.0	24.0	14.1	27.7	17.0
Lorries	34.7	30.0	27.8	42.3	25.3	34.0
Vans	-	2.5	1.3	-	1.2	6.4
Motorbikes/mopeds	-	1.2	2.5	-	1.2	-
Dustcarts	-	-	1.3	-	2.4	-
Don't know	-	-	-	-	-	2.1
More than 1 type	4.2	6.2	1.3	3.8	4.8	2.1

Table 5.68
Sources of vehicular pollution - **commercial respondents** (%).

Type of vehicle	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green
Petrol cars	9.1	13.6	28.4	20.3	7.0	40.8
Diesel cars	6.8	1.7	-	1.7	-	2.0
Buses/coaches	63.6	35.6	39.5	33.9	74.4	26.5
Lorries	15.9	39.0	25.9	35.6	10.5	26.5
Vans	-	3.4	1.2	1.7	2.3	-
Motorbikes/mopeds	-	-	-	-	-	-
Dustcarts	-	-	-	-	4.6	-
Don't know	-	-	-	-	-	-
More than 1 type	4.6	6.8	4.9	6.8	1.2	4.1

5.14 Summary of surveys of traffic nuisance in residential and commercial areas

A methodology to investigate the subjective nuisance effects of air pollution from road traffic on the public has been developed and tested at 7 locations in the UK. The questionnaire data has been collated, analysed and interpreted, and a number of conclusions have been drawn from this information.

Table 5.69
Sources of vehicular pollution - **pedestrian commercial** (%).

Type of vehicle	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green
Petrol cars	20.0	34.7	28.0	34.7	31.2	31.0
Diesel cars	-	8.3	2.7	1.3	1.3	6.9
Buses/coaches	61.3	18.1	42.7	30.7	42.9	6.9
Lorries	17.3	34.7	21.3	30.7	20.8	48.3
Vans	1.3	-	1.3	1.3	2.6	6.9
Motorbikes/mopeds	-	-	1.3	-	-	-
Dustcarts	-	2.8	2.7	-	1.3	-
Don't know	-	-	-	-	-	-
More than 1 type	-	1.4	-	1.3	-	-

Table 5.70
Sources of vehicular pollution - **pedestrian residential** (%).

Type of vehicle	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield
Petrol cars	33.8	28.8	33.3	25.0	19.0
Diesel cars	4.0	1.5	4.0	4.0	6.4
Buses/coaches	24.3	19.7	36.0	9.2	34.9
Lorries	29.7	31.8	24.0	55.3	30.2
Vans	1.4	-	-	-	-
Motorbikes/mopeds	-	-	1.3	1.3	3.2
Dustcarts	1.4	-	-	1.3	-
Don't know	-	-	-	-	-
More than 1 type	5.4	18.2	1.3	-	6.4

The results displayed in Tables 5.14-5.20 (Section 5.4) indicate that the public generally have a high level of concern about the eleven listed social issues. The relative rankings of these issues, summarised in Table 5.71, are very consistent at all sites, which is unexpected given the different social and economic conditions at each location. The data clearly indicates that air pollution from road traffic is an issue of high relative importance to the public when compared to other social issues, with global environmental issues also quite highly ranked. It is perhaps surprising to see air pollution from road traffic consistently ranked above issues such as rising prices, education and health/social services, which are more 'traditional' public concerns.

Table 5.71.
Rank order of respondent concern about major social issues at selected UK sites.

Issue	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green	Overall
Unemployment	1.0	1.2	1.0	1.0	1.0	1.3	1.1
Law & order	2.5	2.2	2.2	3.0	2.8	5.0	2.9
Air pollution from road traffic	3.5	3.2	4.2	3.2	3.8	2.7	3.5
Rising prices	3.8	4.5	5.5	3.2	3.5	5.0	4.2
Global environment	7.0	3.2	3.2	6.0	5.8	4.7	4.8
Education	5.3	7.2	6.8	7.8	5.5	4.3	6.2
Old age pensions	7.2	6.5	6.8	5.5	5.8	6.3	6.3
Health/social services	8.2	8.5	8.8	6.2	8.8	8.7	8.2
Housing	9.5	8.5	7.0	9.0	8.2	7.0	8.3
Local environment	7.2	9.2	8.5	9.2	9.0	8.3	8.6
Rising population	10.0	11.0	11.0	11.0	10.5	11.0	10.7

The relative rankings are based on the number of respondents from each location who were very/extremely worried about each issue.

The observation that air pollution from road traffic is an issue of high relative importance to the public when compared to other social issues is significant because:

- it puts the issue into proper perspective, and
- it means that the specific environmental concerns (detailed below) are of a higher relative importance than if air pollution from road traffic was relatively lowly ranked.

The data summarised in Table 5.71 suggests that local environmental issues are of relatively low priority compared to other major social issues. However, traffic-related nuisances are very important local environmental nuisances, with two of the top three local environmental nuisances being vehicle-derived, as displayed in Table 5.72. Road vehicles also make a contribution to urban dust/dirt, noise, smog and the soiling of buildings. The low ranking of this latter issue is unexpected given its very visible impact, especially on high profile historic buildings such as St Paul's Cathedral, and the economic costs of cleaning soiled buildings. This result, together with the observation that the physical presence of road traffic is as important as the presence of pollutants, may indicate that health and safety concerns are more important to the public than aesthetic issues associated with vehicle-derived pollution.

Table 5.72.
Rank order of respondent concern about local environmental issues at selected UK sites.

Issue	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green	Overall
Litter & rubbish	2.8	2.2	2.0	4.0	1.2	1.3	2.3
Amount of road traffic	1.8	1.8	4.0	1.2	2.2	4.0	2.4
Smoke, fumes & odour	2.0	3.0	1.8	2.2	3.5	2.7	2.5
Dog mess	3.8	2.8	2.0	3.0	4.8	2.0	3.1
Dust & dirt	5.8	5.2	6.8	5.0	5.0	4.3	5.4
Ugly/disused buildings	6.5	6.2	5.2	8.0	6.0	7.3	6.5
Noise	5.8	7.8	6.8	6.0	8.0	7.7	7.0
Graffiti	7.8	8.2	8.2	7.5	5.0	6.7	7.3
Smog	8.5	8.0	7.5	8.0	7.8	8.3	8.2
Blackening of building walls	9.5	9.5	9.2	9.0	9.8	9.7	9.4

The relative rankings are based on the number of respondents from each location who were very/extremely worried about each issue.

Household and business respondents were asked to indicate the frequency of indoor and outdoor disturbance from a number of potential nuisance effects. In general, respondents at commercial sites showed a higher frequency of disturbance than householders. Indoors, 19-49% of business respondents and 23-33% of householders were disturbed frequently or all the time by dust/dirt from road traffic. Smoke, fumes and odour rarely caused indoor disturbance to householders. Noise from road traffic caused the greatest frequency of indoor disturbance at all sites, with between 37-59% of business respondents and 25-48% of householders being disturbed frequently or all the time.

The frequency of outdoor disturbance from smoke, fumes and odour and dust/dirt was generally high. Commercial respondents typically displayed the greatest frequency of disturbance from outdoor smoke, fumes and odour, with between 36-58% of respondents being disturbed frequently or all the time. Commercial respondents also showed the highest frequency of annoyance from dust/dirt, with at least 90% being bothered some of the time and 40% being bothered frequently or all the time.

The questionnaires included questions designed to measure the magnitude of indoor and outdoor nuisance from vehicle-generated smoke, fumes and odour, dust/dirt and general air pollution. Respondents were shown a 7-point bi-polar semantic differential scale, ranging from 0 (not at all bothered) to 6 (extremely bothered) in integers, and asked to indicate the magnitude of their disturbance. The mean and median indoor disturbance scores at the 6 locations are summarised in Table 5.73. The median scores, which are probably a better measure of central location than the mean scores (because the distributions are non-normal), were much more variable, and in a few cases the median scores at some sites were statistically significantly higher than those at others.

Table 5.73.
The magnitude of indoor disturbance from vehicle-derived air pollution, dust/dirt and smoke, fumes and odour at selected UK locations.

Disturbance	Respondent type	Median range	Mean range
Smoke, fumes and odour from road traffic	Household	0 - 2	1.2 - 1.9
	Business	1 - 3	1.5 - 3.3
Dust/dirt from road traffic	Household	0 - 2	1.3 - 2.2
	Business	1 - 3	1.4 - 3.5
Air pollution from road traffic	Household	0 - 2	1.4 - 2.2

Respondents showed more concern about indoor dust/dirt than smoke, fumes and odour, which is consistent with the data relating to the frequency of disturbance. The disturbance scores for indoor dust/dirt were statistically significantly higher than the indoor disturbance scores from smoke, fumes and odour at the household sites in Birmingham, Cardiff and Edinburgh. Female respondents generally showed greater disturbance than males for each nuisance, and middle-aged respondents, particularly those in the 45-64 age group, often displayed higher disturbance than younger or older respondents. The mean disturbance scores for all respondents at each location are usually below the mid-points of the scales utilized, which probably indicates that most of the respondents experience only minor-moderate indoor disturbances from vehicle-derived air pollution.

Householders who registered indoor disturbance from smoke, fumes and odour and dust/dirt from road traffic on the 7-point scale were asked to state specifically what it was about the pollutants that bothered or disturbed them. The actual smell of the traffic fumes caused the most annoyance, with 3-25% of the respondents complaining specifically about an unpleasant odour. Most of the householders who were disturbed by indoor dust/dirt (22-49% of the total respondents, depending on site location) complained about indoor soiling of items such as furniture, carpets, windows, curtains and nets.

The results for outdoor disturbance are summarised in Table 5.74. The mean outdoor disturbance scores from vehicle-induced smoke, fumes and odour were typically above the mid-point, while the mean scores for outdoor disturbance from vehicle-derived dust/dirt were generally more central. The median outdoor disturbance scores for both nuisances were usually 3-4, although at some sites the median scores were statistically significantly higher than at others. Female, commercial and middle-aged respondents generally showed greater disturbance than other respondent types for each nuisance, with some statistically significant data. These observations are consistent with the data for indoor disturbance. At all ten household and commercial sites, the outdoor figures were statistically significantly higher than those for indoor disturbance from both nuisances, and at every site bar four, the disturbance scores from outdoor smoke, fumes and odour were statistically significantly higher than those from outdoor dust/dirt. Overall, the data indicates that the average respondent was moderately-very bothered by both types of nuisance, but generally more concerned about vehicle-derived smoke, fumes and odour.

Table 5.74.
The magnitude of outdoor disturbance from vehicle-derived dust/dirt and smoke, fumes and odour at selected UK sites.

Disturbance	Respondent type	Median range	Mean
Smoke, fumes and odour from road traffic	Household	3 - 4	3.3 - 3.8
	Pedestrian	0 - 4	1.9 - 4.2
	Business	3 - 4	3.3 - 4.1
Dust/dirt from road traffic	Household	3 - 4	2.8 - 3.4
	Pedestrian	0 - 4	1.4 - 3.8
	Business	3 - 4	3.0 - 4.0

Pedestrian and household respondents gave a range of reasons when asked specifically what bothered them outdoors about smoke, fumes and odour from road traffic. At the household sites, 33-51% of respondents were worried about their health, with a further 10-22%

complaining about the odour of the fumes. Pedestrian respondents generally showed a slightly higher level of concern about their health (37-71%) and the odour of the traffic fumes (10-37%). Respondents were also asked what bothered them specifically about outdoor dust/dirt from road traffic. At the household sites, 18-32% of respondents complained of health worries and 15-38% of soiling (usually of clothes, skin, hair). Pedestrian responses were more variable, with 14-52% of respondents being worried about their health and 18-37% complaining about soiling.

In order to gain information about the relative importance of indoor traffic-induced nuisances, business and household respondents were asked to rank five traffic-induced nuisances in order of disturbance when they were inside their homes. The relative rankings, summarised in Table 5.75, consistently indicate that noise caused the greatest indoor traffic-induced disturbance (which is consistent with the frequency data described previously), with dust/ dirt and smoke, fumes and odour sharing second rank. Vibrations and danger from road traffic were consistently ranked fourth and fifth respectively as indoor traffic-related disturbances.

Table 5.75.
Rank order of indoor traffic related disturbances.

Road traffic disturbance	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green	Overall
Noise	2.0	2.1	1.8	1.9	1.8	2.1	2.0
Dust/dirt	2.8	2.7	2.9	2.8	2.7	2.8	2.8
Smoke, fumes & odour	2.7	2.6	2.8	3.0	2.8	3.2	2.8
Vibrations	3.0	3.5	3.0	3.2	3.4	3.0	3.2
Danger	4.4	4.0	4.4	4.0	4.2	4.3	4.2

Respondents were also asked to rank six traffic-induced nuisances in order of disturbance when they were outside their homes. The relative rankings shown in Table 5.76 indicate that danger and smoke, fumes and odour from road traffic were consistently ranked above the other 4 outdoor disturbances. These rankings are consistent with the view that health and safety concerns are more important to the public than aesthetic issues.

Respondents who stated that they suffered some disturbance from a range of health/nuisance effects when they were outdoors were asked what they thought was the cause of their distress.

Using the asumption that <u>all</u> kerbside air pollution and dust/dirt is traffic generated (a worst-case situation), the <u>maximum percentage</u> of respondents who blamed vehicle-generated air pollution for the named health/irritant effects was estimated. With the exception of the pedestrian residential location in Edinburgh, where disturbance was markedly lower than at the other sites, 23-51% of the household and pedestrian respondents felt that traffic pollution was at least partly to blame for their sore or runny eyes; 18-49% for sneezing; 23-69% for throat irritant problems and 30-80% for soiling.

Table 5.76.
Rank order of outdoor traffic related disturbances.

Road traffic disturbance	Birmingham	Cardiff	Coventry	Edinburgh	Sheffield	Wood Green	Overall
Smoke, fumes & odour	2.2	2.2	2.3	2.4	2.4	2.4	2.3
Danger	2.5	2.6	2.7	2.4	2.5	2.5	2.5
Dust/dirt	3.3	3.3	3.3	3.4	3.2	3.6	3.4
Noise	3.3	3.6	3.2	3.6	3.7	3.5	3.5
Splash and spray	4.6	4.2	4.4	3.8	4.0	4.4	4.2
Vibrations	5.0	5.2	5.0	5.2	5.2	4.6	5.0

To summarise, the survey's main findings are:

- vehicle-derived air pollution was an issue of high relative importance to the public when compared to other major social issues;
- dust/dirt was the most important indoor vehicle-derived annoyance, although noise was the most important indoor nuisance overall;
- smoke, fumes and odour were the most important outdoor vehicle-derived nuisances;
- the public were more concerned about the health effects and safety issues associated with road traffic than aesthetic issues, although there was some concern about indoor soiling and the odour of fumes;
- the data suggests that there can be significant differences in disturbance between sites in the same and different cities, between males and females and between different age groups. No association was found between magnitude of reported disturbance and the distance of respondents' homes to a road.

Overall, the survey data are very consistent, which is unexpected given the different social and economic circumstances at each location. In particular, the findings highlight the public's concern about the relationship between vehicle-derived pollution, especially particulate pollution, and human irritant/health effects. In urban areas, particulates, black smoke and unpleasant odours are often associated with the exhaust emissions from diesel vehicles. The findings of this survey are therefore consistent with the recent conclusions of the UK Quality of Urban Air Review Group (1993a) that 'any increase in the proportion of diesel vehicles on our (UK) urban streets is to be viewed with considerable concern unless problems of particulate matter ... are effectively addressed'.

Chapter 6
Air Quality in Commercial and Residential Areas

6.1 Introduction

In addition to the questionnaire data described in Chapter 5, air quality information was required in order to quantify the nuisance generated by vehicle-derived air pollution in commercial and residential areas. This air quality data was collected at the selected sites using the monitoring and assessment techniques described in Chapter 4. This Chapter summarises the air quality and meteorological data accumulated at each site and examines and interprets the observed cycles and trends.

6.2 Meteorological parameters recorded at the mobile laboratory

A limited amount of meteorological data was collected at Wood Green using the equipment installed within the mobile laboratory. Statistical summaries of these meteorological parameters are displayed in Tables 6.1 and 6.2. The hourly average temperature profiles displayed in Figure 6.1 show trends and temperature ranges typical of London during those time periods (Meteorological Office, 1994).

The graphical representations of wind speed illustrated in Figures 6.2 and 6.3 indicate that the frequency distributions are lognormal. It is generally accepted that the lognormal distribution of many primary pollutants is partly due to a strong dependence on wind speed (Bower, 1989). Previous studies (*eg* McCrae, 1991) have indicated that locally measured wind speeds are often lower than those measured at regional weather centres.

6.3 Meteorological parameters recorded by other authorities

Meteorological data was collected at the nearest Meteorological Office weather station to the site locations so that regional and local weather conditions could be compared. Information was collected from Heathrow and the London Weather Centre for the Ealing and Wood Green sites respectively.

Statistical summaries and trends of the hourly temperatures measured at each of the regional weather centres are shown in Table 6.3 and Figures 6.4 and 6.5 respectively. The regionally recorded wind speeds (Figures 6.6 and 6.7) were higher than the locally recorded values (Section 6.2) and the frequency distributions show a lognormal distribution.

Wind direction regularly changes due to the circular and fluctuating nature of wind speed measurements, and is therefore best summarised in terms of the most dominant direction. This

Table 6.1

Statistical summary of meteorological parameters recorded at Site WG-R (February - April 1992).

	Units	N*	Mean	Minimum	Percentiles							Maximum
					10	25	50	75	90	95	98	
Wind speed	m/s	1363	1.5	0.0	0.4	0.8	1.1	2.0	3.0	3.5	4.2	6.0

* Number of readings

Table 6.2

Statistical summary of meteorological parameters recorded at Site WG-C (August - October 1992).

	Units	N*	Mean	Minimum	Percentiles							Maximum
					10	25	50	75	90	95	98	
Wind speed	m/s	1364	0.8	0.0	0.2	0.3	0.5	1.0	1.9	2.7	3.1	3.6
Temperature	°C	1365	13.3	2.3	7.9	10.8	13.5	16.2	18.1	19.7	21.1	23.5
Relative humidity	%	1364	78.8	42.3	61.2	71.2	80.5	88.5	93.2	94.8	96.7	98.0

* Number of readings

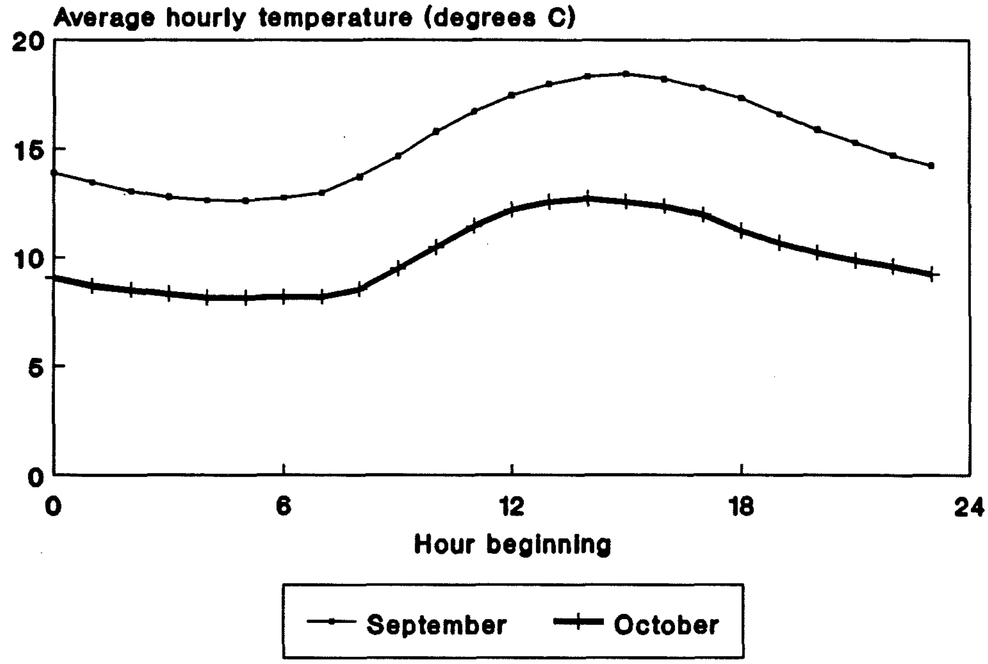


Figure 6.1
Trends in hourly average temperatures recorded at Site WG-C in 1992.

meteorological data is summarised in Table 6.4. In general, locally recorded wind direction and speed was less variable than regionally recorded data, illustrating the modifying effect of urban street buildings and furniture on local wind conditions.

6.4 Traffic classifications

Traffic classifications in terms of the percentage of diesel and petrol-engined vehicles were obtained through manual counting at the Ealing and Wood Green locations. This classification is important due to the differences in pollutant emissions between the two vehicle groups.

The monitoring period was typically between 06:00 - 18:00 hours over a 3 - 5 day period. No classification was performed at Site WG-R because of the extremely low numbers of diesel vehicles present on adjacent roads. Figures 6.8 - 6.10 show the trends in diesel vehicle composition of the vehicle fleets at the 3 other sites. The diagrams clearly show that the percentage of diesel vehicles reduces during rush hour periods at all sites. As expected, the diesel/petrol ratio was higher at the commercial sites due to the presence of buses and commercial vehicles. The average diesel vehicle compositions were 10.8% at Site E-R, 14.9% at Site E-C and 25.4% at Site WG-C. The implications of the different vehicle fleet compositions at these sites are discussed as appropriate in the following Sections.

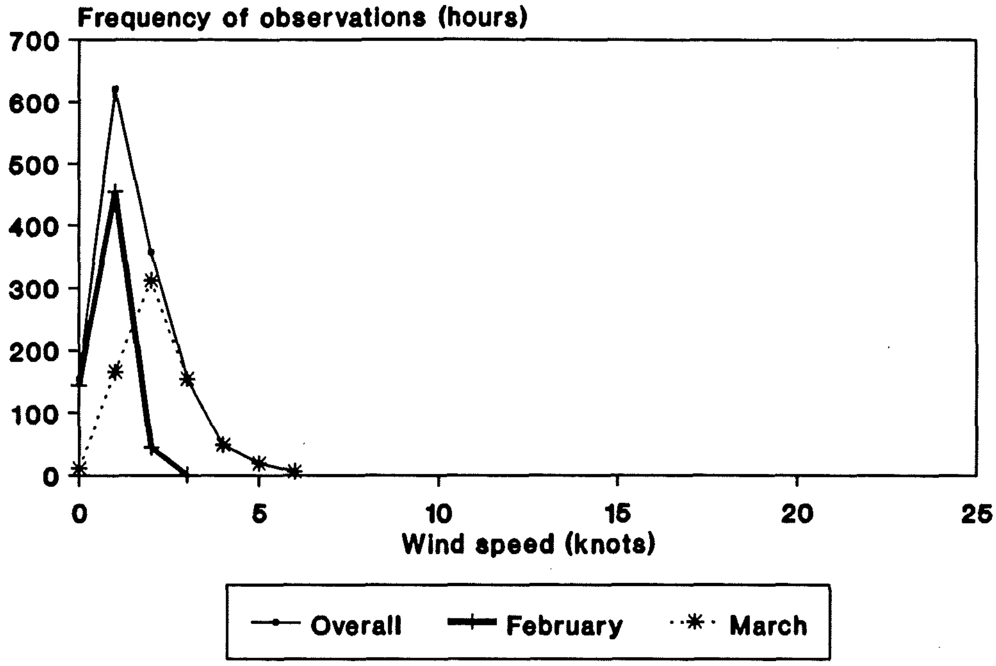


Figure 6.2
Wind speeds recorded at Site WG-R in 1992.

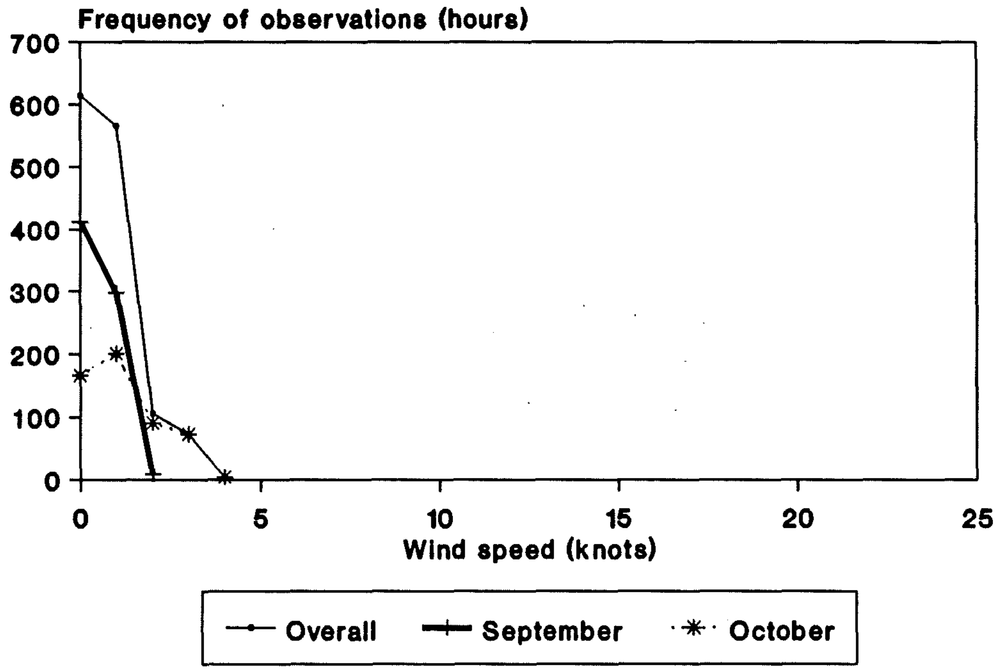


Figure 6.3
Wind speeds recorded at Site WG-C in 1992.

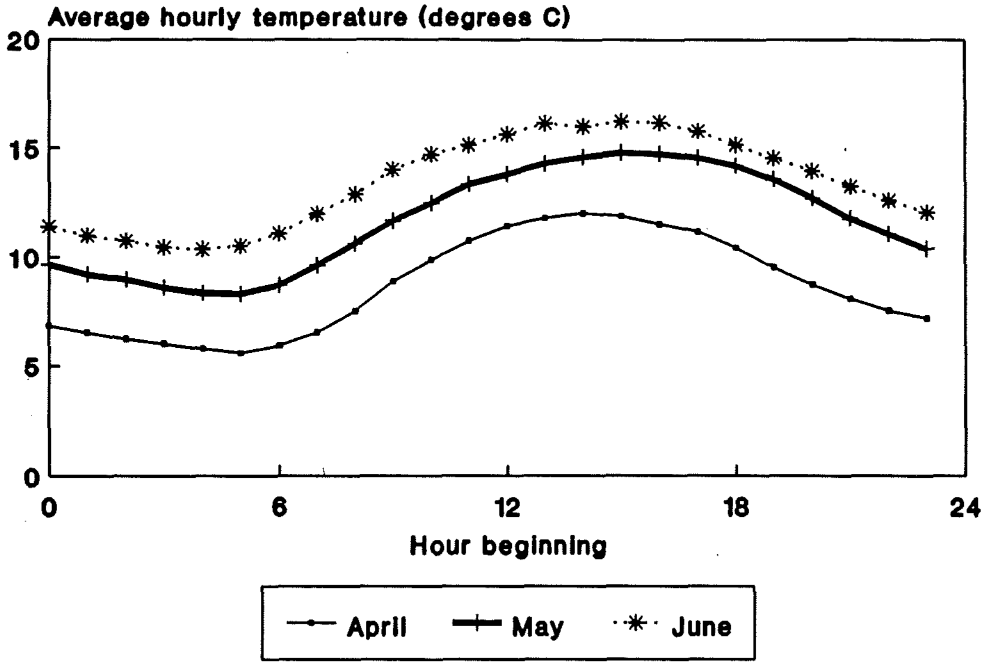


Figure 6.4
Trends in hourly average temperatures recorded at Heathrow in 1991.

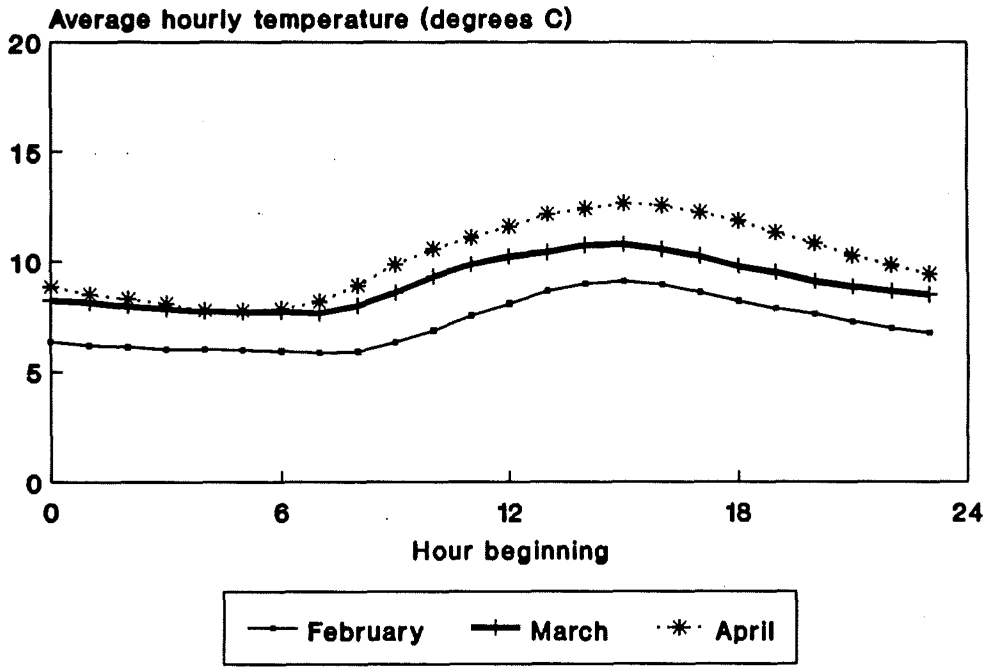


Figure 6.5
Trends in hourly average temperatures recorded at the London Weather Centre in 1992.

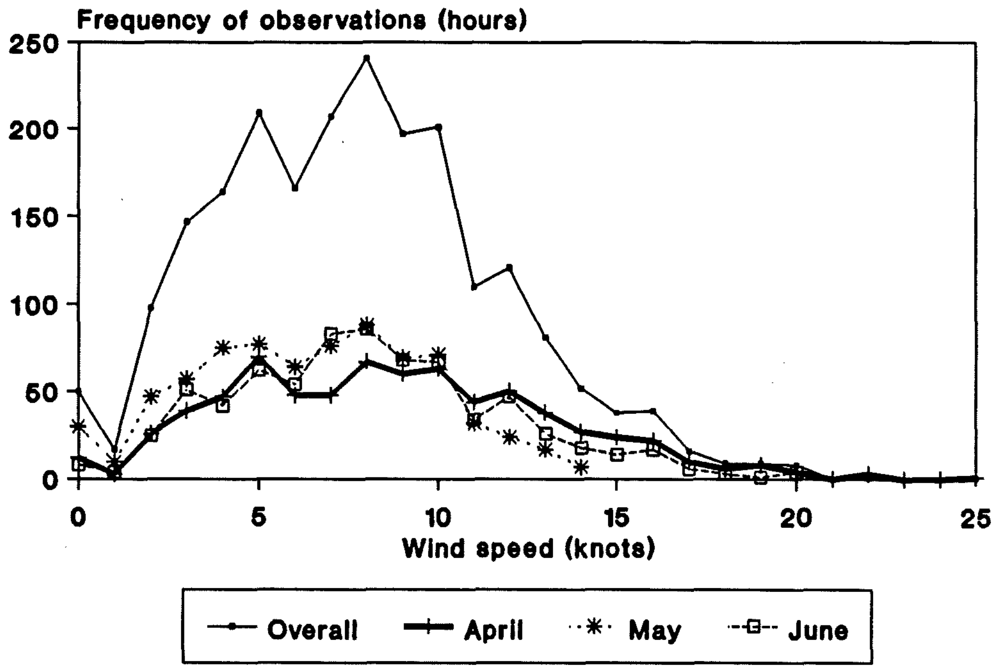


Figure 6.6
Wind speeds recorded at Heathrow in 1991.

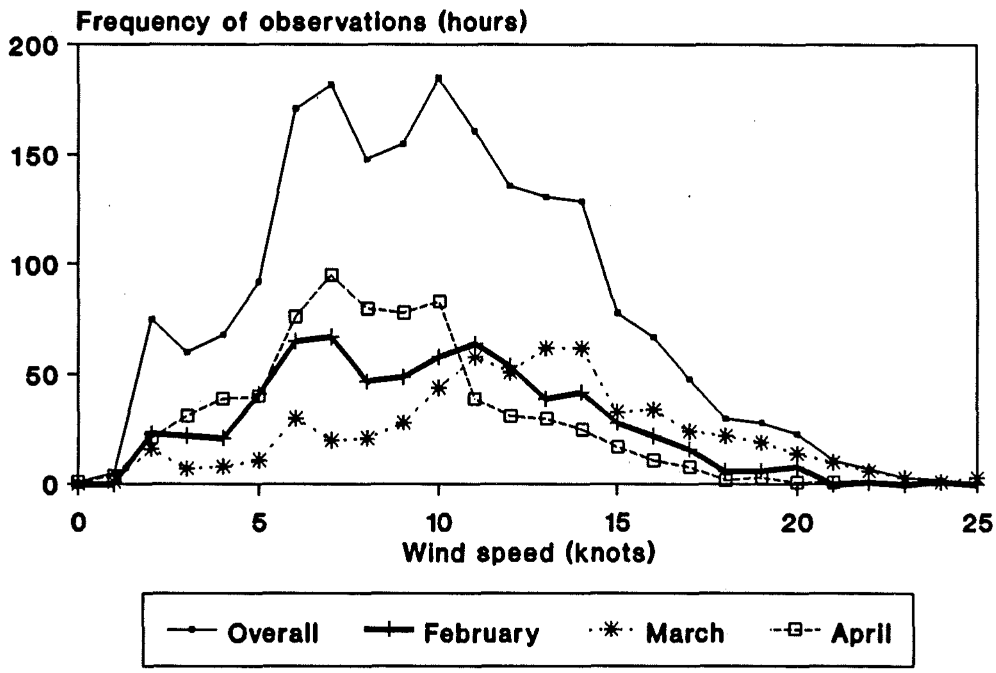


Figure 6.7
Wind speeds recorded at London Weather Centre in 1992.

Table 6.3
Statistical summary of hourly temperature values measured at regional weather centres.

Month	Site location	Number of hourly measurements	Temperature (°C)		
			Mean	Median	Range
Heathrow (1991)					
April	Ealing	720	8.6	8.2	0.0 - 20.8
May		744	11.6	11.0	2.5 - 24.4
June		720	13.4	13.0	3.7 - 22.5
Overall		2184	11.2	11.0	0.0 - 24.4
London Weather Centre (1992)					
February	Wood Green	696	7.2	7.5	-0.1 - 18.2
March		728	9.0	9.1	3.5 - 15.6
April		718	10.1	10.1	3.5 - 18.2
Overall		2142	8.8	9.0	-0.1 - 18.2

Table 6.4
Locally and regionally recorded wind directions.

Site	Dominant wind direction (Degrees from North)	
	Local	Regional
E-R	-	0 - 45
E-C	-	0 - 45
WG-R	135 - 180	225 - 280
WG-C	135 - 180	225 - 280

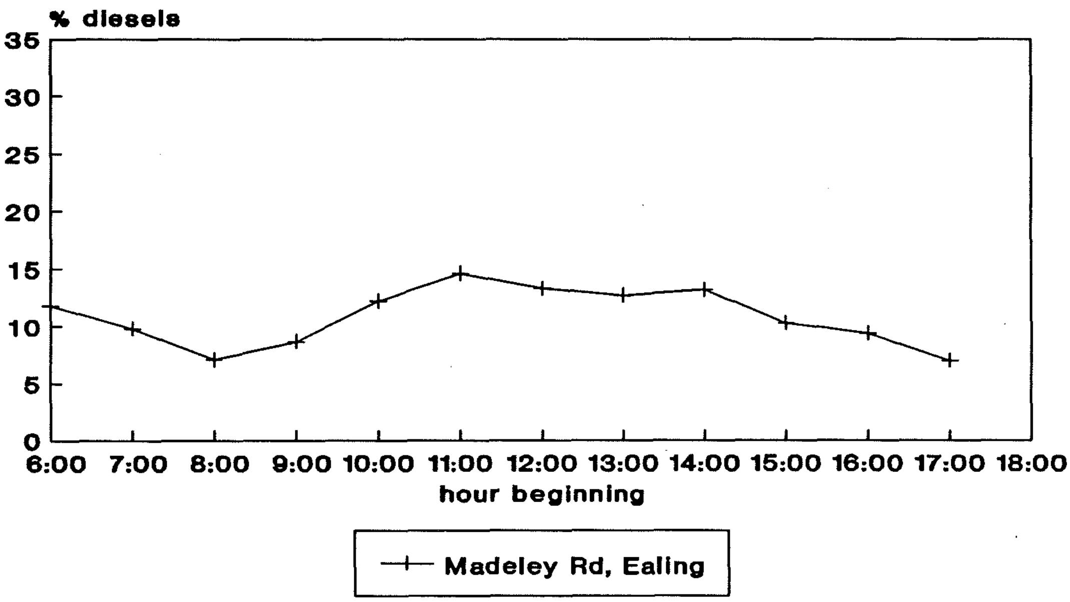


Figure 6.8
Hourly trends in diesel vehicle composition of the vehicle fleet at Site E-R.

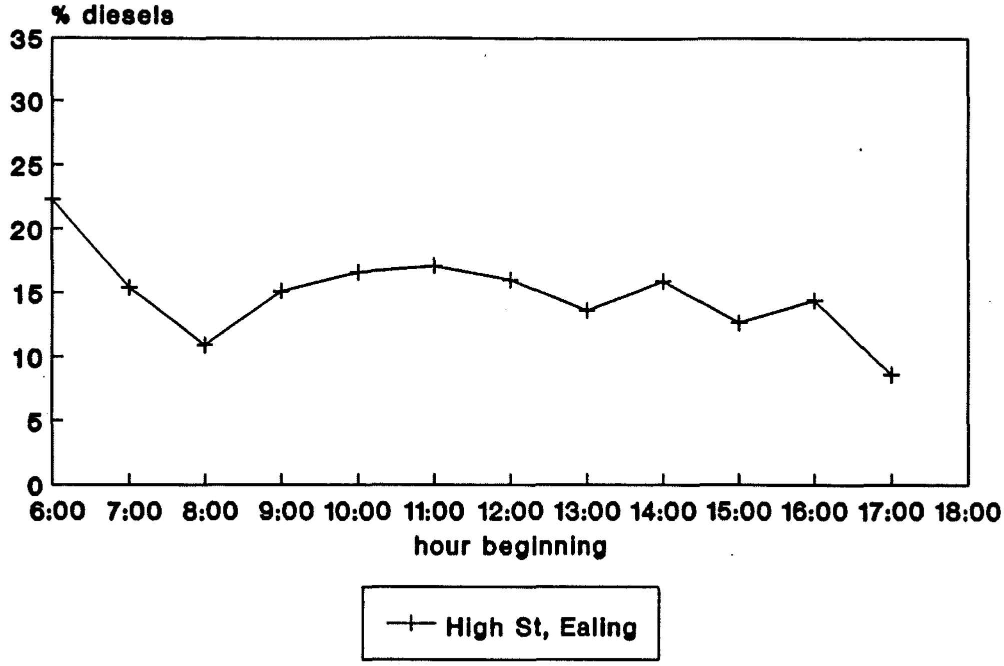


Figure 6.9
Hourly trends in diesel vehicle composition of the vehicle fleet at Site E-C.

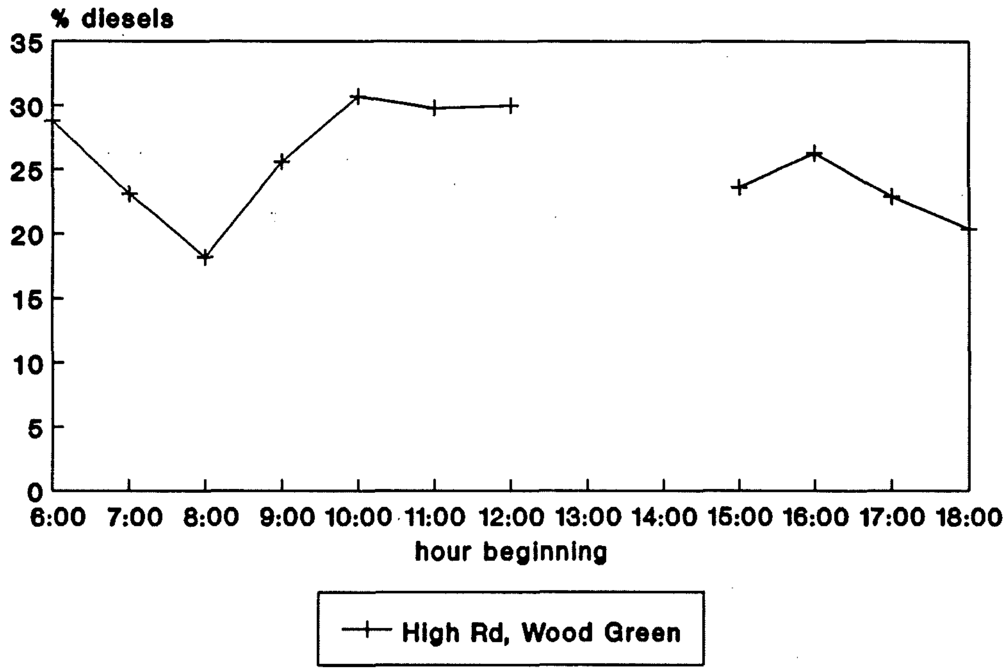


Figure 6.10
Hourly trends in diesel vehicle composition of the vehicle fleet at Site WG-C.

6.5 Gaseous pollutant concentrations recorded at the mobile laboratory

Gaseous pollutant concentrations do not remain constant in the urban atmosphere, but vary according to a number of factors, including source strength and meteorological conditions. In order to compare the concentrations at each site, the gaseous pollutant concentrations recorded at the mobile laboratory are presented as arithmetic mean hourly averages over the different sampling period durations (Tables 6.5-6.8).

At each site, the road can be considered the predominant source for the majority of the monitored pollutants, although a variety of additional sources exist at the individual sites. These additional sources can add to, and distort the pollution profiles within any individual location.

The levels of the various pollutants displayed in Tables 6.5-6.8 generally correspond with values recorded at other similar roadside locations (*eg* McCrae, 1991). At both Ealing and Wood Green, the concentrations of the vehicular primary pollutants, CO, NO and NMHC are higher at the commercial sites than at the residential sites. These trends can be largely explained by the number and average speed of vehicles operating on the individual road systems (see Section 6.8). Vehicle speeds were generally low at all of the roadside sites, but the commercial sites were characterised by relatively high traffic densities and the frequent

Table 6.5
Ambient hourly pollutant concentrations and traffic flows recorded at Site E-R (March - April 1991).

	Concentration units	Arithmetic mean	Standard deviation
Gaseous pollutant			
Carbon monoxide	ppm	1.0	0.6
Nitric oxide	ppb	33.4	38.2
Nitrogen dioxide	ppb	44.3	23.4
Totals oxides of nitrogen	ppb	78.4	59.2
Ozone	ppb	16.1	10.0
Sulphur dioxide	ppb	4.5	4.4
Non-methane hydrocarbons	ppm	0.5	0.6
Methane	ppm	1.3	0.2
Total hydrocarbons	ppm	1.8	0.4
NO_2/NO_x	%	64.6	15.1
Vehicle flow			
Madeley Rd*	vehicles/hour	474	305
* The actual mobile laboratory location was in Westbury Rd.			

Table 6.6
Ambient hourly pollutant concentrations and traffic flows recorded at Site WG-R (February - April 1992).

	Concentration units	Arithmetic mean	Standard deviation
Gaseous pollutant			
Carbon monoxide	ppm	1.0	0.8
Nitric oxide	ppb	31.4	58.2
Nitrogen dioxide	ppb	46.5	31.8
Totals oxides of nitrogen	ppb	77.9	88.2
Ozone	ppb	12.1	8.8
Sulphur dioxide	ppb	6.9	6.9
Non-methane hydrocarbons	ppm	0.3	0.3
Methane	ppm	2.4	0.9
Total hydrocarbons	ppm	2.6	1.1
NO_2/NO_x	%	73.5	15.7
Vehicle flow			
Gladstone Avenue	vehicles/hour	76	74

Table 6.7
Ambient hourly pollutant concentrations and traffic flows recorded at Site E-C (February - July 1991).

	Concentration units	Arithmetic mean	Standard deviation
Gaseous pollutant			
Carbon monoxide	ppm	2.7	2.2
Nitric oxide	ppb	88.2	79.1
Nitrogen dioxide	ppb	57.9	31.6
Totals oxides of nitrogen	ppb	146.8	109.5
Ozone	ppb	9.1	6.1
Sulphur dioxide	ppb	-	-
Non-methane hydrocarbons	ppm	1.0	0.8
Methane	ppm	1.2	0.2
Total hydrocarbons	ppm	2.3	1.9
NO_2/NO_x	%	46.6	12.6
Vehicle flow			
High St*	vehicles/hour	494	301
Broadway	vehicles/hour	1116	600
* The mobile laboratory was situated in the High St.			

Table 6.8
Ambient hourly pollutant concentrations and traffic flows recorded at Site WG-C (August - October 1992).

	Concentration units	Arithmetic mean	Standard deviation
Gaseous pollutant			
Carbon monoxide	ppm	3.3	2.1
Nitric oxide	ppb	171.6	112.8
Nitrogen dioxide	ppb	95.9	44.1
Totals oxides of nitrogen	ppb	268.7	156.6
Ozone	ppb	3.0	3.8
Sulphur dioxide	ppb	38.3	24.0
Non-methane hydrocarbons	ppm	0.7	0.6
Methane	ppm	2.1	0.9
Total hydrocarbons	ppm	2.7	1.2
NO_2/NO_x	%	39.0	7.3
Vehicle flow			
High Rd Northbound*	vehicles/hour	470	242
High Rd Southbound	vehicles/hour	609	306
High Rd Total	vehicles/hour	1104	482
* The mobile laboratory was situated on the northbound side of the High Rd.			

presence of stop-go traffic conditions. Highest urban CO emissions often occur under these circumstances (Peterson and Allen, 1982).

The highest NO levels were recorded at Site WG-C, which also exhibited the highest average hourly vehicle flow (1104 vehicles/hour compared to 494 vehicles/hour at Site E-C). Vehicle speeds were similar at both commercial sites. Although the commercial sites exhibit higher average hourly concentrations of NO_2 than residential sites, they have markedly lower NO_2/NO_x ratios. This is probably partly due to the proximity of the pollutant source to the monitor. In addition, it is likely that the NO_2/NO_x ratios at the commercial sites (which have higher NO levels) are reduced by the lack of available O_3 for $NO \rightarrow NO_2$ conversion. This hypothesis is supported by the data presented in Tables 6.5-6.8, which display the existence of lower concentrations of O_3 at the commercial sites.

Vehicular emission of SO_2 by petrol engines is minimal, although this pollutant is emitted in larger quantities by diesel engines. SO_2 is therefore not considered to be a major vehicular primary pollutant. The concentrations of SO_2 recorded at the residential sites are similar to typical UK background levels and comparable to those recorded at other UK towns and cities (*eg* QUARG, 1993a). However, the average hourly concentration measured at Site WG-C is quite high, and comparable to values recorded at other (busier) kerbside locations in London (*eg* McCrae, 1991). This observation probably reflects the relatively high percentage of diesel vehicles using the road at this location (see Section 6.4). SO_2 concentrations were not recorded at Site E-C due to equipment failure.

The pollutant concentrations recorded in Tables 6.5-6.8 have been compared to the UK Department of the Environment public information air quality criteria for NO_2, SO_2 and O_3, in which pollution concentrations are banded into four categories. The categorisation, displayed in Table 6.9, indicates that the roadside air quality was typically 'very good' for SO_2 and O_3, but sometimes 'poor' for NO_2, especially at Site WG-C.

Table 6.9
Air quality characterisation for roadside sites expressed as the percentage of time spent in each category during the sampling period.

Category	Category bands (ppb)	Site			
		E-C	E-R	WG-C	WG-R
NO_2					
Very Good	<50	48.2	66.6	13.8	66.6
Good	50-99	40.0	31.0	44.4	27.5
Poor	100-299	11.8	2.4	41.7	5.8
Very Poor	≥300	0.0	0.0	0.1	0.1
SO_2					
Very Good	<60	-	100.0	80.8	99.9
Good	60-124	-	0.0	19.2	0.1
O_3					
Very Good	<50	100.0	100.0	100.0	99.9
Good	50-89	0.0	0.0	0.0	0.1

The ambient carbonyl compound concentrations found at all sites, summarised in Table 6.10, are similar to those found previously in other urban areas (see Table 3.3 and Section 3.8.1). The mean values for formaldehyde, acetaldehyde, hexanal and crotonaldehyde were very similar at both Ealing sites, although slightly higher at Site E-C. The mean values found at Wood Green for acetaldehyde and hexanal are similar to those found at Ealing. No crotonaldehyde was detected at Site WG-C. The formaldehyde values at Wood Green appear lower than those at Ealing, but this is probably due to the mean formaldehyde values for both sites at Ealing being strongly influenced by single high outlying figures. These extreme values of 116 and 122 $\mu g/m^3$ at Sites E-R and E-C respectively, may have occurred as a result of high localised photochemical activity or because of emissions from a nearby idling/stationary badly tuned/poorly maintained vehicle. Acrolein, propanal, benzaldehyde and *iso*-valeraldehyde were not detected at either survey location.

Table 6.10
Carbonyl compound concentrations at the monitored sites ($\mu g/m^3$).

Site	Carbonyl compound	N[a]	Arithmetic mean	Standard deviation
E-R (17)[b]	Formaldehyde	10	32.0 (25.6)[c]	30.8 (24.7)[c]
	Acetaldehyde	15	5.2 (2.8)[c]	5.8 (3.2)[c]
	Hexanal	12	9.2 (2.2)[c]	5.3 (1.3)[c]
	Crotonaldehyde	17	3.5 (1.2)[c]	2.6 (0.9)[c]
E-C (9)[b]	Formaldehyde	8	29.9 (24.0)[c]	36.0 (28.8)[c]
	Acetaldehyde	9	2.9 (1.6)[c]	0.6 (0.3)[c]
	Hexanal	9	5.1 (1.2)[c]	0.9 (0.2)[c]
	Crotonaldehyde	9	1.4 (0.5)[c]	0.4 (0.1)[c]
WG-R (40)[b]	Formaldehyde	37	5.4 (4.3)[c]	3.1 (2.5)[c]
	Acetaldehyde	38	3.7 (2.0)[c]	3.3 (1.8)[c]
	Hexanal	23	3.4 (0.8)[c]	1.6 (0.4)[c]
	Crotonaldehyde	40	1.6 (0.5)[c]	0.8 (0.3)[c]
WG-C (7)[b]	Formaldehyde	7	9.2 (7.4)[c]	5.3 (4.2)[c]
	Acetaldehyde	7	4.3 (2.3)[c]	2.6 (1.4)[c]
	Hexanal	5	11.4 (2.7)[c]	13.3 (3.2)[c]
	Crotonaldehyde	0	-	-

[a] Number of samples in which compound was detected.
[b] Figures in brackets refer to the number of samples taken.
[c] Figures in brackets refer to the concentrations in ppb, assuming an ambient temperature of 20°C and an atmospheric pressure of 1013 mb.

At Site WG-R, sufficient samples were collected to allow the data to be statistically divided into morning and afternoon collection periods. These data, illustrated in Table 6.11, show that the aldehyde concentrations were generally slightly higher in the afternoon. This observation is perhaps to be expected since traffic flow was highest during this period and photochemical activity is usually higher after mid-day.

Table 6.11
Carbonyl compound concentrations at Site WG-C during morning and afternoon collection periods ($\mu g/m^3$).

Carbonyl compound	N[a]	Arithmetic mean	Median	Standard deviation
Morning (19)[b]				
Formaldehyde	18	4.8 (3.8)[c]	3.8 (3.0)[c]	3.1 (2.5)[c]
Acetaldehyde	17	3.2 (1.7)[c]	2.4 (1.3)[c]	1.9 (1.0)[c]
Hexanal	13	3.6 (0.9)[c]	2.9 (0.7)[c]	1.9 (0.5)[c]
Crotonaldehyde	19	1.5 (0.5)[c]	1.3 (0.4)[c]	0.7 (0.2)[c]
Afternoon (21)[b]				
Formaldehyde	19	5.9 (4.7)[c]	4.9 (3.9)[c]	3.0 (2.4)[c]
Acetaldehyde	21	4.1 (2.2)[c]	3.5 (1.9)[c]	4.1 (2.2)[c]
Hexanal	10	3.2 (0.8)[c]	3.2 (0.8)[c]	1.2 (0.3)[c]
Crotonaldehyde	21	1.7 (0.6)[c]	1.6 (0.5)[c]	0.8 (0.3)[c]

[a] Number of samples in which compound was detected.
[b] Figures in brackets refer to the number of samples taken.
[c] Figures in brackets refer to the concentrations in ppb, assuming an ambient temperature of 20°C and an atmospheric pressure of 1013 mb.

6.6 Gaseous pollutant concentrations recorded by local authorities

Gaseous pollutant concentrations recorded at the Enhanced Urban Network (EUN)/Department of the Environment (DoE) sites in Birmingham, Cardiff, Edinburgh and Sheffield are displayed in Tables 6.12-6.15.

Table 6.12
Ambient hourly pollutant concentrations recorded at the EUN Site in Birmingham.

	Concentration units	Arithmetic mean	Standard deviation
Carbon monoxide	ppm	0.6	0.4
Nitric oxide	ppb	20.0	26.5
Nitrogen dioxide	ppb	25.1	13.9
Ozone	ppb	16.9	11.5
Sulphur dioxide	ppb	10.7	12.7
NO_2/NO_x	%	66.0	16.9

The EUN sites in Birmingham and Cardiff are situated in pedestrianised areas, well away from major roads (70 m and 190 m respectively). In Edinburgh, the EUN site is positioned in parkland 35 m away from a major road. The DoE site in Sheffield is situated near a community centre in a mixed residential/industrial area 200 m from the M1. The CO and NO_x

Table 6.13
Ambient hourly pollutant concentrations recorded at the EUN Site in Cardiff.

	Concentration units	Arithmetic mean	Standard deviation
Carbon monoxide	ppm	0.6	0.6
Nitric oxide	ppb	19.9	37.3
Nitrogen dioxide	ppb	22.9	11.4
Ozone	ppb	18.2	12.7
Sulphur dioxide	ppb	6.4	6.8
NO_2/NO_x	%	65.9	17.8

Table 6.14
Ambient hourly pollutant concentrations recorded at the EUN Site in Edinburgh.

	Concentration units	Arithmetic mean	Standard deviation
Carbon monoxide	ppm	0.6	0.4
Nitric oxide	ppb	25.1	31.4
Nitrogen dioxide	ppb	25.3	11.8
Ozone	ppb	16.1	8.9
Sulphur dioxide	ppb	7.5	7.5
NO_2/NO_x	%	59.6	16.7

Table 6.15
Ambient hourly pollutant concentrations recorded at the DoE Site in Sheffield.

	Concentration units	Arithmetic mean	Standard deviation
Carbon monoxide	ppm	0.4	0.4
Nitric oxide	ppb	48.5	58.3
Nitrogen dioxide	ppb	30.8	15.8
NO_2/NO_x	%	51.4	20.9

concentrations recorded at these sites are lower than the roadside values recorded at the Ealing and Wood Green sites (Tables 6.5-6.8), with the NO_x concentrations being similar to those determined (by diffusion tubes) at commercial areas in Manchester during 1986-1991 (QUARG, 1993a). The SO_2 concentrations are typical of urban areas in UK towns/cities and (with the exception of the Site WG-C) are similar to those recorded at roadside locations using the mobile laboratory.

Ozone values at the EUN sites were similar to those recorded at Sites E-R and WG-R but higher than those obtained at the commercial sites. The NO_2/NO_x ratios at Birmingham, Cardiff and Edinburgh are similar to the roadside values recorded at Sites E-R and WG-R but markedly higher than the ratios at Sites E-C and WG-C. The lowest NO_2/NO_x ratio was recorded at Sheffield, which like the roadside commercial sites, predicted a mean NO concentration higher than the mean NO_2 concentration.

As at the roadside sites, the pollutant concentrations recorded in Tables 6.12-6.16 have been compared to the UK Department of the Environment public information air quality criteria for NO_2, SO_2 and O_3. The categorisation, displayed in Table 6.16, indicates that the air quality was typically 'very good' for all pollutants at all EUN/DoE locations.

Table 6.16
Air quality characterisation for EUN/DoE sites expressed as the percentage of time spent in each category during the sampling period.

Category	Category bands (ppb)	Site			
		Birmingham	Cardiff	Edinburgh	Sheffield
NO_2					
Very Good	<50	96.5	98.6	97.6	91.0
Good	50-99	3.5	1.4	2.4	8.5
Poor	100-299	0.0	0.0	0.0	0.5
SO_2					
Very Good	<60	98.8	99.8	99.8	-
Good	60-124	1.1	0.1	0.2	-
Poor	125-399	0.1	0.1	0.0	-
O_3					
Very Good	<50	99.6	98.1	100.0	-
Good	50-89	0.4	1.9	0.0	-

In addition to data from the EUN/DoE sites, gaseous pollutant concentrations recorded by local authorities using DOAS (Differential Optical Absorption Spectroscopy) equipment was collected at commercial locations in Cardiff, Coventry and Sheffield. DOAS utilises a long path light beam projected through the atmosphere, where individual gases absorb light of particular wavelengths, each creating a unique spectroscopic fingerprint. The beam of light must be uninterrupted, and measurements therefore tend to be taken at rooftop level. The arithmetic mean hourly averages recorded at the 3 local authority sites are displayed in Tables 6.17-6.19. The values obtained at Cardiff for NO_2, O_3 and SO_2 are very similar to those recorded at the nearby EUN site (Table 6.13). The NO_2 values recorded by OPSIS (a trade name for a commercially available DOAS unit) at Sheffield are markedly lower than those recorded at the DoE site (Table 6.15). The formaldehyde levels recorded by OPSIS were similar to those values obtained at the Wood Green roadside sites, but lower than those recorded at Ealing. There is currently no EUN monitoring station in Coventry.

The SO_2 data already reviewed was further corroborated by a comparison with data recorded using 8-port smoke/SO_2 samplers by local authorities for 24-hour ambient SO_2 concentrations. These data, displayed in Table 6.20, were of a similar magnitude to the hourly average concentrations collected by OPSIS and at EUN sites.

Table 6.17

Ambient hourly pollutant concentrations recorded by OPSIS at a rooftop site in central Cardiff ($\mu g\ m^{-3}$).

Pollutant	Arithmetic mean	Standard deviation
Benzene	32 (9.8)	12 (3.7)
Toluene	41 (10.7)	30 (7.8)
Nitrogen dioxide	59 (30.8)	27 (14.1)
Ozone	46 (23.0)	22 (11.0)
Sulphur dioxide	22 (8.3)	27 (10.2)
Figures in brackets refer to concentrations in ppb, assuming an ambient temperature of 20°C and an atmospheric pressure of 1013 mb.		

Table 6.18

Ambient hourly pollutant concentrations recorded by OPSIS at a rooftop site in central Coventry ($\mu g\ m^{-3}$).

Pollutant	Arithmetic mean	Standard deviation
Benzene	17 (5.2)	5 (1.5)
Toluene	36 (9.4)	20 (5.2)
Nitrogen dioxide	49 (25.6)	23 (12.0)
Ozone	26 (13.0)	18 (9.0)
Sulphur dioxide	24 (9.0)	23 (8.6)
Formaldehyde	4 (3.2)	1 (0.8)
p-xylene	4 (0.9)	2 (0.4)
Phenol	6 (1.5)	3 (0.8)
Figures in brackets refer to concentrations in ppb, assuming an ambient temperature of 20°C and an atmospheric pressure of 1013 mb.		

Table 6.19
Ambient hourly pollutant concentrations recorded by OPSIS at a rooftop site in central Sheffield ($\mu g\ m^{-3}$).

Pollutant	Arithmetic mean	Standard deviation
Benzene	22 (6.8)	10 (3.1)
Toluene	45 (11.8)	22 (5.8)
Nitrogen dioxide	38 (19.9)	17 (8.9)
Ozone	65 (32.5)	30 (15.0)
Sulphur dioxide	46 (17.3)	49 (18.4)
Formaldehyde	11 (8.8)	6 (4.8)
p-xylene	6 (1.4)	2 (0.4)
Figures in brackets refer to concentrations in ppb, assuming an ambient temperature of 20°C and an atmospheric pressure of 1013 mb.		

Table 6.20
Mean daily SO_2 concentrations recorded by 8-Port at Local Authority Sites ($\mu g/m^3$).

Site	Sampling period	Median	Arithmetic mean	Standard deviation
E-C	March - July 1991	13 (4.9)	17 (6.4)	14 (5.3)
B-R	Feb - March 1993	19 (7.1)	21 (7.9)	13 (4.9)
Card-R	Jan - May 1993	20 (7.5)	20 (7.5)	10 (3.8)
Cov-RC	Jan - March 1993	26 (9.8)	30 (11.3)	13 (4.9)
Edin-R	Jan - March 1993	19 (7.1)	22 (8.3)	10 (3.8)
Edin-C	Jan - March 1993	32 (12.0)	38 (14.3)	16 (6.0)
S-R	Jan - May 1993	27 (10.1)	34 (12.8)	21 (7.9)
S-C	Jan - May 1993	36 (13.5)	41 (15.4)	21 (7.9)
Figures in brackets refer to concentrations in ppb, assuming an ambient temperature of 20°C and an atmospheric pressure of 1013 mb.				

6.7 Statistical summaries of gaseous pollutant concentrations

Air quality data sets collected over a period of time are usually very large, and the data sets accumulated during this research are no different. In order to compare and contrast data sets from monitoring sites with varying characteristics, the data are often represented graphically by *frequency distributions* (histograms or frequency polygons). The shape and symmetry of a frequency distribution is extremely important, since it determines the subsequent analysis and interpretation of the data. Gaseous pollutant data sets containing hourly averages characteristically produce frequency plots and histograms which are skewed right (positive skew), *ie* they have a peak (or mode) to the left and a long tail to the right (Clark *et al*, 1984;

Brimblecombe, 1986). Examples of this distribution type are shown in Figures 6.11(a-c). These are typical of air pollution data, which usually approximate to a log-normal distribution.

For normally distributed data, the frequency distribution is symmetrical about the mean, which therefore becomes the most representative (and frequently used) measure of central location. For example, Tables 6.5-6.8 display the measured ambient concentrations at the roadside survey sites in terms of means and standard deviations. However, these statistical parameters are not strictly suitable for non-normally distributed data, which are not symmetrically distributed about the mean. In non-normal distributions, the mean may be strongly affected by extreme values (outliers), and may no longer be the best measure of central location. Thus, in order to obtain a clearer picture of the log-normally distributed gaseous air pollutant data, a wider range of summary statistics (such as medians, percentiles, maxima and minima) have been calculated. These summary statistics are displayed in Tables 6.21-6.28, and indicate that the midsummaries (the 25th, 50th and 75th percentiles) become progressively larger, suggesting that the distributions are skewed right. The statistics also clearly indicate that the NO_2/NO_x ratios do not reach 100% at the roadside commercial sites. This is in marked contrast to the ratios at all other locations and indicates the strong influence of NO concentrations at roadside sites. Overall, this statistical treatment provides a simple and compact representation of the data and ultimately a convenient means for interpolation and extrapolation beyond any observed values (McCrae, 1991).

6.8 The time series analysis of gaseous air quality data

Time series plots have been used widely to display and investigate air quality data (*eg* WHO, 1980; McCrae, 1991; DoE, 1994; QUARG, 1993a&b). A time series may be defined as a set of observations of a variable (*eg* hourly CO concentrations) measured at successive points in time or over successive periods of time.

The information available from a time series plot enables a researcher to monitor historical aspects of data, *ie* to observe how a variable has behaved over a given period of time. These plots are often used to investigate cycles and trends in the data. Cycles refer to effects such as the diurnal or even seasonal variation of urban CO levels as a consequence of traffic density. A trend may be described as the overall tendency of the data, *eg* the reduction in UK ambient smoke levels since 1962. Over a period of years, short-term cycles may be superimposed upon long-term trends due to variations in emission rates.

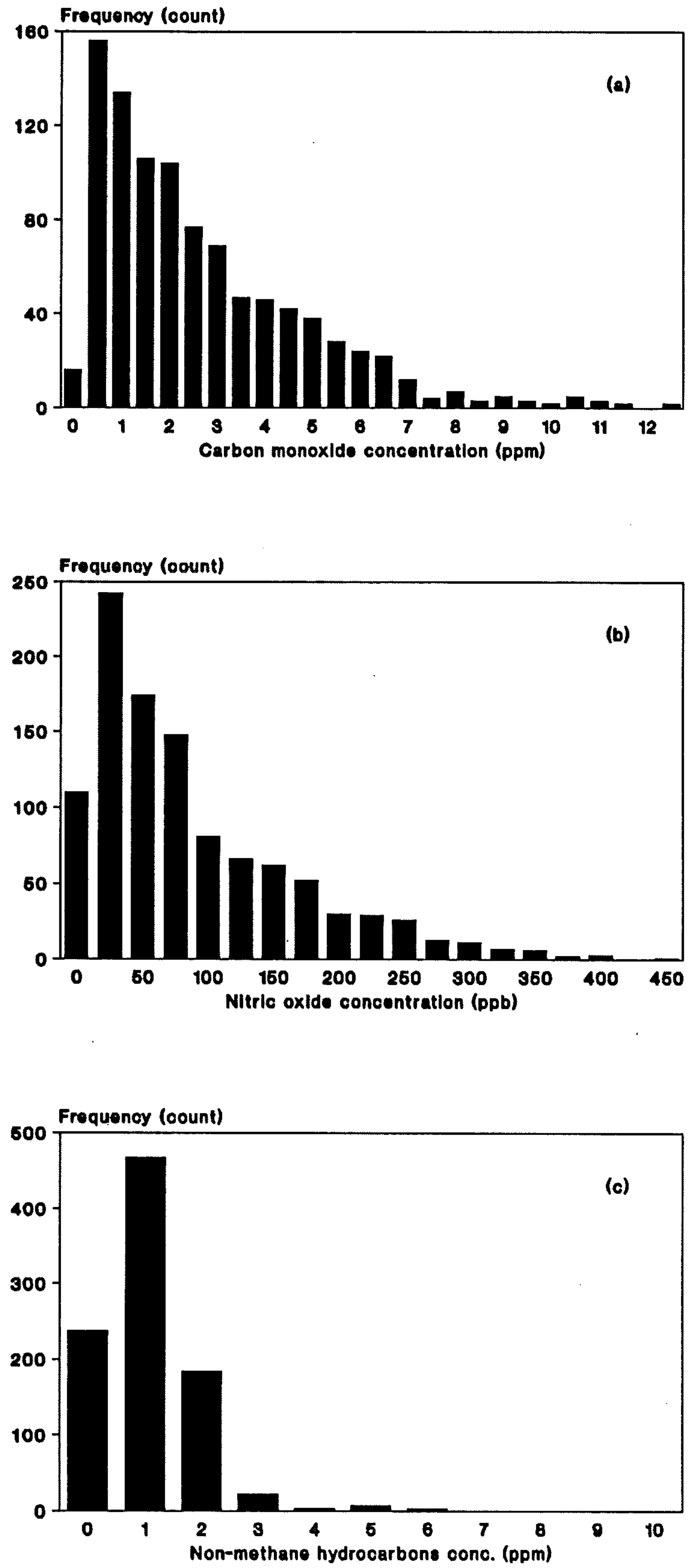


Figure 6.11

Frequency distributions of hourly pollutant concentrations recorded at Site E-C: (a) carbon monoxide; (b) nitric oxide and (c) non-methane hydrocarbons.

Table 6.21
Statistical summary of hourly gaseous pollutant concentrations and traffic flow at Site E-R.

	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Pollutant											
Carbon monoxide	ppm	1253	0.1	0.3	0.5	0.9	1.3	1.8	2.1	2.7	5.2
Nitric oxide	ppb	1253	0.0	2.5	10.0	22.0	44.0	75.0	103.8	149.8	392.8
Nitrogen dioxide	ppb	1254	2.0	19.0	29.0	39.8	56.1	72.8	84.0	105.0	182.2
Total oxides of nitrogen	ppb	1254	2.0	23.8	41.4	63.6	100.0	144.5	187.2	253.8	575.0
Ozone	ppb	1254	0.8	3.2	6.9	15.4	23.7	30.0	33.8	37.4	43.0
Sulphur dioxide	ppb	645	0.0	0.6	1.7	3.2	5.8	9.9	13.2	16.9	28.3
Methane	ppm	1129	0.1	1.2	1.3	1.3	1.4	1.6	1.7	1.9	4.5
Non-methane hydrocarbons	ppm	1114	0.1	0.2	0.2	0.4	0.6	0.9	1.6	2.2	13.4
Total hydrocarbons	ppm	945	1.3	1.5	1.6	1.7	2.0	2.3	2.5	3.0	6.7
NO_2/NO_x	%	1254	28.1	45.7	53.5	63.1	75.4	86.4	91.4	95.9	100.0
Traffic flow											
Madeley Rd	vehicles/hour	2255	12	42	159	523	748	840	874	909	1383

Table 6.22
Statistical summary of hourly gaseous pollutant concentrations and traffic flow at Site WG-R.

	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Pollutant											
Carbon monoxide	ppm	1619	0.1	0.3	0.5	0.8	1.3	2.0	2.8	3.7	9.3
Nitric oxide	ppb	2015	0.0	1.5	4.2	10.8	28.5	85.5	140.0	225.5	642.0
Nitrogen dioxide	ppb	2015	4.0	23.2	26.5	40.0	56.8	78.5	107.5	139.5	315.0
Total oxides of nitrogen	ppb	2015	5.0	25.8	31.8	51.5	84.0	163.5	246.0	364.0	956.5
Ozone	ppb	2015	0.1	2.3	4.1	10.4	18.2	24.8	27.4	30.7	53.1
Sulphur dioxide	ppb	1218	0.0	0.5	2.1	5.0	9.8	15.6	19.9	27.0	64.6
Methane	ppm	1085	0.2	1.8	1.9	2.0	3.0	3.3	3.6	5.0	8.2
Non-methane hydrocarbons	ppm	1319	0.0	0.0	0.1	0.2	0.3	0.6	0.9	1.4	2.4
Total hydrocarbons	ppm	1087	0.1	1.8	2.0	2.2	3.0	3.6	4.4	6.2	8.7
NO_2/NO_x	%	2011	26.3	48.1	64.7	76.1	86.7	91.3	93.3	94.9	100.0
Traffic flow											
Gladstone Avenue	vehicles/hour	1707	0	4	14	49	131	178	223	252	478

Table 6.23
Statistical summary of hourly gaseous pollutant concentrations and traffic flow at Site E-C.

	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Pollutant											
Carbon monoxide	ppm	957	0.1	0.5	1.0	2.1	3.9	5.7	6.7	9.0	12.4
Nitric oxide	ppb	1063	1.2	11.8	29.2	63.0	126.0	200.0	250.0	303.0	460.2
Nitrogen dioxide	ppb	1063	6.0	21.5	35.8	51.2	74.5	103.5	121.0	136.5	173.2
Total oxides of nitrogen	ppb	1063	8.5	35.2	66.0	116.8	200.5	304.8	371.0	439.2	634.2
Ozone	ppb	1063	0.1	2.9	4.3	7.4	12.6	18.4	21.4	23.4	34.3
Sulphur dioxide	ppb	-	-	-	-	-	-	-	-	-	-
Methane	ppm	923	0.6	1.0	1.1	1.2	1.3	1.4	1.5	1.6	2.1
Non-methane hydrocarbons	ppm	924	0.1	0.3	0.5	0.9	1.4	1.9	2.2	2.9	6.1
Total hydrocarbons	ppm	924	1.1	1.4	1.6	2.0	2.7	3.2	3.6	4.6	43.4
NO_2/NO_x	%	1063	22.1	32.2	37.1	44.2	54.5	64.6	70.8	76.0	88.2
Traffic flow											
High St	vehicles/hour	1009	14	59	184	550	772	843	878	915	1039
Broadway	vehicles/hour	2296	0	189	552	1328	1599	1733	1862	2002	2639

Table 6.24

Statistical summary of hourly gaseous pollutant concentrations and traffic flow at Site WG-C.

	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Pollutant											
Carbon monoxide	ppm	1234	0.1	0.9	1.7	2.9	4.3	6.2	7.4	8.5	13.2
Nitric oxide	ppb	1364	3.2	45.5	93.0	149.2	229.2	325.5	383.8	467.0	803.2
Nitrogen dioxide	ppb	1364	8.5	41.5	65.8	92.0	120.8	155.8	177.8	201.0	312.0
Total oxides of nitrogen	ppb	1364	14.8	89.2	159.8	243.8	349.4	477.8	556.8	666.5	1116.0
Ozone	ppb	1090	0.0	0.2	0.6	1.4	4.2	7.9	11.1	15.1	23.3
Sulphur dioxide	ppb	1350	0.1	6.4	17.1	38.3	55.0	70.0	80.2	90.1	107.8
Methane	ppm	1061	1.1	1.3	1.4	2.1	2.5	3.2	4.0	5.1	6.7
Non-methane hydrocarbons	ppm	1042	0.0	0.1	0.3	0.6	1.0	1.6	1.9	2.2	3.5
Total hydrocarbons	ppm	1182	1.0	1.5	1.9	2.5	3.2	4.4	5.2	6.2	7.8
NO_2/NO_x	%	1364	13.1	31.3	34.0	37.8	41.9	48.0	53.3	58.7	83.1
Traffic flow											
High Rd Northbound	vehicles/hour	1079	0	104	235	559	664	740	780	805	902
High Rd Southbound	vehicles/hour	995	0	123	344	709	782	877	1195	1285	1390
High Rd Total	vehicles/hour	995	108	338	687	1315	1467	1584	1648	1790	2049

Table 6.25
Statistical summary of hourly gaseous pollutant concentrations recorded at the EUN Site in Birmingham.

Pollutant	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Carbon monoxide	ppm	4180	0.0	0.2	0.3	0.5	0.8	1.1	1.4	1.7	3.5
Nitric oxide	ppb	4136	0.0	2.0	4.0	9.0	26.0	54.0	73.0	100.0	361.0
Nitrogen dioxide	ppb	3889	0.0	7.0	14.0	25.0	35.0	43.0	47.0	54.0	98.0
Ozone	ppb	4163	0.0	3.0	6.0	16.0	26.0	32.0	35.0	40.0	77.0
Sulphur dioxide	ppb	4134	0.0	2.0	4.0	7.0	12.0	24.0	35.0	51.0	196.0
NO_2/NO_x	%	3886	11.9	41.0	55.4	68.3	80.0	85.7	88.6	91.3	100.0

Table 6.26
Statistical summary of hourly gaseous pollutant concentrations recorded at the EUN Site in Cardiff.

Pollutant	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Carbon monoxide	ppm	4181	0.0	0.1	0.3	0.5	0.7	1.1	1.4	2.0	12.0
Nitric oxide	ppb	4185	0.0	2.0	4.0	8.0	20.0	49.0	75.0	115.0	687.0
Nitrogen dioxide	ppb	4185	0.0	8.0	14.0	23.0	31.0	38.0	41.0	47.0	77.0
Ozone	ppb	4211	1.0	3.0	7.0	17.0	27.0	34.0	39.0	49.0	85.0
Sulphur dioxide	ppb	4202	0.0	2.0	3.0	4.0	8.0	14.0	19.0	26.0	144.0
NO_2/NO_x	%	4183	9.5	39.1	55.5	69.2	79.3	86.7	90.0	92.6	100.0

Table 6.27
Statistical summary of hourly gaseous pollutant concentrations recorded at the EUN Site in Edinburgh.

Pollutant	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Carbon monoxide	ppm	4225	0.0	0.1	0.3	0.5	0.7	1.0	1.4	1.5	4.6
Nitric oxide	ppb	4170	0.0	3.0	6.0	14.0	32.0	60.0	78.0	110.0	508.0
Nitrogen dioxide	ppb	4170	1.0	10.0	17.0	25.0	33.0	40.0	44.0	53.0	84.0
Ozone	ppb	4249	0.0	4.0	9.0	16.0	23.0	28.0	31.0	34.0	44.0
Sulphur dioxide	ppb	4232	0.0	2.0	3.0	5.0	9.0	15.0	19.0	27.0	98.0
NO_2/NO_x	%	4170	9.4	36.4	47.2	61.1	72.2	81.0	85.7	88.9	100.0

Table 6.28
Statistical summary of hourly gaseous pollutant concentrations recorded at the EUN Site in Sheffield.

Pollutant	Units	N	Minimum	Percentiles							Maximum
				10	25	50	75	90	95	98	
Carbon monoxide	ppm	3934	0.0	0.1	0.2	0.4	0.5	0.8	1.2	1.5	5.6
Nitric oxide	ppb	4318	0.0	4.0	11.0	30.0	68.0	111.0	148.0	208.0	823.0
Nitrogen dioxide	ppb	4318	2.0	14.0	21.0	29.0	38.0	48.0	57.0	74.0	175.0
NO_2/NO_x	%	4318	6.7	25.6	35.7	49.4	65.7	82.0	90.0	100.0	100.0

The gaseous pollutant data sets for the Ealing and Wood Green locations (4 survey sites) contain between 645 to 2015 hourly averages for each pollutant, supplemented by local and regional meteorological data and traffic flow information. At each site, the measured hourly average data has been condensed into a seven day, 168 hour period data set for ease of interpretation. This was achieved by calculating an average concentration for each hour of each day of the week during the monitoring periods. These time series plots are displayed with a starting time of 00:00 hours on Monday.

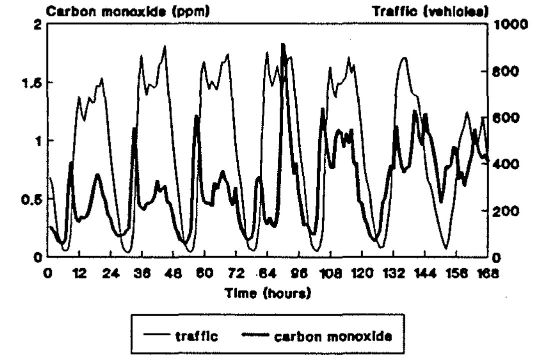
In this analysis, time plots for concentration levels of the measured air pollutants at each monitoring site are used to identify cycles and trends in the data. The graphs are also used as an initial tool for the identification of possible pollutant inter-relationships and relationships with traffic flows.

6.8.1 The analysis of time series plots for residential sites

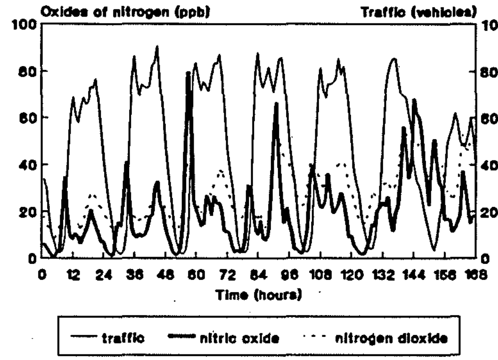
6.8.1.1 Site E-R

Time series plots for Site E-R are illustrated in Figures 6.12(a-f). The pollutant concentrations recorded at this site were generally lower than those reported for other (busier) roadside sites in London (*eg* McCrae (1991)), but higher than data recorded at EUN/DoE sites. At this site, the mobile laboratory was parked on the western side of Westbury Road, a heavily parked but lightly trafficked residential street. The instruments for traffic counting were not located in Westbury Road, but were positioned approximately 200 metres to the south of the laboratory in a more densely trafficked residential street called Madeley Road. The traffic flow data displayed in Figures 6.12(a-e) does not therefore represent the volume of traffic passing immediately adjacent to the mobile laboratory, but is representative of the traffic flows within the surveyed area.

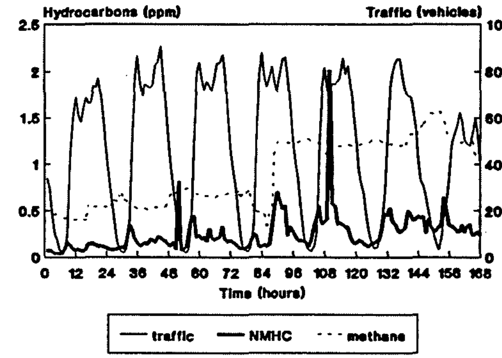
During weekdays, the traffic flow in Madeley Road was characterised by a trimodal distribution, with the larger peaks relating to the morning and evening peak traffic periods, and the smaller peak in mid-afternoon possibly relating to school traffic. The weekday morning peak traffic period occurred between 11:00-12:00 hours, mainly due to commercial traffic using Madeley Road as a short-cut to and from the town centre. The evening peak traffic period occurred between 20:00-21:00 hours on Mondays to Thursdays, and 18:00-19:00 hours on Fridays. The time series indicates a gradual build-up of traffic throughout the morning and early afternoon on Saturdays, culminating with a single peak between 15:00-17:00 hours. A distinct reduction in traffic is evident on Sundays, when a bimodal distribution relating to traffic peaks between 15:00-16:00 and 21:00-22:00 hours respectively was observed.



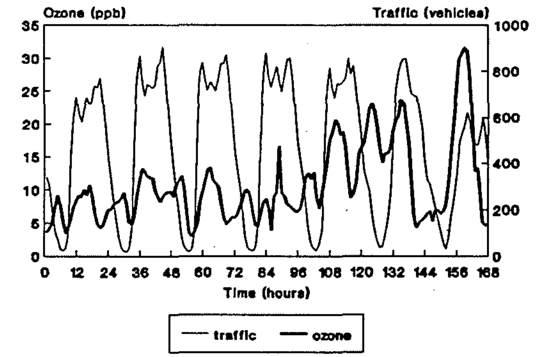
(a) Traffic flow and carbon monoxide plotted against time.



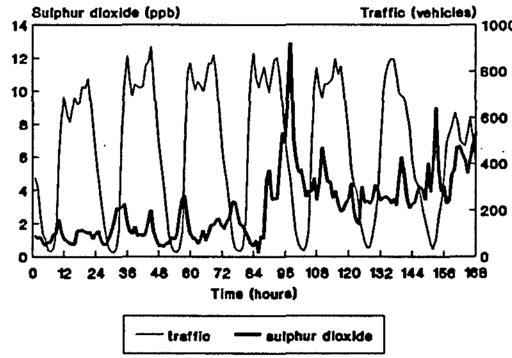
(b) Traffic flow and nitrogen oxides plotted against time.



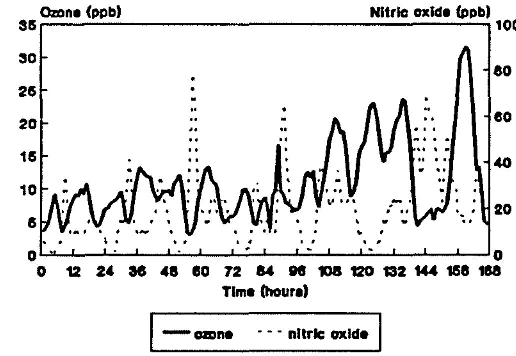
(c) Traffic flow and hydrocarbons plotted against time.



(d) Traffic flow and ozone plotted against time.



(e) Traffic flow and sulphur dioxide plotted against time.



(f) Nitric oxide and ozone plotted against time.

Figure 6.12(a-f)
Time series plots of gaseous pollutants recorded at the mobile laboratory, at site E-R.

The carbon monoxide concentrations exhibit similar diurnal and weekly cycles to those for traffic flow, although the peak CO concentrations generally occur 2-3 hours before the peaks in traffic density (Figure 6.12a). Since average CO emissions tend to be highest at low speeds (Rogers, 1984), these CO peaks may be explained by the occurrence of slow-moving traffic queuing on Madeley Road between 08:00-10:00 and 17:00-19:00 hours in order to gain access to and from the busy North Circular Road. During the mid-morning, traffic speeds tended to be higher because of easier access to the North Circular, resulting in lower CO emissions. In urban areas, CO emissions generally reduce with increasing speed. The timing of the peak CO levels also tallies with the usage of Westbury Road during the early morning and evening periods as an area for commuter parking. During the early part of the week, morning CO concentrations exceeded afternoon levels, although the highest CO concentrations occurred on Thursday evenings.

Non-methane hydrocarbons show a weak but positive relationship with traffic density, as ilustrated in Figure 6.12(c). The large, distinct peak appearing on Friday afternoons results from a single, unusually high hourly average concentration recorded on 26/4/91. Methane concentrations show little correlation with traffic flow, and were consistently higher from Thursday evenings to Sundays than from Mondays to Thursday mornings. Non-methane hydrocarbons show a similar, though less distinct, trend. These data may indicate an additional weekend source of hydrocarbons, possibly domestic space heating.

The relationship between traffic flows and sulphur dioxide concentrations, shown in Figure 6.12(e), does not display a recognisable pattern, although some SO_2 and traffic peaks do coincide. As with hydrocarbon concentrations, SO_2 levels are consistently higher from Thursdays to Sundays, possibly reflecting the impact of increased domestic fuel usage during the weekend period.

The relationship between traffic flow, nitrogen oxides and ozone are shown in Figures 6.12(b,d and f). The time series for nitric oxide exhibits similar characteristics to that for CO, which is unsurprising since they are both primary vehicular pollutants. Nitric oxide is oxidised relatively rapidly to nitrogen dioxide after emission through photochemical reactions, and being a primary vehicular pollutant shows a similar distribution to CO.

The data displayed in Figure 6.12(d) suggests that there are two diurnal ozone peaks during weekdays and Saturdays; one in the early morning and one in the early afternoon. These peaks probably correspond to periods of low traffic flow (and thus less associated NO available for photochemical reactions) and maximum photochemical activity respectively. On Sundays, the early morning ozone peak disappears, and only a single mid-afternoon peak is visible. This may be explained by the elevated concentrations of nitric oxide on Sunday mornings, possibly as a result of domestic space heating. This conclusion is supported by the data in Figure 6.12(f), which shows a tendency for an inverse relationship between concentrations of ozone and nitric oxide.

6.8.1.2 Site WG-R

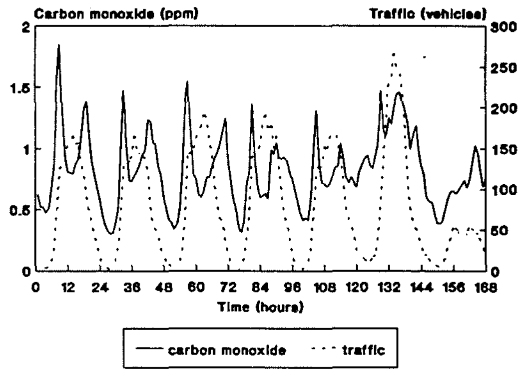
Figures 6.13(a-e) display data obtained at Site WG-R. The pollutant concentrations at this site were very similar to those recorded at Site E-R. The mobile laboratory was parked in Vincent Road, at the junction of Vincent Road and Gladstone Avenue. At this junction, traffic is prevented from entering Vincent Road by the presence of a wall across the road. The traffic counting apparatus was therefore positioned in Gladstone Avenue, approximately 20 m to the east of the mobile laboratory (see Figure 4.3).

On weekdays, the traffic flow gradually built up during the morning, peaking at about 180 vehicles per hour at 14:00-16:00 pm. The same pattern is evident on Saturdays, when traffic flows are distinctly higher, possibly due to 'rat-running' of vehicles towards the multi-storey car parks in the nearby commercial area. On Sundays, a clear decrease in traffic is apparent, with two peaks at 13:00 pm and 18:00 pm, respectively.

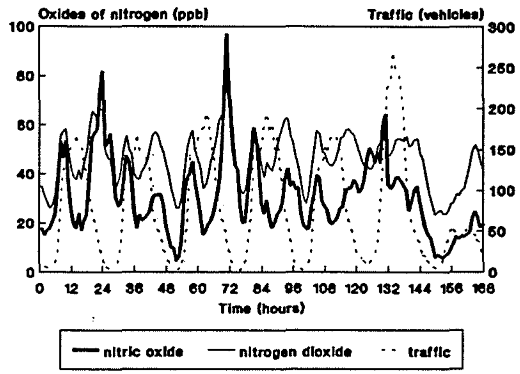
Weekday CO concentrations show a bimodal distribution, with morning peaks occurring between 07:00-08:00 and afternoon peaks between 16:00-18:00, except on Wednesdays, which show a later peak (21:00-22:00). Peak CO levels generally occurred 2-3 hours before the peaks in traffic density, as at Site E-R. However, since traffic flows at Vincent Road and Gladstone Avenue were very low, this may indicate that the CO was transported to this site from other busy roads nearby (*eg* Green Lanes, the A10).

Traffic densities plotted in combination with hydrocarbons for this site are displayed in Figure 6.13(c). As expected, methane concentrations were relatively constant and largely independent of traffic flow. Non-methane hydrocarbon concentrations were slightly elevated during peak traffic periods and display a weaker relationship than CO with traffic density.

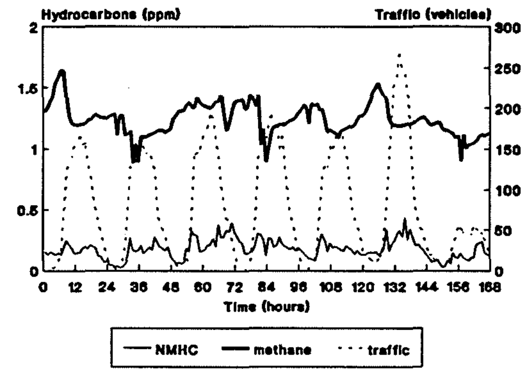
The relationship between SO_2 and traffic flow is complex and unclear (Figure 6.13(e)), with highest concentrations occuring in the period from Wednesdays to Fridays. Sulphur dioxide peaks often occur during the morning and sometimes during the night, although no particular



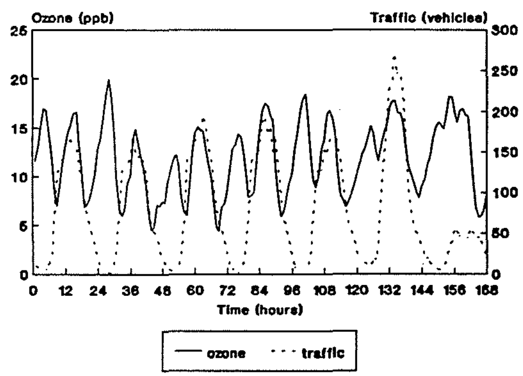
(a) Traffic flow and carbon monoxide plotted against time.



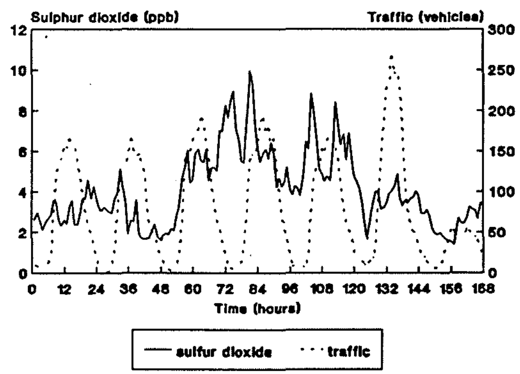
(b) Traffic flow and nitrogen oxides plotted against time.



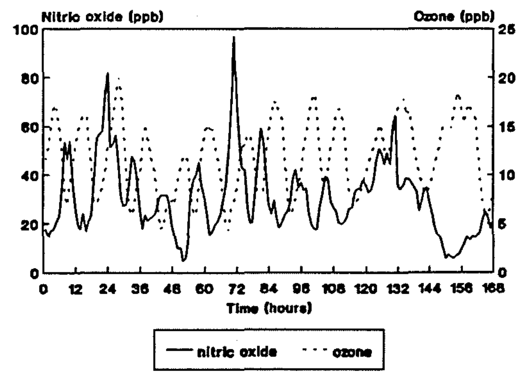
(c) Traffic flow and hydrocarbons plotted against time.



(d) Traffic flow and ozone plotted against time.



(e) Traffic flow and sulphur dioxide plotted against time.



(f) Nitric oxide and ozone plotted against time.

Figure 6.13(a-f)
Time series plots of gaseous pollutants recorded at the mobile laboratory, at Site WG-R.

pattern is apparent. The data may indicate the presence of other (imported) sources of SO_2 since the reduction of SO_2 levels at the weekend suggests that the influence of domestic space heating is minor.

The relationship between traffic flow and NO_x are shown in Figures 6.13(b & d). As with carbon monoxide, peak nitric oxide levels usually occured 2-3 hours before maximum traffic flow on weekdays and Saturdays, indicating the influence of additional sources of NO, in particular, the local road network. Nitrogen dioxide levels show two distinct peaks occuring at 9:00-10:00 and 20:00-24:00 hours during the weekday periods and a single peak at 21:00 on Sundays. The NO_2 peaks were quite broad, and were possibly influenced by the input of NO_2 (as a result of $NO \rightarrow NO_2$ conversion) from nearby transportation sources.

The time series plots for ozone with traffic flow and NO (Figures 6.13(d & f) are very similar to those for Site E-R (Section 6.8.5.1), although the O_3 peaks are more distinct and discrete at this location.

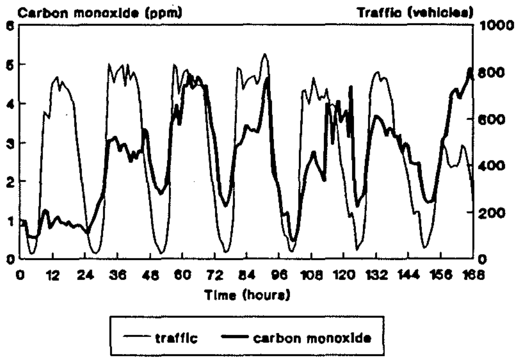
6.8.2 The analysis of time series plots for commercial sites

6.8.2.1 Site E-C

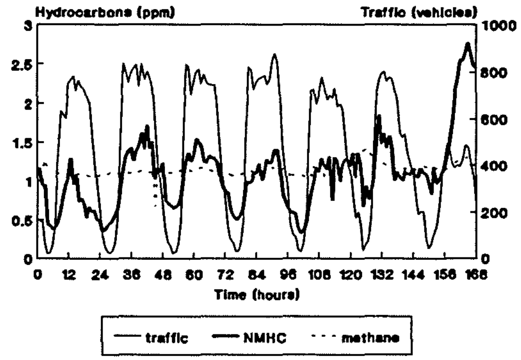
Time series distributions for data recorded at Site E-C are illustrated in Figures 6.14(a-f). The pollutant concentrations at this commercial location were higher than those recorded at the residential site (Site E-R) and slightly lower than previously reported concentrations from other more densely trafficked sites in London (McCrae, 1991).

The traffic flow in the High St during weekdays was characterised by an approximately trimodal distribution. The morning peak traffic period occured between 09:00-10:00 on Mondays to Thursdays, and 10:00-11:00 on Fridays. The evening peak traffic period, occuring between 16:00-17:00 on Mondays to Wednesdays was 2 hours later on Thursdays to Fridays. The week day mid-afternoon peak, between 14:00-15:00 hours, was possibly due to increased commercial traffic shortly after lunch. The time series indicates that no reduction of traffic volume occured on Saturdays, with a gradual build-up of traffic to a single peak at 13:00-14:00 hours. On Sundays, there was a well-defined reduction in traffic flows, the data showing a bimodal distribution with peaks between 13:00-14:00 and 20:00-21:00 hours respectively.

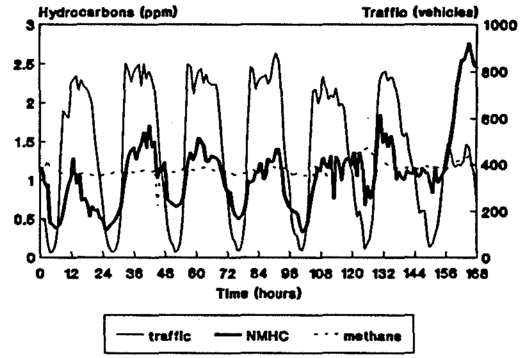
The data illustrated in Figure 6.14(a) indicates a strong correlation between CO concentrations and traffic flow, with slightly higher concentrations occuring during the weekday evening peak traffic periods, particularly on Thursday evenings when the shopping centre was open until



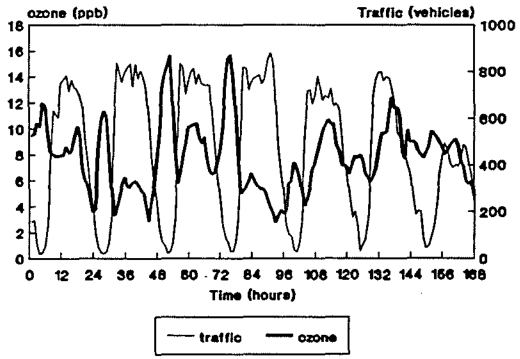
(a) Traffic flow and carbon monoxide plotted against time.



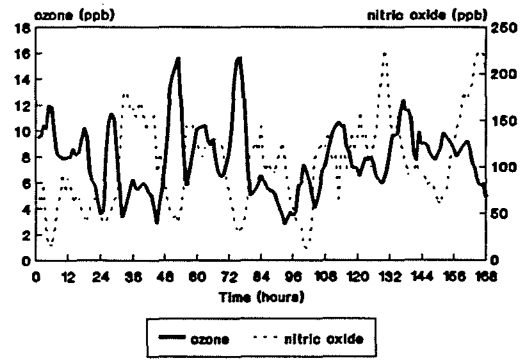
(b) Traffic flow and nitrogen oxides plotted against time.



(c) Traffic flow and hydrocarbons plotted against time.



(d) Traffic flow and ozone plotted against time.



(e) Nitric oxide and ozone plotted against time.

Figure 6.14(a-e)
Time series plots of gaseous pollutants recorded at the mobile laboratory, at site E-C.

20:00 hours. The broadening of the CO peak late into Friday evenings was probably caused by heavy traffic congestion in the High St and Uxbridge Road as a result of westward-bound traffic on the nearby North Circular Road which feeds the M4 and A4. It seems reasonable to assume that the CO peak late on Saturday nights was due to vehicles transporting people away from the busy town centre pubs and clubs.

The relationships between hydrocarbons and traffic density are displayed in Figure 6.14(c). Methane levels vary little with traffic density, while non-methane hydrocarbons concentrations show a strong positive relationship with traffic density. Peak NMHC levels occur at 12:00-14:00 hours on weekdays and Saturdays, and 22:00-23:00 hours on Sundays, which suggests the presence of additional (possibly imported) hydrocarbon sources.

The weekly distributions of NO_x and O_3 in conjunction with traffic flow are illustrated in Figure 6.14(b, d & e). The time series plots indicate a strong relationship between traffic densities and NO_x levels, with peak concentrations typically occuring an hour or two after peak traffic flows. The broad NO peak on Friday evenings probably reflects the level of congestion on the High St and Uxbridge Rd (as discussed for CO above).

Ozone concentrations tend to show an inverse relationship with NO, although the relationship is complex, particularly in the latter half of the week. From Mondays to Thursdays, O_3 concentrations tend to be highest during the early hours of the morning, when NO levels are at their lowest. A second peak occured during mid-afternoon, possibly during the period of highest photochemical activity. The presence of relatively large NO peaks on Friday and Sunday nights result in less distinct O_3 peaks at the weekend.

6.8.2.2 Site WG-C

Time series plots for data recorded at Site WG-C are displayed in Figures 6.15(a-f). As at Ealing, the pollutant concentrations at this commercial location were higher than those recorded at the residential site (Site WG-R). The concentrations of primary vehicular pollutants were similar to those previously reported at other roadside sites in London (McCrae, 1991).

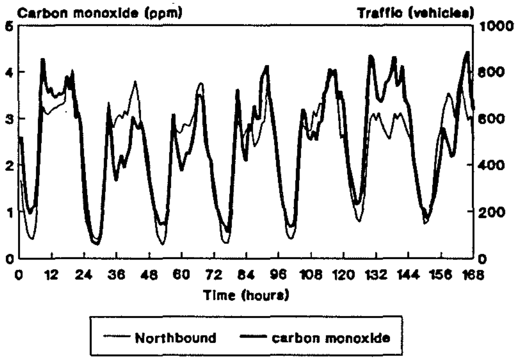
Both the northbound and southbound traffic flows in the High Rd were recorded at this location, as shown in Figure 6.16. The data clearly shows that traffic flows predominantly towards central London in the morning (*ie* south) during weekdays whereas in the afternoon the north and south flows were similar. On Mondays to Fridays, the morning peak traffic flows occured between 07:00-08:00 and 08:00-09:00 for south- and north-bound traffic respectively.

The evening peak traffic flows occured between 18:00-20:00 in both directions on weekdays. At the weekend, typical traffic levels were not significantly reduced except that the southbound morning peak was markedly lower. The traffic flow data for Saturdays shows a bimodal distribution in both directions, with morning peaks occurring at 10:00-11:00 and 08:00-09:00 for north- and south-bound traffic respectively. The evening peak occurred at 20:00-21:00 in both directions. On Sundays, the data again shows a bimodal distribution with north- and south-bound peaks occurring simultaneously between 13:00-15:00 and 17:00-19:00 hours.

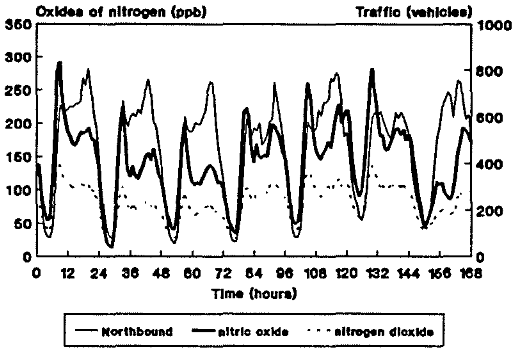
The data illustrated in Figure 6.15(a) indicates a strong relationship between CO concentrations and traffic flow, with slightly higher concentrations occuring as the week progresses from Monday to Friday. The highest weekday peak occurs on Thursday evenings when the shopping centre was open until 20:00 hours. The broadening of the CO peak late into Friday evenings was probably caused by heavy traffic congestion in the High Rd and a number of adjacent roads (*eg* Lordship Lane) towards central London and the nearby North Circular Road (which feeds the M1, M4, M11, M25 and M40). Because Wood Green contains a busy shopping precinct, the CO levels on Saturdays were similar to those encountered on weekdays. The CO peaks which occurred on Saturday and Sunday nights may be attributed to the presence of a popular bingo hall in Wood Green High Rd.

The relationships between hydrocarbons and traffic density are displayed in Figure 6.15(c). Methane levels vary little with traffic density, while non-methane hydrocarbons concentrations show a strong positive relationship with traffic density. Peak NMHC levels generally occured at 17:00-18:00 hours on weekdays, with a similar distribution on Saturdays, and a bimodal distribution on Sundays.

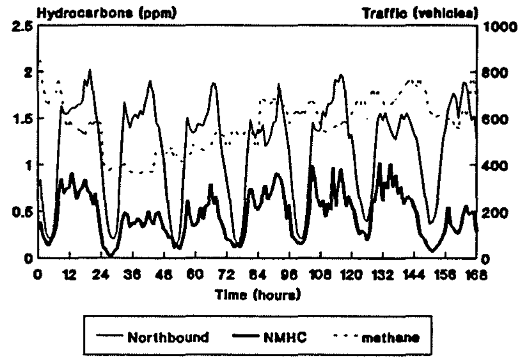
The weekly distribution of NO_x and O_3 in conjunction with traffic flow are illustrated in Figure 6.15(b, d & e). The time series plots indicate a strong relationship between traffic densities and NO_x levels, with peak concentrations typically occuring at the same time as traffic peaks. NO maxima typically occurred at 08:00-09:00 and 18:00-20:00 hours, with the morning peaks higher than those in the afternnon. This contrasts with the CO distributional shape and shows the importance of photochemical reactions with O_3 in the afternoon. Ozone concentrations tend to show an inverse relationship with NO, although as previously noted, the relationship is complex. From Mondays to Fridays, O_3 concentrations tend to be highest during the early hours of the morning, when NO levels are at their lowest. A second peak occured during mid-afternoon, possibly during the period of highest photochemical activity. The presence of low NO concentrations on Sunday nights results in a broad and distinct O_3 peak throughout the day.



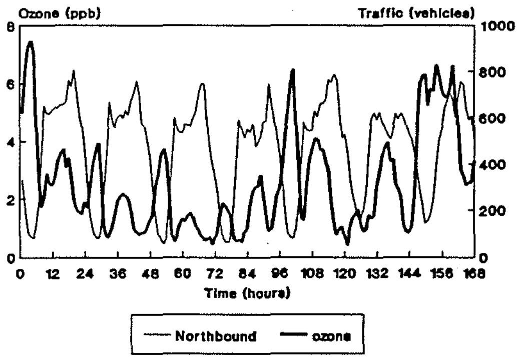
(a) Traffic flow and carbon monoxide plotted against time.



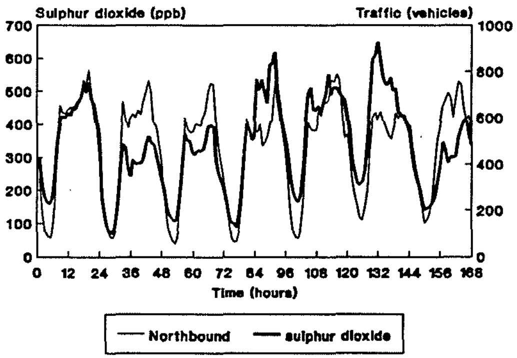
(b) Traffic flow and nitrogen oxides plotted against time.



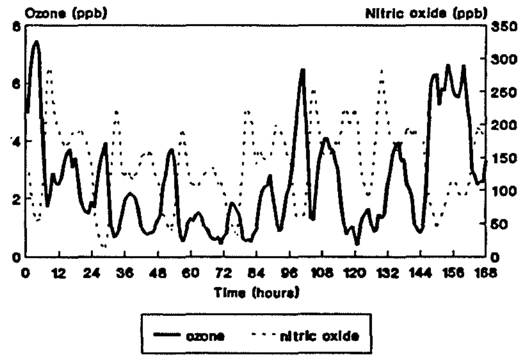
(c) Traffic flow and hydrocarbons plotted against time.



(d) Traffic flow and ozone plotted against time.



(e) Traffic flow and sulphur dioxide plotted against time.



(f) Nitric oxide and ozone plotted against time.

Figure 6.15(a-f)
Time series plots of gaseous pollutants recorded at the mobile laboratory, at Site WG-C.

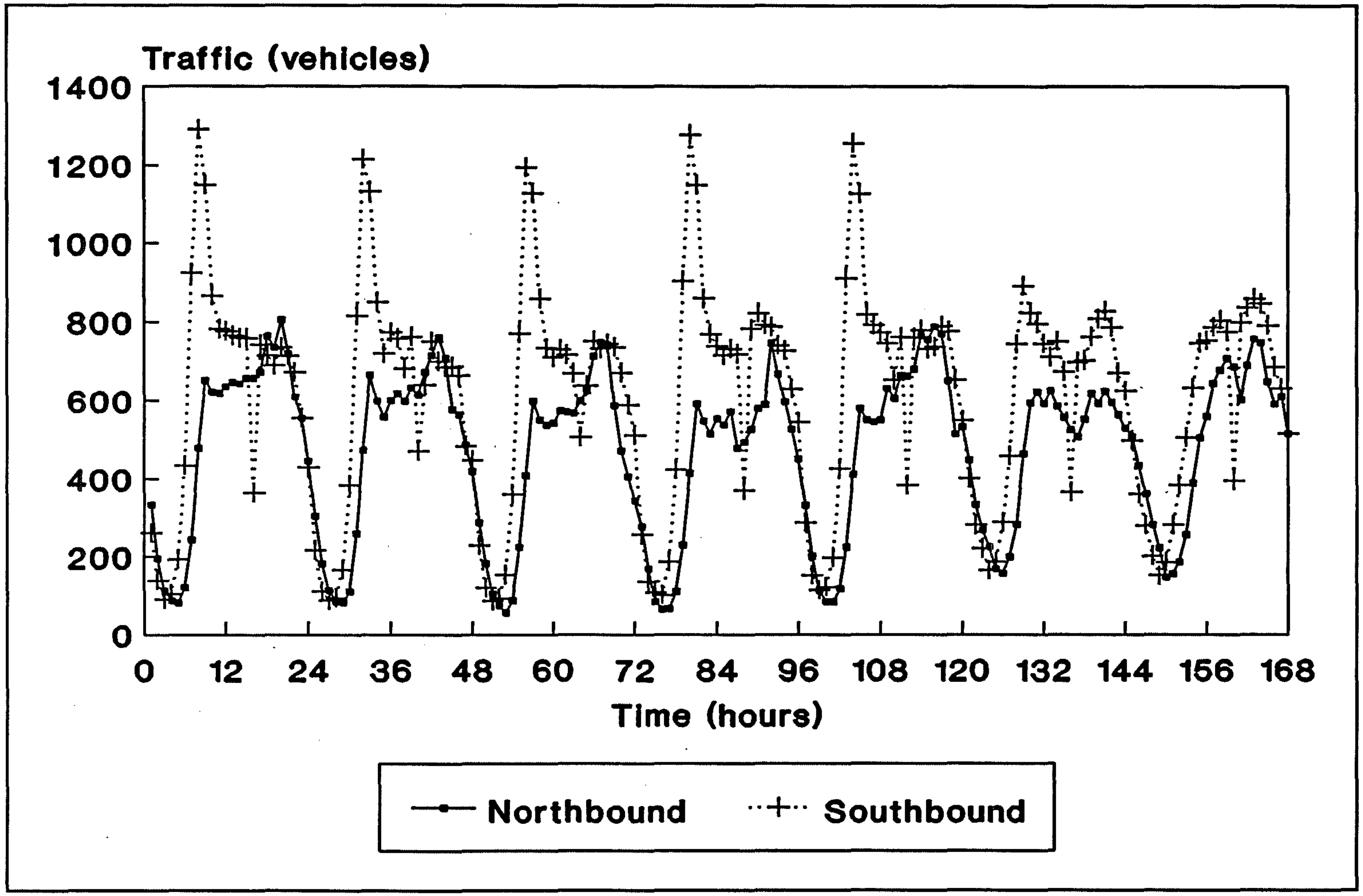


Figure 6.16
Hourly averages of north- and south-bound traffic at Site WG-C.

6.9 The measurement of inter-pollutant association using the correlation coeficient

The time series plots displayed in Figures 6.12-6.16 indicated relationships between variables in a strictly qualitative manner. The use of correlation theory allows the evaluation of any statistical degree of relationship between variables. If two variables are associated such that the data points of a scatterplot tend to fall in a straight line, then they are linearly correlated. The strength of the association between the two variables may be measured using the *correlation coefficient* (r). The value of r will always be between -1 and +1; the closer it is to either -1 or +1 the stronger the linear relationship between the variables. If r is 0, then the variables are not linearly correlated (Kitchens, 1987).

For normally distributed data, Pearson's correlation coefficient is usually employed. However, in recognition of the distributional shapes illustrated in Figures 6.11(a-c), Spearman's rank correlation coefficient was employed within this study. The correlation matrices for the traffic flows and gaseous pollutants monitored using the TRL mobile laboratory are displayed in Tables 6.29-6.32.

In a two-tailed test for significant correlation between two variables at a given significance level, the observed correlation coefficient must exceed the critical statistic (τ). Within this study, the number of data points in each data set is large, ranging from 645 to 2015. Therefore for each data set, the τ at the 95% significance level would be equivalent to a value of ≤ 0.195 with a two-tailed test (Murdoch and Barnes, 1970) (0.195 representing the tabulated value for 100 degrees of freedom). This suggest that all values within the correlation matrices illustrated in Tables 6.29-6.32 greater than 0.195 are statistically significant at the 95% significance level, regardless of sign. In practice however, it is misleading to draw such confident conclusions, and the correlation coefficients displayed should be viewed as *indicative* of the strength of association between variables.

At both the residential and commercial sites, the data indicates the existence of positive and significant correlations between traffic flow and the vehicular primary pollutants of CO, NO and NMHC. Indeed, only O_3 and CH_4 were not significantly correlated with traffic flow at the commercial sites. These exceptions are unsurprising since O_3 is a secondary pollutant and CH_4 is generally derived from non-vehicular sources. Sulphur dioxide is usually associated with emissions from power stations and industry. However at Site WG-C, the correlation between SO_2 and traffic flow may be credited to the relatively high level of diesel vehicles operating on this road. At the residential sites, significant correlations relating traffic flow and pollutant concentration were not indicated for O_3 and SO_2 (both sites), and CH_4 (Site WG-R).

Table 6.29

Correlation matrix for data recorded at Site E-R.

	CO	NO	NO_2	NO_X	O_3	SO_2	NMHC	CH_4	THC	Traffic
NO	0.903									
NO_2	0.830	0.842								
NO_X	0.902	0.962	0.954							
O_3	-0.396	-0.512	-0.650	-0.599						
SO_2	0.225	0.235	0.437	0.353	-0.308					
NMHC	0.827	0.817	0.740	0.811	-0.409	0.243				
CH_4	0.053	0.081	0.275	0.177	-0.300	0.482	-0.052			
THC	0.716	0.747	0.767	0.785	-0.487	0.504	0.852	0.332		
Traffic	0.629	0.541	0.310	0.447	0.187	-0.013	0.480	-0.293	0.266	

Table 6.30
Correlation matrix for data recorded at Site WG-R.

	CO	NO	NO_2	NO_X	O_3	SO_2	NMHC	CH_4	THC	Traffic
NO	0.898									
NO_2	0.874	0.893								
NO_X	0.907	0.951	0.985							
O_3	-0.638	-0.762	-0.784	-0.792						
SO_2	0.561	0.571	0.638	0.635	-0.450					
NMHC	0.855	0.826	0.779	0.821	-0.534	0.576				
CH_4	0.234	0.267	0.297	0.302	-0.30.	0.386	0.315			
THC	0.460	0.458	0.473	0.488	-0.403	0.502	0.560	0.928		
Traffic	0.533	0.386	0.248	0.307	-0.045	0.009	0.494	-0.008	0.190	

Table 6.31
Correlation matrix for data recorded at Site E-C.

	CO	NO	NO_2	NO_X	O_3	NMHC	CH_4	THC	Traffic
NO	0.939								
NO_2	0.909	0.949							
NO_X	0.939	0.995	0.976						
O_3	-0.389	-0.499	-0.478	-0.502					
NMHC	0.932	0.876	0.840	0.874	-0.404				
CH_4	0.358	0.369	0.488	0.407	-0.220	0.288			
THC	0.926	0.869	0.867	0.877	-0.419	0.957	0.507		
Traffic	0.522	0.442	0.445	0.449	-0.015	0.535	0.017	0.475	

Table 6.32
Correlation matrix for data recorded at Site WG-C.

	CO	NO	NO_2	NO_X	O_3	SO_2	NMHC	CH_4	THC	Traffic - Northbound	Traffic - Southbound	Traffic - Total
NO	0.860											
NO_2	0.880	0.976										
NO_X	0.870	0.997	0.987									
O_3	-0.416	-0.594	-0.541	-0.580								
SO_2	0.612	0.538	0.559	0.544	-0.178							
NMHC	0.896	0.836	0.862	0.849	-0.485	0.454						
CH_4	0.379	0.335	0.285	0.323	-0.445	-0.183	0.368					
THC	0.704	0.629	0.610	0.627	-0.530	0.126	0.718	0.877				
Traffic - Northbound	0.572	0.396	0.448	0.415	-0.063	0.332	0.502	0.020	0.337			
Traffic - Southbound	0.535	0.483	0.518	0.496	-0.087	0.276	0.450	0.006	0.283	0.577		
Traffic - Total	0.616	0.528	0.571	0.544	-0.102	0.343	0.528	-0.037	0.325	0.812	0.909	

As expected, the correlations between the vehicular primary pollutants CO, NO and NMHC are positive and significant at each site. The relationship between the primary and the secondary pollutants and between individual secondary pollutants is more complex, as such relationships are complicated by factors which include variations in the hours of photo-activity, seasonal variations in the $NO \rightarrow NO_2$ oxidation rate, import and export of gases to and from the site and meteorological conditions.

6.10 Particulate concentrations recorded at the mobile laboratory

6.10.1 Black smoke

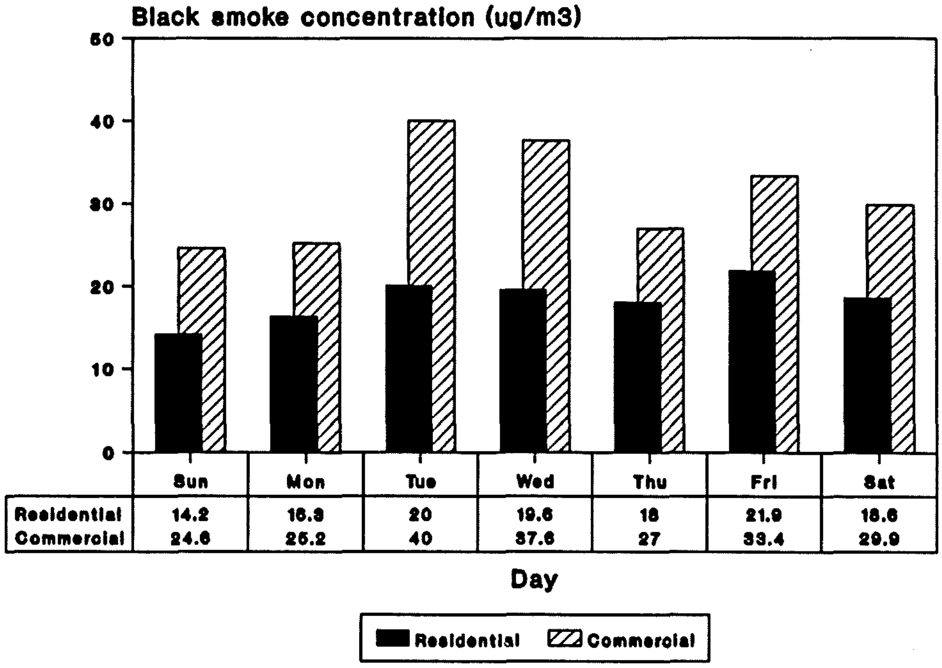
Black smoke concentrations were recorded at the mobile laboratory using an eight-port smoke sampler, as described in Section 4.3.5.1. Roadside black smoke concentrations at Ealing and Wood Green are displayed in Table 6.33. The values clearly show that concentrations were higher at the commercial sites where vehicle flow was highest and where there was a greater proportion of diesel vehicles. This observation is shown more clearly in Figures 6.17 and 6.18, which display the mean daily black smoke concentrations for both sites at each location. The disparity between sites is most evident at Wood Green, where black smoke concentrations at the commercial site were typically 3-4 times higher than at the residential site. In addition, the highest median black smoke concentrations were recorded at Site WG-C, which had the highest vehicle flow and greatest proportion of diesels of the 4 sites. At each site, the lowest mean daily value was recorded on Sundays when the daily traffic density was at its lowest.

Table 6.33
Black smoke concentrations recorded at the mobile laboratory ($\mu g/m^3$).

Site	N	Median	Arithmetic mean	Standard deviation
E-R	59	18.0	18.3	6.8
E-C	39	30.0	30.6	14.7
WG-R	80	16.0	20.5	13.6
WG-C	35	71.0	69.5	22.2

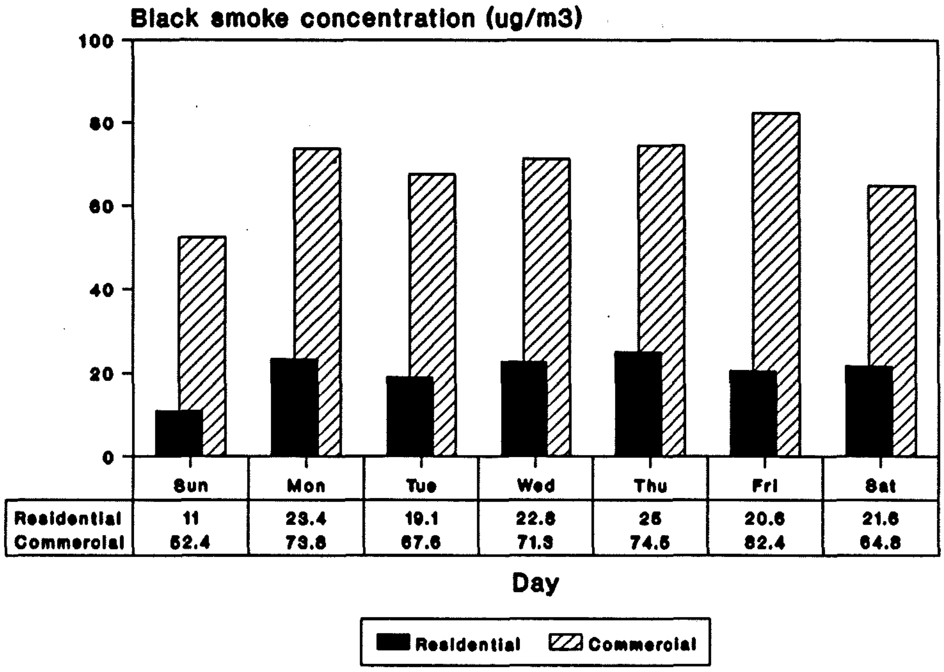
The roadside concentrations shown in Table 6.33 are much higher than typical UK smoke values recorded using the same apparatus at rooftop level. This observation may indicate:

- the strong influence of diesel vehicle emissions on black smoke concentrations at street level, *or*



	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Residential	14.2	16.3	20	19.6	18	21.9	18.6
Commercial	24.6	25.2	40	37.6	27	33.4	29.9

Figure 6.17
Mean daily black smoke concentrations recorded at the Ealing location.



	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Residential	11	23.4	19.1	22.8	25	20.6	21.6
Commercial	52.4	73.6	67.6	71.3	74.5	82.4	64.8

Figure 6.18
Mean daily black smoke concentrations recorded at the Wood Green location.

- the extreme 'blackness' of the diesel particles, which may cause an over-estimation of roadside black smoke concentrations using the reflectance technique. The calibration curves and equations for quantitative black smoke determination using this method were originally obtained using coal smoke as reference material.

It is possible that both the above factors contributed to the higher than usual black smoke values recorded roadside at Ealing and Wood Green.

6.10.2 Total suspended particulates

Total suspended particulates were collected over 3 time periods at each of the 4 sites; morning (06:00-10:00), evening (16:00-20:00) and daily (00:00-24:00). The morning and afternoon collection periods usually coincided with peak traffic periods at the 4 sites. A summary of the particulate concentrations characterised at each site is displayed in Table 6.34.

Table 6.34
TSP concentrations recorded at the mobile laboratory ($\mu g/m^3$).

Time period	N	Median	Arithmetic mean	Standard deviation
Site E-R				
06:00 - 10:00	11	55.2	114.7	211.8
16:00 - 20:00	12	42.6	129.5	302.9
24 hours	12	35.6	37.3	12.5
Site E-C				
06:00 - 10:00	14	61.2	53.9	26.5
16:00 - 20:00	16	75.8	77.2	33.0
24 hours	13	51.6	61.6	35.8
Site WG-R				
06:00 - 10:00	22	33.2	42.7	32.5
16:00 - 20:00	23	28.8	34.1	24.0
24 hours	23	29.8	41.5	29.9
Site WG-C				
06:00 - 10:00	11	65.4	75.0	9.1
16:00 - 20:00	12	55.8	60.4	4.0
24 hours	11	52.4	56.7	4.2

Median TSP levels recorded during peak traffic periods are typically higher than daily values, with the exception of Site WG-R, where the 3 median values were aritlimetically close together. The high mean values obtained at Site E-R result from two exceptionally high TSP values on the 24th and 25th of April 1991, which produces a highly skewed data set and distorts the figures. The strong influence of these outliers illustrates that median values are better measures of central location than mean values for non-normal data.

The roadside TSP values displayed in Table 6.34 are slightly lower than those previously recorded at similar (busier) London sites (McCrae, 1991), but within typical urban ranges (see Table 3.3).

6.11 Particulate concentrations recorded by local authorities

Black smoke concentrations recorded at local authority sites, summarised in Table 6.35, were obtained using 8-port smoke samplers generally situated at rooftop level. The black smoke levels displayed in Table 6.35 were much lower than the roadside values obtained at Wood Green and Ealing, but typical of current UK ambient air concentrations (see, for example, QUARG, 1993a). Comparative data for residential and commercial areas was only available at Edinburgh and Sheffield, where TSP concentrations at commercial sites were 1.5-2 times higher than at residential sites. Black smoke concentrations in UK towns and cities are generally quite low because of the presence of legally enforcable smokeless zones in urban areas.

Table 6.35

Daily black smoke concentrations recorded by 8-Port at Local Authority Sites ($\mu g/m^3$).

Site	Sampling period	Median	Arithmetic mean	Standard deviation
B-R	Feb - March 1993	5	6	4
Card-R	Jan - May 1993	10	12	9
Cov-RC	Jan - March 1993	5	7	6
Ealing[1]	Feb - July 1991	9	11	7
Edin-R	Jan - May 1993	3	5	5
Edin-C	Jan - May 1993	7	8	6
S-R	Jan - May 1993	6	8	7
S-C	Jan - May 1993	9	13	11

[1] Values recorded in Percival House, Uxbridge Rd, W5, close to the Ealing Commercial site.

PM_{10} concentrations recorded at the EUN sites in Birmingham, Cardiff and Edinburgh are displayed in Table 6.36. The mean values are similar to figures previously recorded at these (and other UK) sites (QUARG, 1993a). This data shows the same trend as that displayed in Table 6.35, as both the smoke and PM_{10} figures were higher in Cardiff than in Birmingham and Edinburgh. Despite the recent concern over urban particulate levels, there are currently no UK air quality guidelines for PM_{10} levels to compare with this data, although the values fall well below the US EPA annual mean guideline of 50 $\mu g/m^3$.

Table 6.36
PM_{10} concentrations recorded at EUN sites ($\mu g/m^3$).

EUN Site	Arithmetic mean	Standard deviation
Birmingham	27.5	18.1
Cardiff	31.2	20.5
Edinburgh	22.5	12.7

6.12 Statistical summaries of particulate concentrations

Summary statistics of the particulate concentrations recorded at the selected sites are displayed in Tables 6.37-6.39. In general, the quartiles become progressively larger, indicating that the distributions are skewed right, although this trend is not as marked as that displayed by the gaseous pollutants (Tables 6.21-6.28). Unsurprisingly, the median (50th percentile) values were higher at commercial sites (where there were more people and traffic) than at residential sites. However, the maximum TSP values were recorded at Site E-R, indicating the potential importance of other sources (*eg* wind-carried dust) of particulates.

Table 6.37
Statistical summary of black smoke concentrations recorded at the mobile laboratory.

Site	N	Min	Percentiles			Max
			25	50	75	
Site E-R	59	6	14	18	23	42
Site E-C	39	10	18	30	40	77
Site WG-R	80	6	10	16	27	58
Site WG-C	35	22	59	71	90	103

Table 6.38
Statistical summary of TSP concentrations recorded at the mobile laboratory.

Time period	N	Min	Percentiles			Max
			25	50	75	
Site E-R						
06:00 - 10:00	11	26.9	34.4	55.2	74.9	750.3
16:00 - 20:00	12	24.1	34.4	42.6	54.7	1090.8
24 hours	12	21.4	25.3	35.6	47.5	57.7
Site E-C						
06:00 - 10:00	14	12.0	30.0	61.2	67.5	105.0
16:00 - 20:00	15	26.1	51.7	75.8	94.3	146.2
24 hours	14	23.2	29.8	51.6	72.8	121.3
Site WG-R						
06:00 - 10:00	22	15.2	24.8	33.2	47.9	149.9
16:00 - 20:00	23	10.8	19.8	28.8	36.3	131.4
24 hours	23	14.3	27.3	29.8	40.3	134.7
Site WG-C						
06:00 - 10:00	11	42.6	50.8	65.4	88.7	148.3
16:00 - 20:00	12	39.4	50.6	55.8	72.8	84.7
24 hours	11	40.2	45.1	52.4	71.6	80.6

Table 6.39
Statistical summary of PM_{10} concentrations recorded by local authorities.

EUN Site	N	Min	Percentiles			Max
			25	50	75	
Birmingham	3186	0	15	23	35	160
Cardiff	3524	0	17	26	41	280
Edinburgh	3753	0	14	20	29	89

Chapter 7

The Relationship between Traffic Nuisance and Air Quality

7.1 Introduction

One of the primary aims of this research was to quantify the subjective impact of traffic nuisance on the general public. In order to achieve this goal, the data from the public opinion surveys (presented in Chapter 5) needs to be combined with the air quality data (presented in Chapter 6) to see if any relationship exists between the two types of variable. In this chapter, an examination of the data using graphical methods is presented. From this initial analysis, pollutants which display a correlation with nuisance are identified and the relationships are examined statistically. At the end of the chapter, a method for estimating public nuisance from vehicle-derived air pollution is presented.

7.2 Investigation of the relationship between traffic nuisance and air quality

This data analysis considers only the relationship between the disturbance score for a specific nuisance and individual pollutant concentrations, thus ignoring the influence of social and other factors. The analysis was divided into 5 sections:

- outdoor disturbance from vehicle-derived smoke, fumes and odour
- outdoor disturbance from vehicle-derived dust and dirt
- indoor disturbance from vehicle-derived smoke, fumes and odour
- indoor disturbance from vehicle-derived dust and dirt
- sensitivity to air pollution

Air quality information was not available for every pollutant at each site, and therefore only certain pollutants could be used for the analysis. For these selected pollutants, the mean (or median) pollutant concentrations recorded over the sampling period were plotted against the mean disturbance scores for each site and respondent type. This straightforward graphical investigation was however complicated by a number of factors:

- The air quality data was recorded by different authorities using the same and/or different monitoring techniques. To aid interpretation, the different sources of data are displayed on the graphs using suitable symbols.
- The pollutant concentrations used may not give a wholly accurate indication of the pollution exposure of the respondents. For example, some respondents may be regularly exposed to elevated concentrations of CO because of the proximity of their

home/workplace to a road, their occupation (*eg* taxi driver, traffic warden) and/or their personal habits (*eg* smoking). Modelling the individuals' pollutant exposure was not considered appropriate since:

1) models only exist for a small number of pollutants;
2) insufficient data were collected for such analyses.

However, it is considered that the pollutant concentrations utilised are reasonably representative of the sample population's exposure to typical urban background pollutant levels (EUN and local authority data) and kerbside values (MU data) at each location.

- At each site there were two types of respondent (pedestrian and business at commercial sites; pedestrian and household at residential sites). For outdoor disturbance, this results in 2 data points for some pollutants at each site. This situation does not arise for indoor disturbance since pedestrians were not asked this question.

7.3 Outdoor disturbance from vehicle-derived smoke, fumes and odour

Scatterplots displaying the relationships between the outdoor disturbance scores from smoke, fumes and odour and the pollutants CO, NO_2, SO_2, and O_3 are illustrated in Figures 7.1-7.4 respectively. If we ignore the data obtained from the MU roadside sites, Figures 7.1-7.3 generally show disturbance scores of 3-4 (moderately to very bothered) when pollutant concentrations ranged from 0.4-0.6 ppm (CO), 20-30 ppb (NO_2) and 6-17 ppb (SO_2). These concentration ranges are typical for urban background sites in the UK (QUARG, 1993a). The pollutant concentrations recorded at roadside locations by MU were in excess of these ranges and no marked increase in disturbance scores was apparent.

The scatterplot for O_3 displayed in Figure 7.4 is more complex. The respondents at all the sites typically recorded disturbance scores of 3.3-4.0 over a wide range of O_3 concentrations. The O_3 levels recorded at EUN sites covered a narrow range which probably reflects the careful site selection employed by DoE for these urban background sites. The OPSIS data were more varied due to the differing monitoring heights etc. As expected, the roadside O_3 concentrations were lower than those recorded at other sites due to atmospheric chemical reactions with NO (see Section 3.9). These discrepancies highlight the difficulties of data interpretation when using information from different sources.

However, some conclusions may be drawn from the data displayed in Figures 7.1-7.4. Moderate to high disturbance from smoke, fumes and odour was generally recorded at pollutant concentrations which are usual for urban background locations in the UK. This is an important

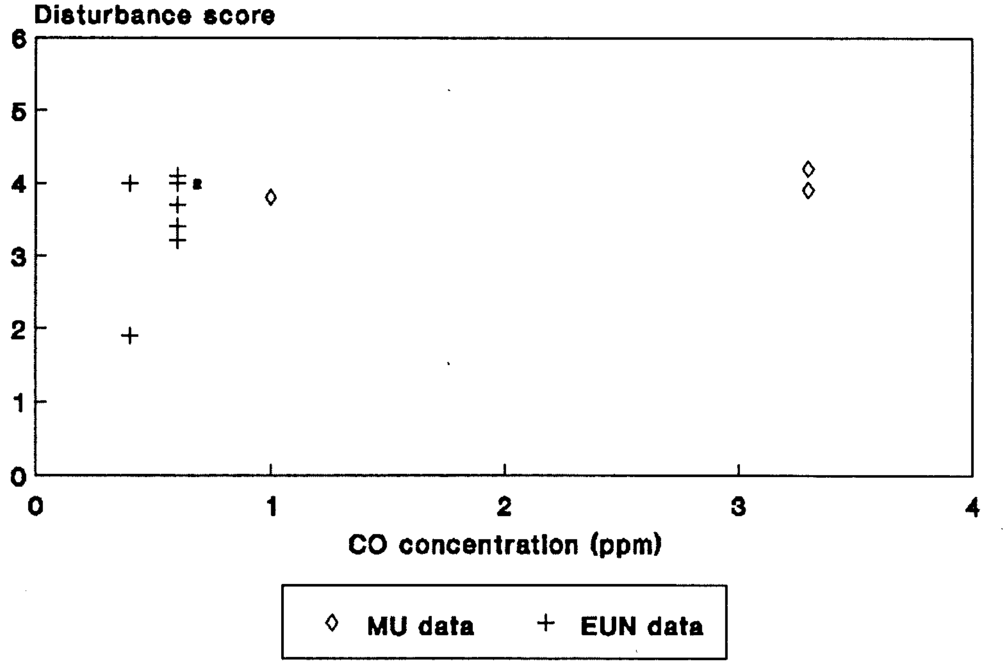


Figure 7.1
Scatterplot showing the relationship between outdoor disturbance from vehicle-derived smoke, fumes and odour and mean CO concentrations.

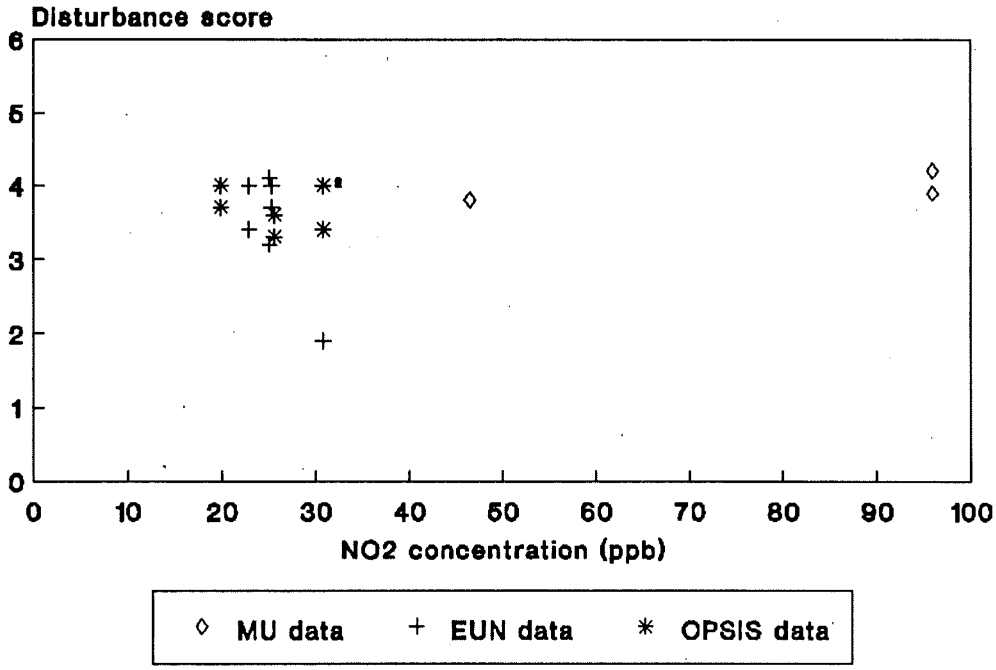


Figure 7.2
Scatterplot showing the relationship between outdoor disturbance from vehicle-derived smoke, fumes and odour and mean NO_2 concentrations.

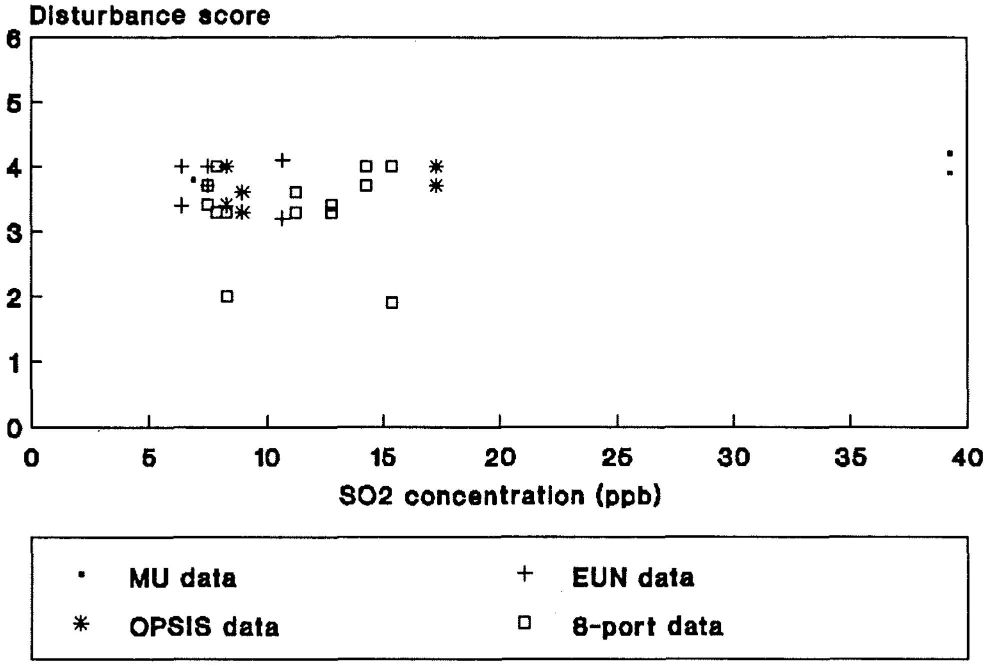


Figure 7.3
Scatterplot showing the relationship between outdoor disturbance from vehicle-derived smoke, fumes and odour and mean SO_2 concentrations.

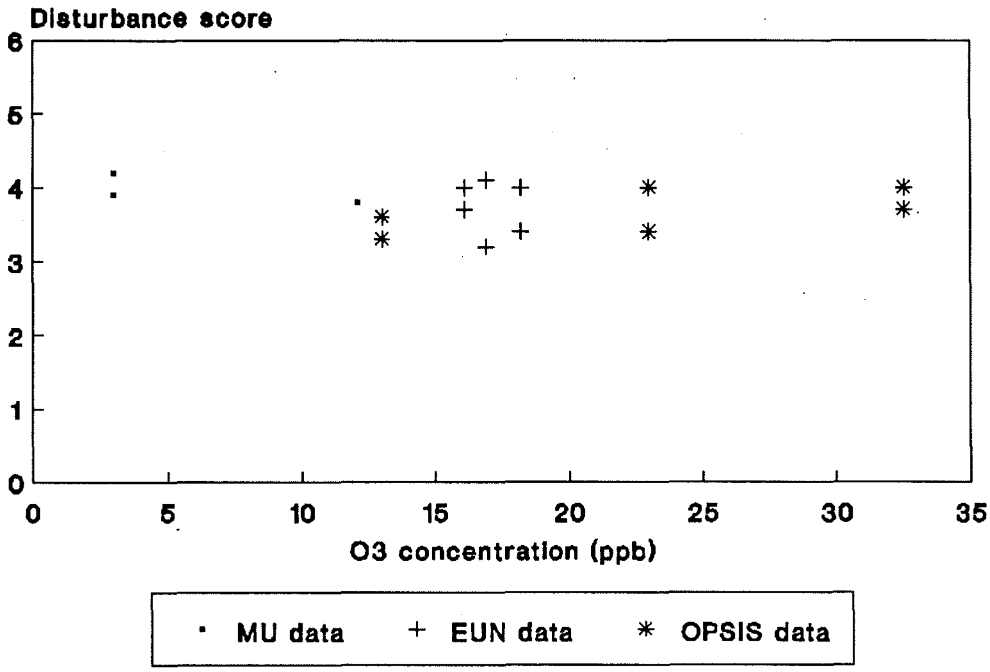


Figure 7.4
Scatterplot showing the relationship between outdoor disturbance from vehicle-derived smoke, fumes and odour and mean O_3 concentrations.

observation since some members of the public may be exposed to these pollutant concentrations for significant periods of time in urban areas. If this data may be extrapolated to the UK as a whole, it suggests that large numbers of people may be significantly disturbed outdoors by vehicle-derived smoke, fumes and odour at current UK pollutant levels.

No correlation between outdoor disturbance from smoke, fumes and odour and gaseous pollutant concentrations is apparent from the information displayed in Figures 7.1-7.4. However, this observation is not precise:

- No extreme (*ie* low or high) mean pollutant concentrations were recorded at the urban background (EUN) sites. It is possible that the public would complain more (or less) about outdoor smoke, fumes and odour if they were exposed continuously to higher (or lower) urban background pollutant concentrations. It is extremely difficult to interpret the graphs without knowing the public's reaction to extreme situations.
- Interviewing respondents at the roadside (where the MU recorded pollutant concentrations are much higher than those recorded at EUN sites) does not appear to significantly influence the reported disturbance scores. This may suggest:
    i) That the public may base their annoyance upon their experience of typical local air quality rather than transient exposure to elevated roadside pollutant concentrations. For this hypothesis, it would probably be better to use urban background data in preference to roadside values.
    ii) That the public's response assesses nuisance for a particular environment. For example, exposure to concentration X at the side of a road generates little disturbance because at this location the public expects a certain amount of annoyance. However, exposure to concentration X when sitting on the beach would generate much more disturbance because here the expectation of air quality is higher. For this hypothesis, short-term exposure to elevated pollutant concentrations may be important.

The scatterplot displaying the relationship between outdoor disturbance from smoke, fumes and odour and black smoke (as measured by BS1747, Part 2, 1969) is shown in Figure 7.5. If only the data collected by local authorities is considered, disturbance scores of 3.3-4.0 were reported (with 2 exceptions) when black smoke concentrations ranged from 3-10 $\mu g/m^3$. The black smoke concentrations recorded roadside were much higher than typical urban background values (see discussion in Section 6.10.1), and as noted previously, no marked increase in disturbance scores is apparent. This again supports the use of pollutant concentrations to which the public are typically exposed rather than elevated roadside values in this type of research. Figure 7.6 uses only the information supplied by local authorities. The graph suggests a slight increase of disturbance score with increases in black smoke concentrations. In order to predict the disturbance score from the recorded black smoke concentrations, the regression equation for the data in Figure 7.6 was calculated to be:

$$OD_{SFO} = 3.03 + (0.0504 \times S) \qquad (R^2 = 3.3\%) \qquad \textbf{Equation 7.1}$$

where:

OD_{SFO} = outdoor disturbance score from vehicle-derived smoke, fumes and odour

S = black smoke concentration in $\mu g/m^3$

Since regression analysis is concerned with investigating the relationship between variables in the presence of random error, it is important to test how well the model fits before any data interpretation is attempted. The values displayed in Table 7.1 indicate reasonable agreement between the observed and estimated values of disturbance score, although the narrow range of estimated values reflects the small value of the constant in Equation 7.1 and the narrow range of observed black smoke concentrations.

Table 7.1
Observed and estimated outdoor disturbance scores from vehicle-derived smoke, fumes and odour.

Site	Black smoke concentration ($\mu g/m^3$)	Observed disturbance score	Estimated disturbance score
-	0*	-	3.0
Edin-R	3	2.0	3.2[R]
Edin-R	3	3.3	3.2
B-R	5	3.3	3.3
Cov-RC	5	3.3	3.3
B-R	5	4.0	3.3
Cov-RC	5	3.6	3.3
S-R	6	3.3	3.3
S-R	6	3.3	3.3
Edin-C	7	4.0	3.4
Edin-C	7	3.7	3.4
S-C	9	4.0	3.5
S-C	9	1.9	3.5[R]
C-R	10	3.7	3.5
C-R	10	3.4	3.5
-	60*	-	6.0

* Hypothetical smoke value [R] Large residual.

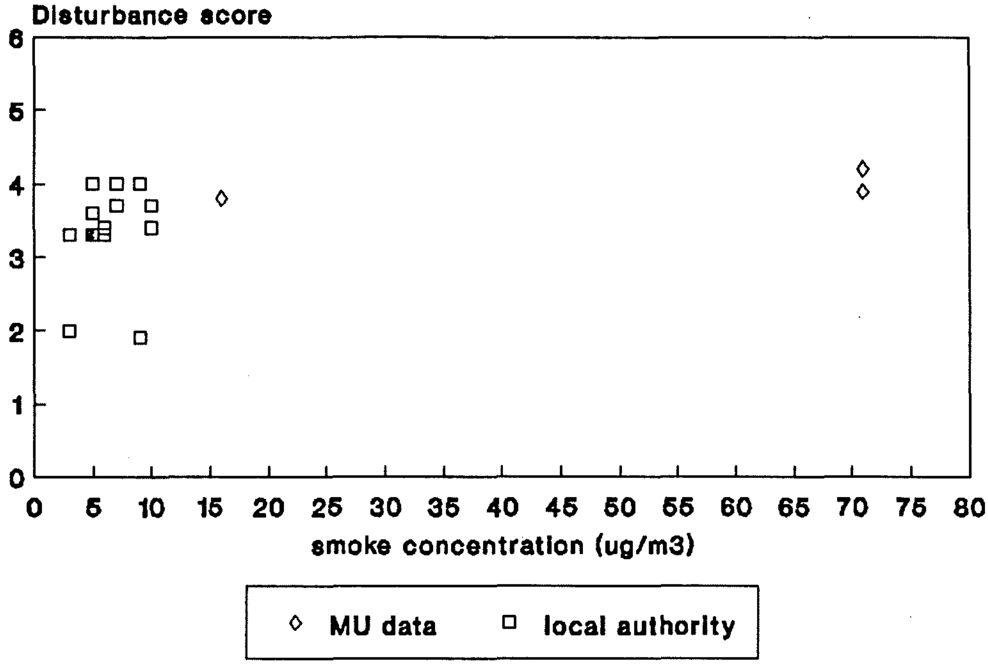


Figure 7.5
Scatterplot showing the relationship between outdoor disturbance from vehicle-derived smoke, fumes and odour and median black smoke concentrations.

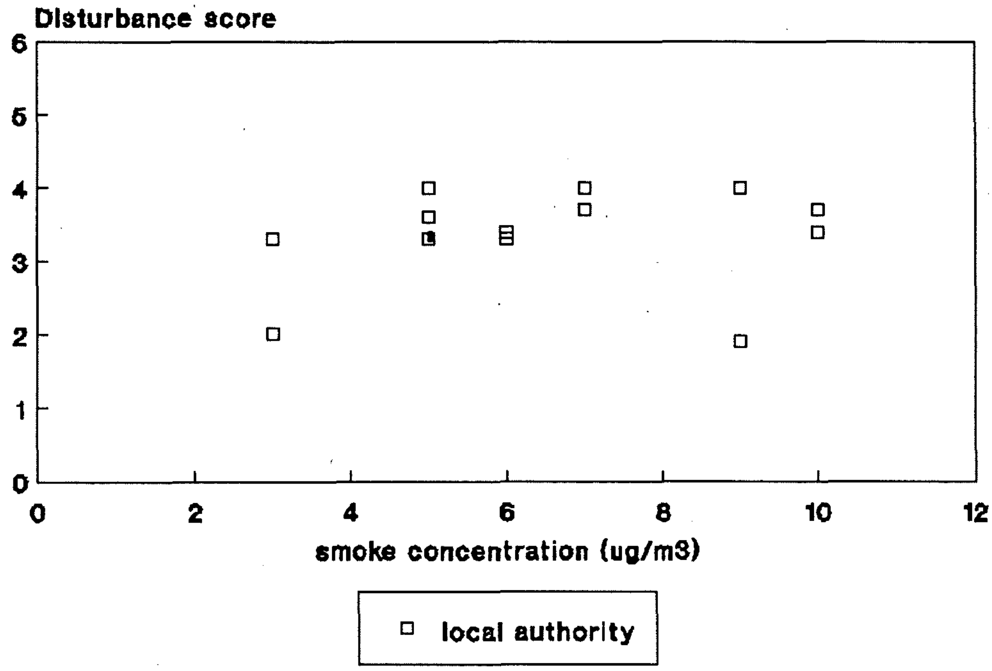


Figure 7.6
Scatterplot showing the relationship between outdoor disturbance from vehicle-derived smoke, fumes and odour and median black smoke concentrations (local authority only).

An examination of the residuals (the deviations between the observed and fitted values) suggests that the model is acceptable. However, an ANOVA procedure provides no evidence at the 5% level to support the significance of the regression relationship. Combining the 95% confidence intervals (CI) for disturbance score ($\pm$ 1.0) with the 95% CI for black smoke concentration ($\pm$ 0.1) indicates that there is likely to be a wide variation in disturbance score for a small variation in black smoke concentration. This highlights the lack of extreme values of both disturbance scores and urban background black smoke levels. Thus, there is no strong evidence to support Equation 7.1 and the suggestion of a linear relationship between disturbance score and black smoke concentration must be viewed with considerable uncertainty.

However, if it is assumed that the relationship described by Equation 7.1 is correct, then for a black smoke concentration of 0 $\mu g/m^3$, the equation estimates a disturbance score of 3 (moderate disturbance). This estimate may suggest that at typical urban black smoke concentrations, factors other than actual air pollution levels have a strong influence on public nuisance from smoke, fumes and odour. A hypothetical smoke concentration of 60 $\mu g/m^3$ would give an estimated disturbance score of 6.0, the maximum value possible on the 7-point scale. This is not an unreasonable situation, since recently recorded UK urban background black smoke concentrations have peaked at about 40 $\mu g/m^3$ (QUARG, 1993a). However, this evidence is not supported by data from Site WG-C (roadside), where a disturbance score of 4.0 was recorded at a black smoke concentation of 71 $\mu g/m^3$.

7.4 Outdoor disturbance from vehicle-derived dust and dirt

The relationship between the outdoor disturbance scores for dust and dirt and the pollutants CO, NO_2, SO_2, O_3 and smoke are illustrated in Figures 7.7-7.11. The graphs are similar to those displayed in Figures 7.1-7.5, although the disturbance scores were slightly lower and the range was slightly wider. With 2 exceptions, the non-roadside data shown in Figures 7.7-7.10 display disturbance scores of 2.8-4.0 when pollutant concentrations ranged from 0.4-0.6 ppm (CO), 20-30 ppb (NO_2) and 6-17 ppb (SO_2). These data indicate that the public report moderate - high disturbance from outdoor dust and dirt at typical UK urban background pollutant concentrations. The scatterplot for O_3 (Figure 7.10) shows the similar complex pattern discussed in Section 7.3 and no clear correlation between outdoor disturbance from dust and dirt and the gaseous pollutant concentrations is visible.

The graph shown in Figure 7.12, which uses only local authority data, indicates a slight increase of disturbance score with increasing black smoke concentrations. The regression equation for this relationship was calculated to be:

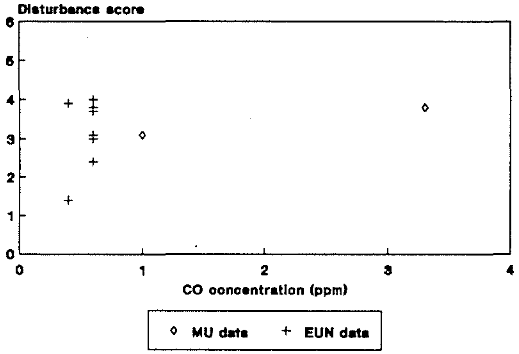


Figure 7.7 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived dust and dirt and mean CO concentrations.

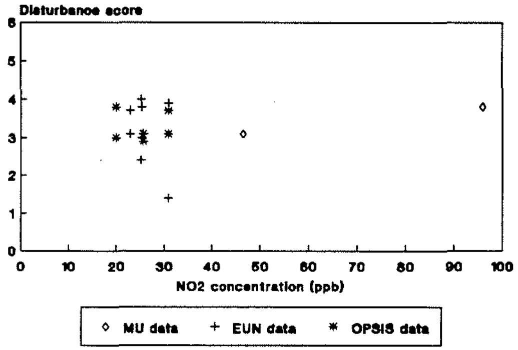


Figure 7.8 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived dust and dirt and mean NO_2 concentrations.

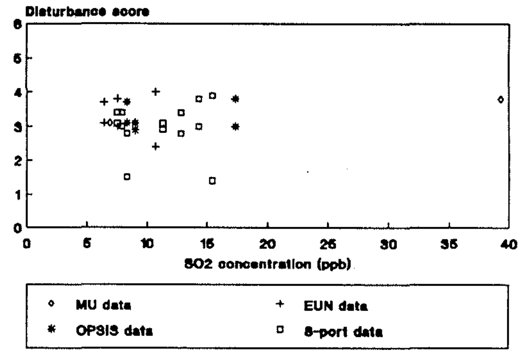


Figure 7.9 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived dust and dirt and mean SO_2 concentrations.

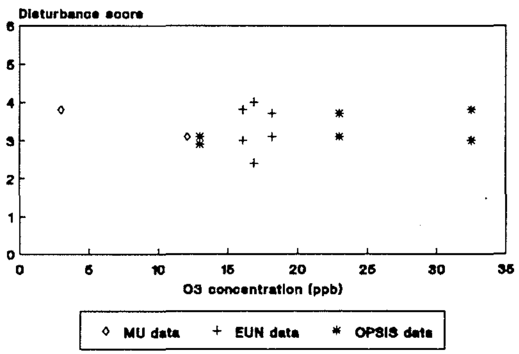


Figure 7.10 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived dust and dirt and mean O_3 concentrations.

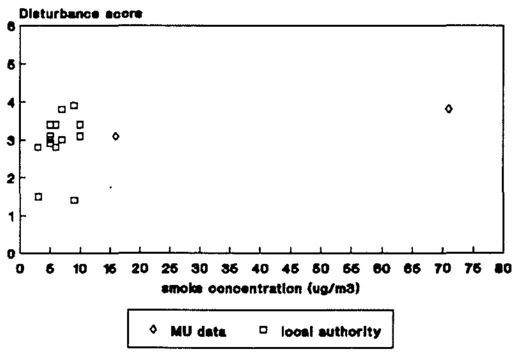


Figure 7.11 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived dust and dirt and median smoke concentrations.

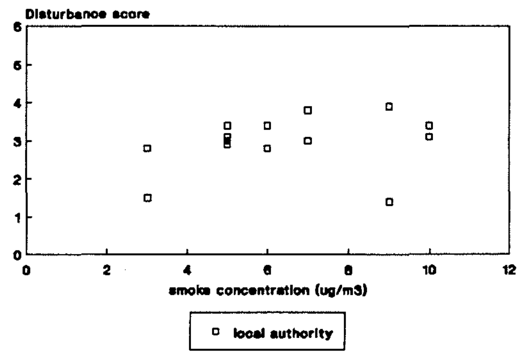


Figure 7.12 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived dust and dirt and median smoke concentrations *(local authority data only)*.

$$OD_{D/D} = 2.46 + (0.0786 \times S) \qquad (R^2 = 6.5\%) \qquad \textbf{Equation 7.2}$$

where:

$OD_{D/D}$ = outdoor disturbance score from vehicle-derived dust and dirt

S = black smoke concentration in $\mu g/m^3$

As in Section 7.3, the data shown in Table 7.2 suggest reasonable accord between the observed and estimated values of disturbance score. An analysis of the residuals suggests that the model is adequate, although an ANOVA procedure provides no evidence at the 5% level to support the significance of the regression relationship. Combining the 95% CI for disturbance score (± 1.0) with the 95% CI for black smoke concentration (± 0.1) implies that there is likely to be a wide variation in disturbance score for a small variation in smoke concentration. There is therefore no strong statistical evidence to support Equation 7.2.

Table 7.2
Observed and estimated outdoor disturbance scores from dust and dirt.

Site	Black smoke concentration ($\mu g/m^3$)	Observed disturbance score	Estimated disturbance score
-	0*	-	2.5
Edin-R	3	2.8	2.7
Edin-R	3	1.5	2.7
B-R	5	3.0	2.8
Cov-RC	5	2.9	2.8
B-R	5	3.4	2.8
Cov-RC	5	3.1	2.8
S-R	6	2.8	2.9
S-R	6	3.4	2.9
E-R	7	3.8	3.0
E-R	7	3.0	3.0
S-C	9	3.9	3.2
S-C	9	1.4	3.2[R]
C-R	10	3.4	3.2
C-R	10	3.1	3.2
-	45*	-	6.0

* Hypothetical smoke value [R] Large residual.

With these uncertainties in mind, using a black smoke concentration of 0 $\mu g/m^3$ in Equation 7.2 estimates a disturbance score of 2.5 (moderate disturbance), which as in Section 7.3, may imply that factors other than black smoke levels have a strong influence on outdoor public nuisance from dust and dirt at normal UK urban black smoke concentrations. However, the maximum disturbance score (6.0) would be obtained at a hypothetical smoke concentration of 45 $\mu g/m^3$, which is lower than the value predicted for maximum disturbance from outdoor smoke, fumes and odour. This is inconsistent with the observation that outdoor disturbance from smoke, fumes and odour is generally higher than that from dust/dirt (see Section 5.13) and illustrates both the uncertainties in the regression equations and the dangers of using extrapolated data for predictive purposes.

7.5 Indoor disturbance from vehicle-derived smoke, fumes and odour

Scatterplots displaying the relationships between pollutant concentrations and the indoor disturbance scores from smoke, fumes and odour are illustrated in Figures 7.13-7.17. Ignoring the roadside (MU) data, Figures 7.13-7.15 show indoor disturbance scores of 1.2-3.3 (low to moderate disturbance) when outdoor pollutant concentrations ranged from 0.4-0.6 ppm (CO), 20-30 ppb (NO_2) and 6-17 ppb (SO_2). The scatterplot for O_3 (Figure 7.16) displays disturbance scores ranging from 1.7-3.3 (low to moderate disturbance) over a wide range of O_3 levels (see discussion in Section 7.2.1). The only correlation between disturbance score and pollutant concentrations is observed in Figure 7.18, where a slight increase of disturbance score with increasing black smoke concentrations is indicated.

The regression equation for this relationship was calculated to be:

$$ID_{SFO} = 0.998 + (0.129 \times S) \qquad (R^2 = 33.2\%) \qquad \textbf{Equation 7.3}$$

where:

ID_{SFO} = indoor disturbance score from vehicle-derived smoke, fumes and odour

S = black smoke concentration in $\mu g/m^3$

The values displayed in Table 7.3 indicate moderate agreement between the observed and estimated values of disturbance score, although as in Sections 7.3 and 7.4 there is no statistical evidence to support the regression equation (Equation 7.3) at the 5% level. The 95% CI for disturbance score and black smoke concentration are $\pm$ 1.4 and $\pm$ 0.2 respectively.

A low level of indoor disturbance from smoke, fumes and odour (1.0) is estimated when a black smoke concentration of 0 $\mu g/m^3$ is used in Equation 7.3. This contrasts with the intercepts for outdoor disturbance estimated from Equations 7.1 and 7.2, and may reflect the public's reduced exposure to vehicle-derived air pollution when indoors. However, the maximum disturbance score (6.0) would be obtained at a hypothetical average smoke

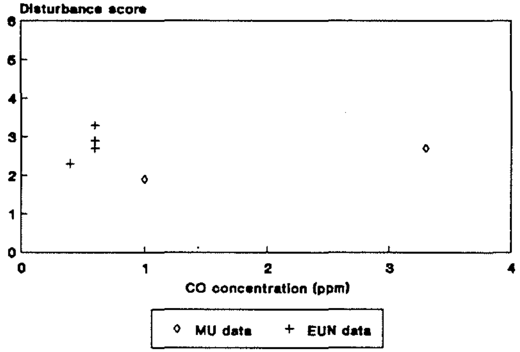


Figure 7.13 Scatterplot showing the relationship between indoor disturbance from vehicle-derived smoke, fumes and odour and mean CO concentrations.

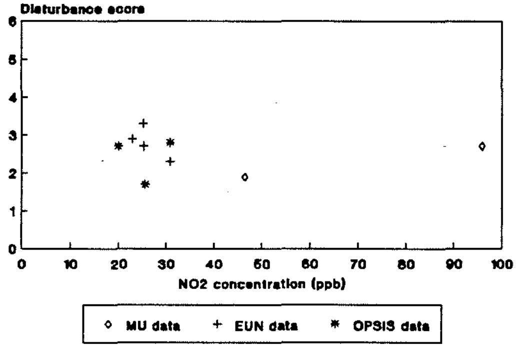


Figure 7.14 Scatterplot showing the relationship between indoor disturbance from vehicle-derived smoke, fumes and odour and mean NO_2 concentrations.

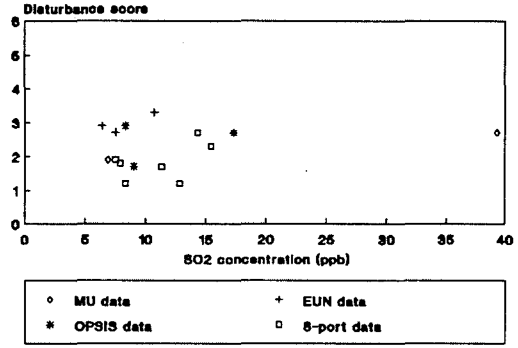


Figure 7.15 Scatterplot showing the relationship between indoor disturbance from vehicle-derived smoke, fumes and odour and mean SO_2 concentrations.

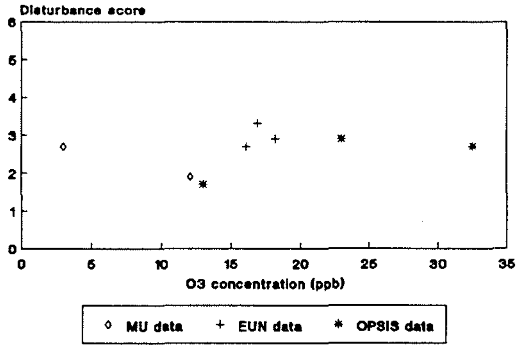


Figure 7.16 Scatterplot showing the relationship between indoor disturbance from vehicle-derived smoke, fumes and odour and mean O_3 concentrations.

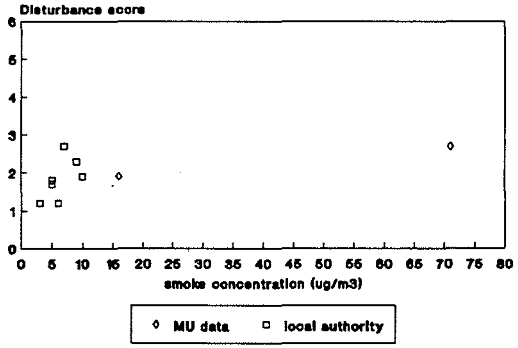


Figure 7.17 Scatterplot showing the relationship between indoor disturbance from vehicle-derived smoke, fumes and odour and median smoke concentrations.

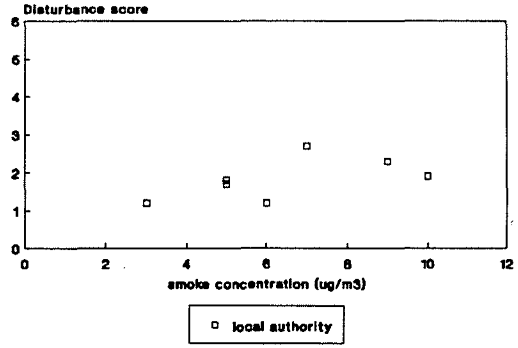


Figure 7.18 Relationship between indoor disturbance from vehicle-derived smoke, fumes and odour and median smoke concentrations *(local authority data only)*.

concentration of 39 $\mu g/m^3$, which is lower than the value predicted for maximum disturbance from outdoor smoke, fumes and odour. Since the outdoor disturbance scores for smoke, fumes and odour were statistically significantly higher than those for indoor disturbance at all of the 10 sites visited (see Section 5.7.2), this inconsistency may support the hypothesis that the public's response assesses nuisance for a particular environment (Section 7.3) and again emphasises the large uncertainties in the regression equations.

Table 7.3
Observed and estimated indoor disturbance scores from vehicle-derived smoke, fumes and odour.

Site	Black smoke concentration ($\mu g/m^3$)	Observed disturbance score	Estimated disturbance score
-	0*	-	1.0
E-R	3	1.2	1.3
Cov-RC	5	1.7	1.6
B-R	5	1.8	1.6
S-R	6	1.2	1.8
Edin-C	7	2.7	1.9[R]
S-C	9	2.3	2.2
C-R	10	1.9	2.3
-	39*	-	6.0

* Hypothetical smoke value   [R] Large residual.

7.6 Indoor disturbance from vehicle-derived dust and dirt

The relationships between the indoor disturbance scores for dust and dirt and the selected pollutants are shown in Figures 7.19-7.23. These scatterplots display indoor disturbance scores of 1.3-3.5 (low to moderate disturbance) at typical urban background pollutant concentrations. No clear correlation between indoor disturbance from dust and dirt and the gaseous pollutant concentrations is noticeable, although a slight correlation between disturbance score and black smoke concentrations is suggested in Figure 7.24. The regression equation for this relationship was calculated to be:

$$ID_{D/D} = 1.34 + (0.105 \times S) \qquad (R^2 = 24.0\%)$$ **Equation 7.4**

where:

$ID_{D/D}$ = indoor disturbance score from vehicle-derived dust and dirt

S = black smoke concentration in $\mu g/m^3$

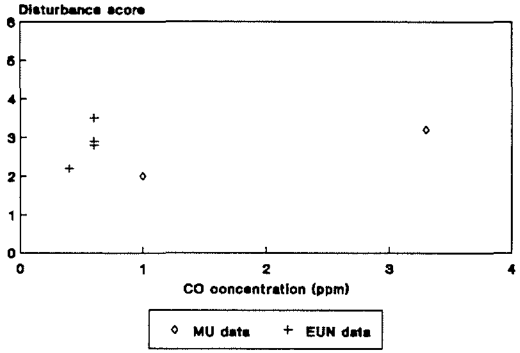


Figure 7.19 Scatterplot showing the relationship between indoor disturbance from vehicle-derived dust and dirt and mean CO concentrations.

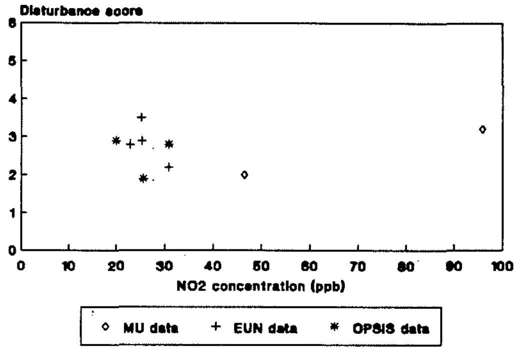


Figure 7.20 Scatterplot showing the relationship between indoor disturbance from vehicle-derived dust and dirt and mean NO_2 concentrations.

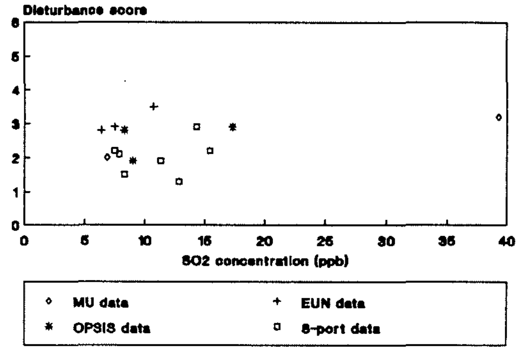


Figure 7.21 Scatterplot showing the relationship between indoor disturbance from vehicle-derived dust and dirt and mean SO_2 concentrations.

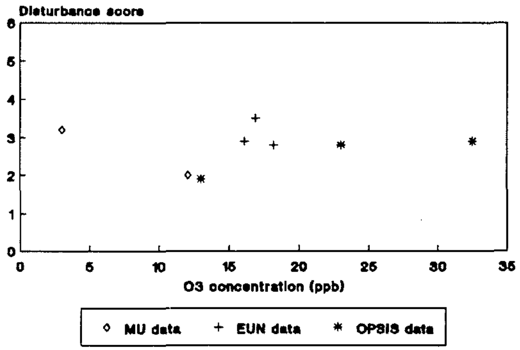


Figure 7.22 Scatterplot showing the relationship between indoor disturbance from vehicle-derived dust and dirt and mean O_3 concentrations.

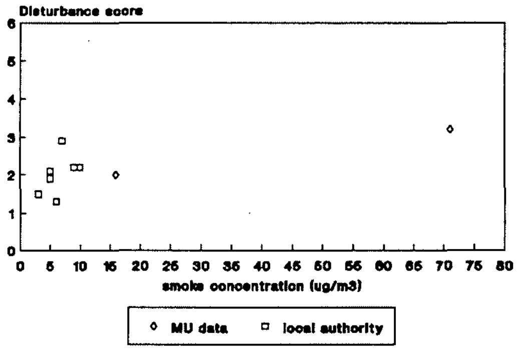


Figure 7.23 Scatterplot showing the relationship between indoor disturbance from vehicle-derived dust and dirt and median smoke concentrations.

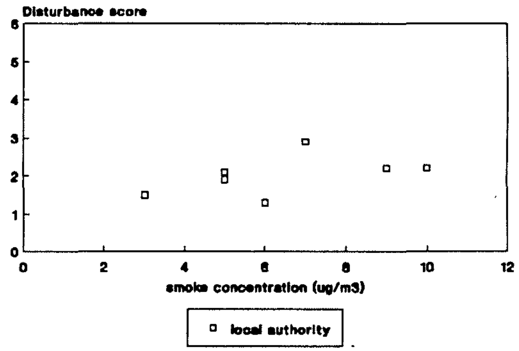


Figure 7.24 Scatterplot showing the relationship between indoor disturbance from vehicle-derived dust and dirt and median smoke concentrations *(local authority data only)*.

The data shown in Table 7.4 suggest only moderate agreement between the observed and estimated values of disturbance score, and as in previous Sections there is no statistical evidence to support the regression equation (Equation 7.4) at the 5% level. The 95% CI for disturbance score and smoke concentration are ± 1.5 and ± 0.2 respectively.

Using a black smoke concentration of 0 $\mu g/m^3$, Equation 7.4 estimates a disturbance score of 1.3 (low disturbance), a similar trend to that described in Section 7.5. The maximum disturbance score (6.0) would be obtained at a theoretical black smoke concentration of 45 $\mu g/m^3$, the same value predicted to cause maximum disturbance outdoors.

Table 7.4
Observed and estimated indoor disturbance scores from vehicle-derived dust and dirt.

Site	Black smoke concentration ($\mu g/m^3$)	Observed disturbance score	Estimated disturbance score
-	0*	-	1.3
Edin-R	3	1.5	1.6
Cov-RC	5	1.9	1.9
B-R	5	2.1	1.9
S-R	6	1.3	2.0^R
Edin-C	7	2.9	2.1^R
S-C	9	2.2	2.3
C-R	10	2.2	2.4
-	45*	-	6.0

* Hypothetical smoke value   ^R Large residual.

7.7 Sensitivity to air pollution

Scatterplots displaying the relationships between pollutant concentrations and the public's reported sensitivity to air pollution are illustrated in Figures 7.25-7.30. The graphs show sensitivity scores of 1.3-3.8 (low to moderate sensitivity) at typical urban background pollutant concentrations. No significant increases in the reported sensitivity scores are apparent at roadside locations with higher recorded pollutant concentrations and no correlation between sensitivity to air pollution and pollutant levels is evident from the data displayed in Figures 7.25-7.30. However, the discussion presented in Section 7.3 is also relevant to these data.

7.8 Prediction of traffic nuisance from air quality data

The data presented in Sections 7.3-7.7 suggests that the public experiences significant outdoor disturbance from vehicle-generated dust/dirt and smoke, fumes and odour at pollutant concentrations typical of UK urban background locations. Indoor disturbance is generally low

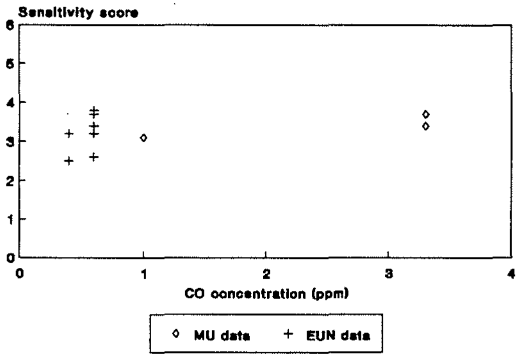


Figure 7.25 Scatterplot showing the relationship between sensitivity to air pollution and mean CO concentrations.

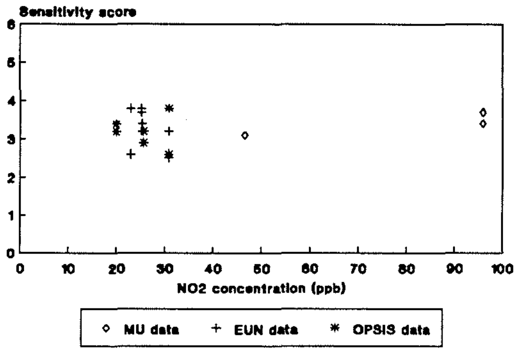


Figure 7.26 Scatterplot showing the relationship between sensitivity to air pollution and mean NO_2 concentrations.

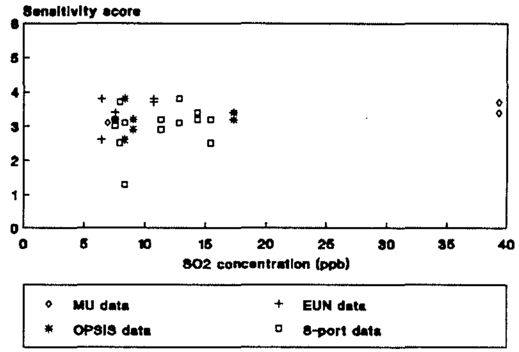


Figure 7.27 Scatterplot showing the relationship between sensitivity to air pollution and mean SO_2 concentrations.

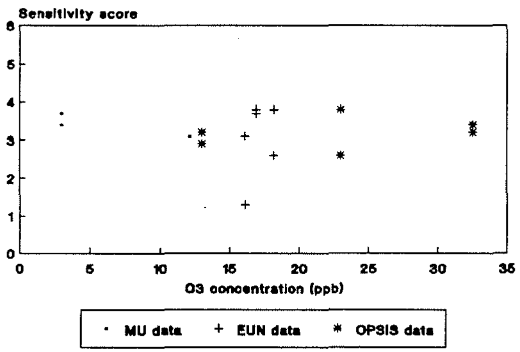


Figure 7.28 Scatterplot showing the relationship between sensitivity to air pollution and mean O_3 concentrations.

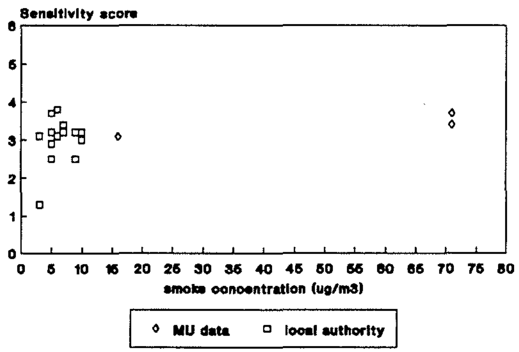


Figure 7.29 Scatterplot showing the relationship between sensitivity to air pollution and median smoke concentrations.

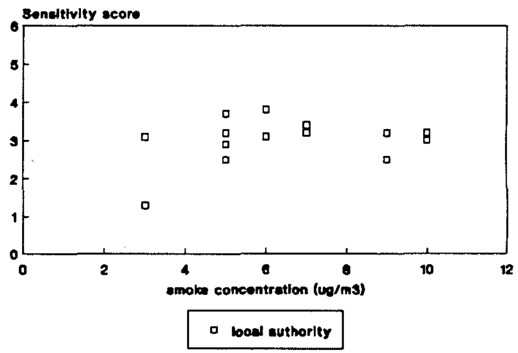


Figure 7.30 Scatterplot showing the relationship between sensitivity to air pollution and median smoke concentrations <u>(local authority data only)</u>.

to moderate at these pollutant values. In addition, the data presented in Sections 7.3-7.7 indicates that there is no observable correlation between reported disturbance from vehicle-derived pollution and measured concentrations of *gaseous* pollutants in urban areas. This contradicts previous research by NTNF in Norway (see Section 2.3.1), whose research suggested an almost linear relationship between calculated CO levels and annoyance. However:

- NTNF's graph incorporates CO values which were estimated by means of a modelrather than actual measured values;
- NTNF estimated maximum CO concentrations for individual homes and plotted these figures against disturbance. The CO values utilised were much higher than those typically encountered in urban areas in the UK. Data from this research, presented in Figures 7.31-7.34, suggests that there is no correlation between measured maximum CO concentrations and traffic nuisance. This is supported by the observation that interviewing respondents at roadside locations does not significantly influence the reported disturbance scores.

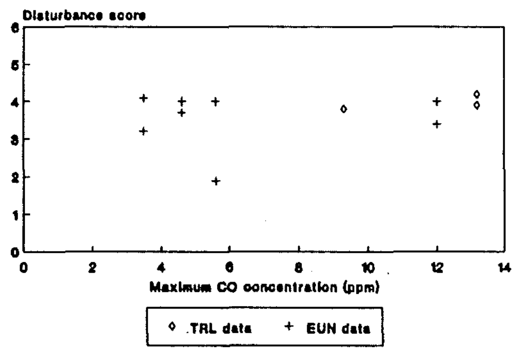


Figure 7.31 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived smoke, fumes and odour and maximum CO concentrations.

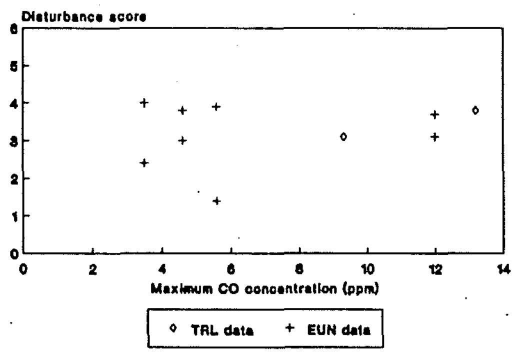


Figure 7.32 Scatterplot showing the relationship between outdoor disturbance from vehicle-derived dust and dirt and maximum CO concentrations.

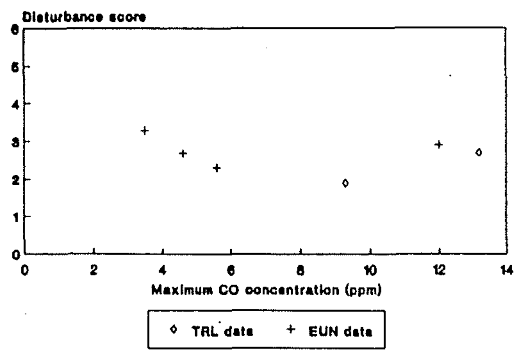


Figure 7.33 Scatterplot showing the relationship between indoor disturbance from vehicle-derived smoke, fumes and odour and maximum CO concentrations.

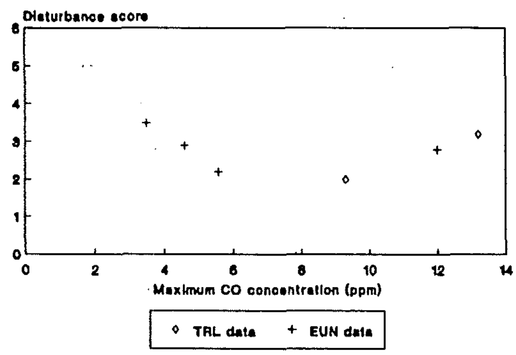


Figure 7.34 Scatterplot showing the relationship between indoor disturbance from vehicle-derived dust and dirt and maximum CO concentrations.

- The pollutant concentrations recorded at all sites were below the levels suspected to cause irritant effects to the public (see Sections 3.6-3.12).

A weak correlation between smoke concentrations and disturbance score was implied by the data presented in Figures 7.6, 7.12, 7.18 and 7.24. Regression equations to predict disturbance score from urban background smoke concentrations have been calculated (Equations 7.1-7.4) and the uncertainties discussed. This information is displayed graphically in Figures 7.35-7.38. However, <u>considerable care must be exercised if these graphs are used to predict nuisance</u>. The 95% CI for these data were very wide, typically 2 and 3 units of disturbance score for outdoor and indoor disturbance respectively. Only a limited range of black smoke concentrations were recorded (maximum 10 $\mu g/m^3$), so that disturbance at high black smoke concentrations has to be predicted using extrapolated data. It has already been demonstrated that inconsistent information can be obtained when using the extrapolated region of the graph (see Sections 7.3-7.5). All the graphs predict very high disturbance scores at background black smoke concentrations of approximately 40 $\mu g/m^3$. In reality this may not be true - people exposed regularly to this level of smoke pollution are likely to become 'acclimatised', so that expectations of air quality are lowered, resulting in lower than predicted disturbance scores.

The graphs also estimate that at black smoke concentrations of 0 $\mu g/m^3$ outdoor disturbance from vehicle-derived pollutants would be moderate, while indoor disturbance would be very low. This suggests that factors other than actual air pollution levels have a strong influence on public nuisance from vehicular sources. Some of these factors may be related to the actual presence of road traffic in the vicinity of the public. Previous research has suggested a relationship between traffic levels and irritant/health effects (Whitelegg *et al*, 1994; Aas *et al*, 1991; Morton-Williams *et al*, 1978), although the derived relationships are far from conclusive. Factors such as danger, noise, severance, perceived damage to human health and the environment from air pollution and local/national media coverage may also be influential.

However, there are many non-traffic related factors which may have an influence on subjective nuisance effects. The data presented in Chapter 5 has demonstrated that there can be significant differences in disturbance between locations, between females and males and between different age groups. No significant differences in annoyance were recorded between smokers/non-smokers. The distance of a person's home/workplace from a road did not appear to influence their reported disturbance in urban areas. Many other potentially significant considerations, such as the overall health and personal experiences/circumstances of the respondents, mobility requirements, awareness of environmental issues and personal exposure to pollution were not

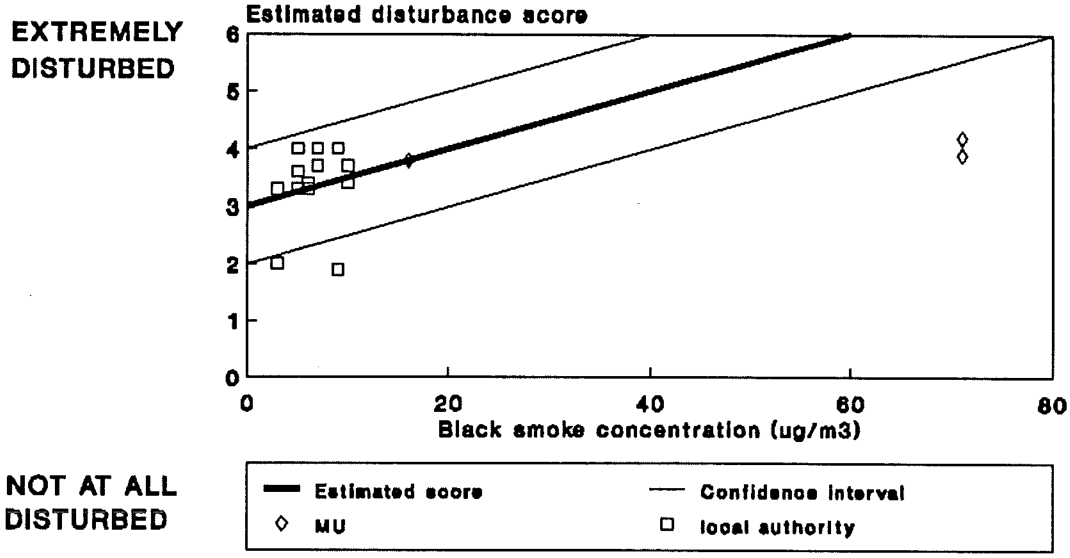


Figure 7.35
Estimated outdoor disturbance from vehicle-derived smoke, fumes and odour.

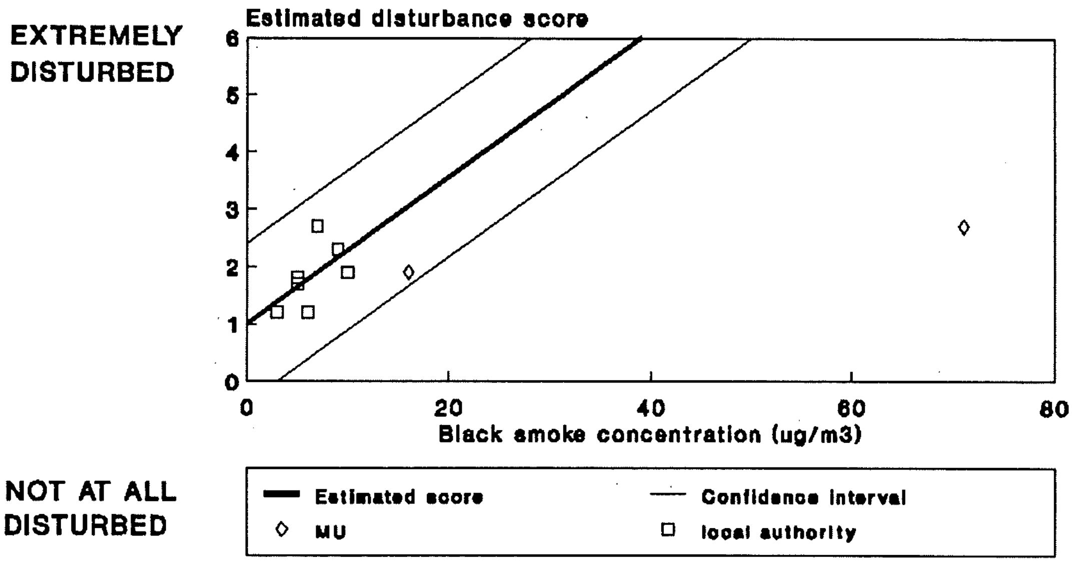


Figure 7.36
Estimated outdoor disturbance from vehicle-derived dust and dirt.

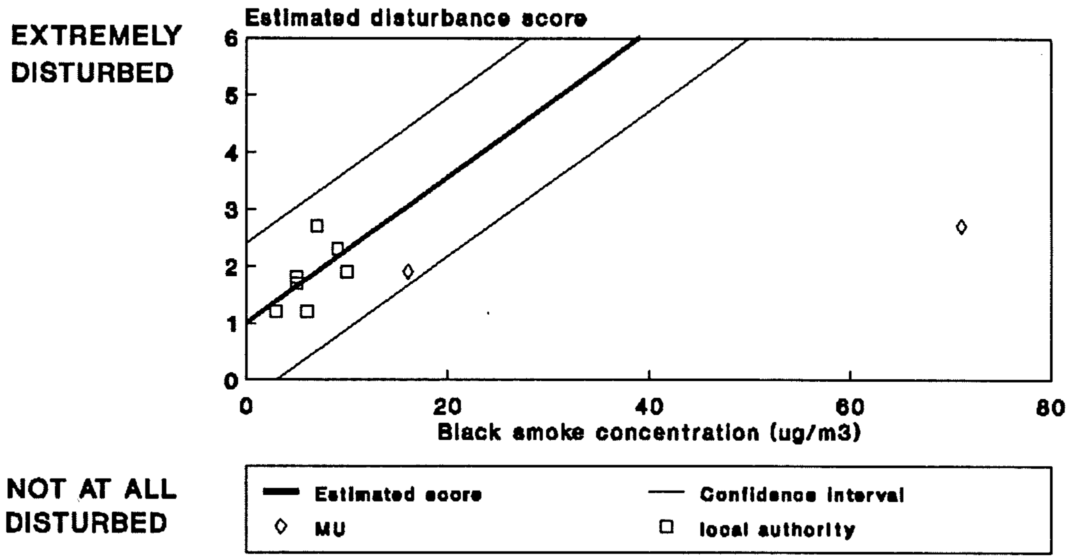


Figure 7.37
Estimated indoor disturbance from vehicle-derived smoke, fumes and odour.

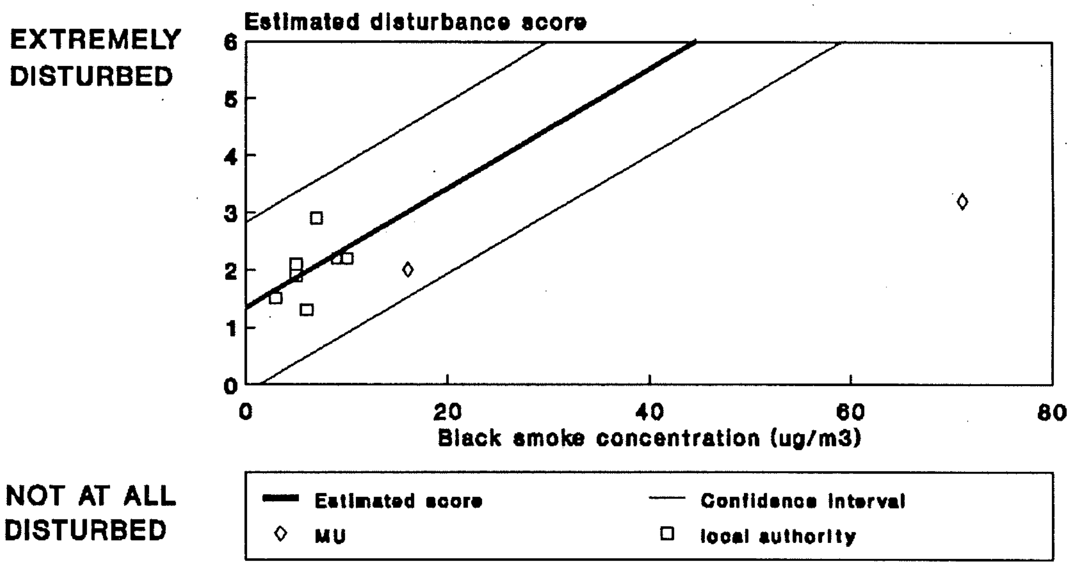


Figure 7.38
Estimated indoor disturbance from vehicle-derived dust and dirt.

measured for logistical reasons. These factors will be exceptionally difficult, time-consuming and costly to identify and will probably be site specific. Thus, regression equations incorporating such factors will be extremely difficult to create and may not result in improvements in the accuracy of nuisance prediction.

In summary therefore, no significant evidence of a direct link between public nuisance and measured pollutant concentrations has been found. A weak correlation between urban background black smoke concentrations and nuisance has been identified and regression equations have been calculated. However, estimates of annoyance at smoke concentrations above 10 $\mu g/m^3$ must be regarded as uncertain in the absence of confirmative data. In addition, the research indicates that although actual levels of pollution may play a part in influencing public annoyance from vehicle-derived pollution, other factors, which may be numerous and difficult to quantify, are likely to be more significant considerations.

If time allows, more accurate information may be obtained through the use of the questionaires described in Chapter 5 and included in Appendix A. This will give the researcher an overview of the respondents' opinions of vehicle-derived air pollution in their area. To evaluate the overall annoyance from each of the individual vehicle-derived nuisances, the index displayed in Table 7.5 is suggested.

Table 7.5
Index for the evaluation of nuisance from vehicle-derived pollution.

Mean disturbance score	Magnitude of disturbance
0.0 - 2.0	low disturbance
2.1 - 3.0	low to moderate disturbance
3.1 - 4.0	moderate to high disturbance
4.1 - 6.0	high disturbance

Using this index, the magnitude of disturbance from the various vehicle-derived nuisances in the Edinburgh area is displayed in Table 7.6. For comparison, disturbance from the various vehicle-derived nuisances in Edinburgh has been estimated using Equations 7.1-7.4 and the index illustrated in Table 7.5. The results, displayed in Table 7.7, show reasonable agreement with the observed disturbance reported in Table 7.6.

Table 7.6
Magnitude of disturbance of nuisance from vehicle-derived pollution in Edinburgh.

Nuisance effect	Magnitude of disturbance			
	Residential area		Commercial area	
	Pedestrians	Householders	Pedestrians	Commercial
Outdoor smoke, fumes and odour	low	moderate to high	moderate to high	moderate to high
Outdoor dust and dirt	low	moderate to high	moderate to high	moderate to high
Indoor smoke, fumes and odour	-	low	low to moderate	-
Indoor dust and dirt	-	low	low to moderate	-

Table 7.7
Estimated disturbance of nuisance from vehicle-derived pollution in Edinburgh.

Nuisance effect	Estimated disturbance			
	Residential area		Commercial area	
	Pedestrians	Householders	Pedestrians	Commercial
Outdoor smoke, fumes and odour	moderate to high	moderate to high	moderate to high	moderate to high
Outdoor dust and dirt	low to moderate	moderate to high	moderate to high	moderate to high
Indoor smoke, fumes and odour	-	low	low	-
Indoor dust and dirt	-	low	low to moderate	-

Chapter 8
Conclusions and Recommendations

8.1 Introduction

The UK Department of Transport currently recommends an assessment of the environmental effects of any new road scheme. One of the main considerations of this environmental appraisal is the amount of air pollution likely to be generated by motor vehicles. The existing appraisal concentrates on the emission and roadside concentrations of those regulated pollutants which are potentially harmful to the health or well-being of human, animal or plant life, or to ecological systems.

However, vehicle emissions, especially those from diesel vehicles, also cause a number of aesthetic and nuisance problems, such as visibility reduction, urban soiling and physical irritation. Currently, the Department of Transport's assessment scheme does not include detailed methodology for the evaluation of public nuisance from vehicle-derived pollution. This research project has investigated the subjective nuisance effects of air pollution from road traffic on the public through the simultaneous measurement of public attitudes and opinions towards vehicle-generated nuisance and air quality in residential and commercial areas. A methodology for predicting public nuisance from vehicle-derived air pollution has been created from the results of this study.

8.2 Vehicle pollutants contributing to public nuisance

A review of the sources and effects of air pollution, provided in Chapter 3, identifies carbon monoxide, nitrogen oxides, volatile organic compounds and particulates as the most important vehicular pollutants. Within the UK, emissions from road traffic have increased markedly because of the rapid growth in vehicle numbers and the increasing distances travelled by vehicles. This phenomenon has resulted in increased concern about air quality, especially in urban areas, and the introduction of stringent exhaust emission legislation. The new legislation, introduced into the UK in 1993, effectively forced new petrol vehicles to be fitted with catalyst technology in order to meet reduced emission limits. It is predicted that significant reductions (80-90% from 1992 values) in emissions from petrol vehicles will result from the introduction of exhaust emission controls. Consequently, there will be a reduction in the total vehicular contribution to national emissions, although this may be negated in the future by growth in the vehicle fleet.

However, the same catalyst technology cannot be fitted to diesel vehicles because of their different operating characteristics. Consequently, the relative contribution of the diesel fleet to total vehicular emissions is likely to increase as a result of catalyst technology for petrol vehicles and the growing popularity of diesel vehicles. This is particularly significant, since in the view of the Quality of Urban Air Review Group (1993b), 'an increased market penetration of diesel cars at the expense of three-way catalyst petrol cars will have a deleterious effect on urban air quality.' Urban air quality has become a high profile media issue and as such is likely to have a significant impact on the public's perception of vehicle-derived air pollution.

Particulates have been identified as the major contributor to public nuisance from air pollution since they contribute to every category of nuisance effects. Emissions from diesel vehicles make a significant contribution to particulate pollution in urban areas since they are the major source of black smoke in the UK and are responsible for over 90% of total PEC emissions. Diesel vehicles are therefore more likely to be associated with nuisance effects than petrol vehicles. This clearly has implications for future air quality given the substantial recent increase of diesel vehicles in the new car fleet.

The concentrations of VOCs and O_3 may cause some public nuisance through their contributions to photochemical smogs, odour and physical irritation, but urban concentrations of CO, NO_x and SO_2 are unlikely to contribute significantly to nuisance levels.

8.3 Monitoring of air quality

Air quality monitoring at all of the sampling sites was performed using procedures recommended by the relevant monitoring authorities. The use of TRL's state-of -the-art mobile laboratory allowed comprehensive measurements of air quality to be made at four roadside sites within the London area. The siting of the laboratory at kerbside locations allowed measurements to be made of typical roadside air quality in urban commercial and residential areas. Large data sets were generated through the use of continuous analysers allowing a comprehensive assessment of air quality at each site.

To provide realistic comparisons of pollutant concentrations at the different sites, statistical summaries of the data were produced. Air pollution values recorded at these locations were similar to those recorded previously at comparable sites, with concentration values of the major vehicular pollutants being higher at the commercial sites characterised by higher traffic densities. Positive and significant correlations were recorded between traffic flow and the major vehicular primary pollutants of CO, NO and NMHC at all sites. The NO_2/NO_x ratios were markedly lower at the commercial sites, reflecting the lack of available O_3 for $NO \rightarrow NO_2$

conversion. Atypically, a significant correlation between traffic flow and SO_2 levels was recorded at Site WG-C. This observation, and the unusually high mean SO_2 and smoke concentrations recorded at Site WG-C, probably reflected the high percentage of diesel vehicles operating at this site.

According to the DoE's public information criteria, the air quality at all four roadside locations was typically 'very good' for SO_2 and O_3, but sometimes 'poor' for NO_2, especially at Site WG-C. This particular example of regularly elevated roadside NO_2 concentrations raises the question of the siting of pollutant monitoring stations. The Department of the Environment has sited its EUN sites at urban background locations. The findings of this research suggest that there is a need for a limited amount of roadside monitoring in order to estimate the pollutant exposure of particularly vulnerable occupation groupings such as drivers of public transportation, traffic wardens/police and construction workers. Pollutant concentrations recorded using EUN/DoE monitoring stations showed that air quality was generally very good during the monitoring periods.

The time series analyses provided visual evidence to support the observed correlations between primary vehicular pollutants and traffic flow data. This type of analysis also allows the identification of time periods when pollutant concentrations are at their peak and assists in the identification of pollutant sources during unexpected pollution events. The time series graphs also vividly display the inverse relationship that exists between NO_2 and O_3 peaks in urban areas and highlight the importance of meteorological conditions and imported plumes of pollution on urban pollutant concentrations.

Urban concentrations of extremely reactive and volatile carbonyl compounds were reported using derivatization techniques. The employed methodology for sampling, extraction and quantitative analysis worked effectively but was time consuming and labour intensive. Because derivatisation techniques were utilised, the accuracy of the technique is difficult to assess.

Black smoke concentrations recorded at the four roadside sites were much higher than those typically recorded at rooftop level in the UK. This observation may indicate the strong influence of diesel vehicle emissions on roadside black smoke concentrations and/or the extreme 'blackness' of diesel particles. The latter explanation would suggest an over-estimation of roadside smoke concentrations. The values of TSP recorded at these sites were within typical UK urban ranges. Median concentrations of both black smoke and TSP were higher at commercial sites than at residential sites.

8.4 Public attiudes to air pollution from road vehicles

The main objective of this research was to develop a methodology to investigate the subjective nuisance effects of air pollution from road traffic on the public. This methodology has been developed and tested at 7 locations in the UK. The data clearly indicates that air pollution from road traffic was an issue of high relative importance to the public when compared to other social issues, with global environmental issues also quite highly ranked. This finding is in agreement with two other recent surveys carried out on behalf of the DoE (DoE, 1994; Hedges, 1994). Comparison of these results with previous surveys by the DoE (1986, 1989) suggests that concern about environmental issues has been maintained despite four years of recession, during which period environmental issues would have been expected to have a lower priority. This indicates that concern for the environment is now an established social issue rather than a transient preoccupation. In general, there was good agreement between the three surveys where similar questions were asked, suggesting that questionnaires, properly designed and implemented, can give reproducible results and act as an accurate barometer of public opinion.

Local environmental issues were generally of relatively low priority compared to other major social issues,although traffic-related nuisances were very important local environmental nuisances, with the physical presence of road traffic and its associated smoke, fumes and odour being particularly important. Concern about traffic exhaust fumes has consistently risen over the last 8 years and traffic congestion and pollution is predicted by the publicto be their greatest environmental concern in 20 years time (DoE, 1994).

Indoors, noise from road traffic was the most important vehicle-derived disturbance since it was the most frequent and highly ranked indoor traffic-induced nuisance. This is in agreement with other studies by SCPR (Morton-Williams *et al*, 1978) and NTNF (Aas *et al*, 1991). The most frequent unprompted complaints about indoor vehicle-derived pollution concerned the soiling of surfaces and the malodour of the fumes. Health effects were rarely mentioned in association with indoor pollution. This may indicate that the public feel protected from the potentially health-damaging effects of vehicle pollution when they are indoors and are generally more concerned with aesthetic issues.

Outdoors, disturbance from smoke, fumes and odour was the most frequently complained about traffic-induced nuisance, with danger ranking equally highly. Most respondents were concerned about the effects of fumes upon their health, with adverse effects widely assumed. The malodour of the fumes and the soiling of clothes *etc* generally caused less concern. Issues such as the soiling of buildings by vehicle-derived pollution generated little public concern. This was unexpected given its very visible impact on high profile historic buildings, the potentially high economic costs of cleaning soiled buildings and the relatively high degree of scientific interest in this subject. This observation may imply that direct sensory (*ie* personal) experience of pollution is more important than its visual impact in triggering public concern. All of these responses were unprompted. These data thus indicate that the public perceive traffic fumes as a health hazard when they are outdoors, and are also highly concerned about the potential danger arising from the close proximity of road traffic.

Significant differences in disturbance between sites in the same and different cities, between females and males and between different age groups were recorded. There was no readily apparent reason for the differences in disturbance between different locations. Women and people in the 25-44/45-64 age groups were consistently more concerned about environmental issues/nuisance effects than men and younger/older respondents, an observation supported by the recent DoE survey (DoE, 1994). No significant differences in annoyance were noted between smokers/non-smokers and different socio-economic groupings, although commercial respondents often reported the highest levels of concern. In addition, the level of nuisance experienced by people in urban areas did not depend upon the proximity of their home/workplace to a road, an observation supported by Whitelegg *et al* (1994).

Respondents who stated that they suffered some disturbance from a range of health/nuisance effects when they were outdoors were asked what they thought was the cause of their distress. Using the asumption that <u>all</u> kerbside air pollution and dust/dirt is traffic generated (a worst-case situation), the <u>maximum percentage</u> of respondents who blamed vehicle-generated air pollution for the named health/irritant effects was estimated. With the exception of the pedestrian residential location in Edinburgh, where disturbance was markedly lower than at the other sites, 23-51% of the household and pedestrian respondents felt that traffic pollution was at least partly to blame for their sore or runny eyes; 18-49% for sneezing; 23-69% for their irritated throat and 30-80% for soiling.

In general, the findings highlight the public's concern about the relationship between vehicle-derived pollution, especially particulate pollution, and human irritant/health effects. In urban areas, particulates, black smoke and unpleasant odours are often associated with the exhaust emissions from diesel vehicles. The findings of this survey are therefore consistent with the recent conclusions of the UK Quality of Urban Air Review Group (1994) that 'any increase in the proportion of diesel vehicles on our (UK) urban streets is to be viewed with considerable concern unless problems of particulate matter ... are effectively addressed'.This result, together with the observation that the physical presence of road traffic is as important as the presence of pollutants, may indicate that health and safety concerns are more important to the public than aesthetic issues associated with vehicle-derived pollution.

8.5 Prediction of public nuisance from vehicle-derived air pollution

No observable correlations between reported disturbance from vehicle-derived pollution and measured concentrations of gaseous pollutants in urban areas were observed, contradicting the findings of previous research. A weak correlation between urban background black smoke concentrations and disturbance score was observed and regression equations were calculated. However, these equations were not statistically significant and may not be reliable predictors of nuisance. It is not recommended that these equations are used for predictive purposes without extra data (such as that obtained via the questionnaires outlined previously) which would provide an overview of the nuisance effects in the area under study.

It is considered that the factors which contribute to a person's annoyance from vehicle-derived pollution are highly personal, numerous and exceptionally difficult to quantify, making predictions of the magnitude of nuisance from pollutant concentrations undependable. An alternative index for the evaluation of nuisance from vehicle-derived pollution has been suggested for use with questionnaire data.

8.6 Recommendations for further research

- There is a need for a similar type of survey to be performed in an area where smoke concentrations are abnormally high. This would enable the regression equations derived in Chapter 7 to be verified or otherwise.
- This research has taken a 'scientific' approach to the problem of nuisance form vehicle-derived air pollution by utilising structured questionnaires containing key questions with multiple-choice answers. Given that a person's background and experiences may be important factors in determining their opinions towards such pollution, an alternative approach could incorporate detailed questionning of a much smaller group of (representative) individuals to try and identify common features and experiences amongst individuals with high/low disturbance scores.
- Social surveys of public attitudes towards vehicle-derived pollution need to be repeated in urban areas on a regular basis so that changes in public opinion may be monitored alongside changes in urban air quality. For comparative purposes, surveys in semi-urban, rural and heavily industrialised areas should also be performed. On a larger

scale, a European-wide survey would provide much information on social attitudes within different cultures.

- The number of roadside monitoring stations in urban areas in the UK needs to be increased so that the pollutant exposure of vulnerable groups and occupational cohorts may be estimated.
- Emissions inventories for selected pollutants in important UK towns and cities are urgently required. This is particularly important in the case of particulates because of the potential increase in the diesel vehicle population. Improved methodologies for estimating emissions should also be investigated.
- Improved techniques for the quantititve determination of carbonyl compounds are required to improve efficiency and accuracy. A comparion of the technologies utilising bubblers and diffusion tubes would be an effective starting point.

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THE TRANSPORT RESEARCH LABORATORY

TRANSPORT RESEARCH LABORATORY

PEDESTRIAN QUESTIONNAIRE

INTERVIEWER NAME ....

LOCATION ....

DATE ....

INTRODUCTION

Good morning/afternoon/evening.

I am <**GIVE NAME**> of Public Attitude Surveys Ltd, contracted by the Transport Research Laboratory.

SHOW IDENTITY CARD. DO NOT WAIT TO BE ASKED.

Would it be possible to ask you some questions about the .... area ***NAME AREA***?

Answering the questionnaire will take between 5–10 minutes.

1 Firstly, I would like to ask you a general question.

I'm going to read out a list of issues.

Using one of the statements written on this card, would you please tell me how worried you personally feel about each of these issues.

SHOW RESPONDENT CARD 1 AND READ OUT LIST FROM COLUMN A.

CIRCLE CODE FOR EACH RESPONSE.

1	**Column A**	Not at all worried	Not very worried	Moderately worried	Very worried	Extremely worried
a	**Health & social services**	0	1	2	3	4
b	**Law & order**	0	1	2	3	4
c	**Education**	0	1	2	3	4
d	**Unemployment**	0	1	2	3	4
e	**Local environment**	0	1	2	3	4
f	**Rising population**	0	1	2	3	4
g	**Rising prices**	0	1	2	3	4
h	**Housing**	0	1	2	3	4
i	**Old age pensions**	0	1	2	3	4
j	**Global environment**	0	1	2	3	4
k	**Air pollution from road traffic**	0	1	2	3	4

2 Next I would like to concentrate on some local environmental issues.

I'm going to read out a list of some possible environmental concerns in .... ***NAME AREA.***

Using this card, would you tell me how much these issues bother you when you are out walking in .... ***NAME AREA.***

SHOW RESPONDENT CARD 2 AND READ OUT LIST FROM COLUMN B.

CIRCLE CODE FOR EACH RESPONSE.

2	**Column B**	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	**Graffiti**	0	1	2	3	4
b	**Litter & rubbish**	0	1	2	3	4
c	**Smoke, fumes and odour**	0	1	2	3	4
d	**Amount of road traffic**	0	1	2	3	4
e	**Dog mess**	0	1	2	3	4
f	**Ugly\disused buildings**	0	1	2	3	4
g	**Noise**	0	1	2	3	4
h	**Dust & dirt**	0	1	2	3	4
i	**Smog**	0	1	2	3	4
j	**Blackening of building walls**	0	1	2	3	4

3a For this question, I would like you to reply using one of the statements written on this card.

SHOW STATEMENTS ON CARD 3

When you are out walking in .... ***NAME AREA***, how often are you bothered or disturbed by the following effects?

READ OUT LIST FROM COLUMN C AND CIRCLE CODE IN TABLE BELOW.

3a	Column C	Never	Occasionally	Frequently	All the time
a	**Smoke, fumes and odour**	0	1	2	3
b	**Dust & dirt**	0	1	2	3
c	**Noise**	0	1	2	3
d	**Smog**	0	1	2	3
e	**Blackening of building walls**	0	1	2	3

3b ***DO NOT ASK IF RESPONDENT ANSWERS <u>'NEVER'</u> IN QUESTION 3a:***

In .... ***NAME AREA***, what do you think is the main cause of the ....? ***NAME EFFECT FROM COLUMN C.***

RECORD ANSWERS IN TABLE BELOW

3b	Column C	Cause	Code (office use only)
a	**Smoke, fumes and odour**		
b	**Dust & dirt**		
c	**Noise**		
d	**Smog**		
e	**Blackening of building walls**		

4a I would like you to think now about smoke, fumes and odour from road traffic.

Using this scale ***SHOW SCALE ON CARD 4***, would you please choose a number which indicates overall, how much you are bothered or disturbed by smoke, fumes and odour from road traffic when you are out walking in .... ***NAME AREA***?

CIRCLE RESPONSE. **0 ... 1 ... 2 ... 3 ... 4 ... 5 ... 6**

IF ANSWER IS '0' GO TO QUESTION 5a.

4b ***ASK IF ANSWER TO QUESTION 4a IS NOT '0'.***

What is it specifically about smoke, fumes and odour from road traffic that bothers or disturbs you when you are out walking in .... ***NAME AREA***?

RECORD RESPONSE BELOW.

5a I would like you to think now about dust and dirt from road traffic.

Using this scale ***SHOW SCALE ON CARD 4***, would you please choose a number which indicates overall, how much you are bothered or disturbed by dust and dirt from road traffic when you are out walking in .... ***NAME AREA***?

CIRCLE RESPONSE. **0 ... 1 ... 2 ... 3 ... 4 ... 5 ... 6**

IF ANSWER IS '0' GO TO QUESTION 6a.

5b ***ASK IF ANSWER TO QUESTION 5a IS NOT '0'.***

What is it specifically about dust and dirt from road traffic that bothers or disturbs you when you are out walking in .... ***NAME AREA***?

RECORD RESPONSE BELOW.

6a For this question, I would like you to reply using one of the statements written on this card.

SHOW STATEMENTS ON CARD 5

When you are out walking in .... ***NAME AREA***, how much are you bothered or disturbed by the following problems?

READ OUT LIST FROM COLUMN D AND CIRCLE CODE IN TABLE BELOW.

6a	Column D	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	**Sore or runny eyes**	0	1	2	3	4
b	**Sneezing**	0	1	2	3	4
c	**Dirt on your clothes**	0	1	2	3	4
d	**Dirt on your skin, nails or hair**	0	1	2	3	4
e	**Irritated throat**	0	1	2	3	4

6b ***DO NOT ASK IF RESPONDENT ANSWERS <u>'NOT AT ALL BOTHERED'</u> TO QUESTION 6a:***

In .... ***NAME AREA***, what do you think is the main cause of the\your ....? ***NAME APPROPRIATE EFFECT FROM COLUMN D.***

CIRCLE CODE IN TABLE BELOW

6b	Column D	Cause	Code (office use only)
a	**Sore or runny eyes**		
b	**Sneezing**		
c	**Dirt on your clothes**		
d	**Dirt on your skin, nails or hair**		
e	**Irritated throat**		

7 Please look at these cards. ***SHOW CARDS A–F.***

Which of these things causes you personally most bother or disturbance when you are out walking in .... ***NAME AREA***?

CIRCLE CODE IN APPROPRIATE COLUMN BELOW.

Which next? ***CONTINUE TO OBTAIN RANK ORDER FOR EACH ITEM.***

7		Most	Next most	Next most	Next most	Next most	Next most
a	**Noise from road traffic**	1	2	3	4	5	6
b	**Dust & dirt from road traffic**	1	2	3	4	5	6
c	**Smoke, fumes & odour from road traffic**	1	2	3	4	5	6
d	**Vibrations from road traffic**	1	2	3	4	5	6
e	**Danger from road traffic**	1	2	3	4	5	6
f	**Splash & spray from road traffic**	1	2	3	4	5	6

8 This list shows some different types of road vehicles ***SHOW CARD 6.***

In .... ***NAME AREA,*** which group of vehicles do you think contributes the most air pollution to the overall air pollution?

CIRCLE CODE.

Petrol cars 1

Diesel cars 2

Buses\coaches 3

Lorries 4

Vans 5

Motorbikes\mopeds 6

Dustcarts 7

9 Could I ask, how sensitive would you say you are to air pollution in general?

Using this scale, ***SHOW SCALE ON CARD 7,*** please use a number from '0' to '6' which indicates how sensitive you are to air pollution in general.

CIRCLE RESPONSE. **0 ..... 1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

PERSONAL DETAILS

These remaining questions are standard for most questionnaires and are only used for our own classification purposes. Your answers are entirely confidential.

10 Gender ***CIRCLE CODE:***

Male 1

Female 2

11 Using this card ***SHOW RESPONDENT CARD 8,*** can you please indicate which age group you belong to?

CIRCLE CODE:

Under 18 1

18 - 24 2

25 - 44 3

45 - 64 4

65 and over 5

12 What is the job title of the main wage earner in your household? ***(PROBE?)***

WRITE IN ________________________________

TELL RESPONDENT That is all. Thank you very much for your time.

I certify that this is a true record of an interview for this survey with a person unknown to me and has been conducted within the code of conduct.

Signature.............................. No.................................. Date.....................................

Respondent Number...

THE TRANSPORT RESEARCH LABORATORY

TRANSPORT RESEARCH LABORATORY

BUSINESS QUESTIONNAIRE

(To be completed by any member of staff)

Name of Business.. **Location/Town**...

1 A number of issues are listed in Table 1 below.

Using Table 1, please tick the box which indicates how worried you personally feel about each of the issues listed in Column A.

TABLE 1.

1	**Column A**	Not at all worried	Not very worried	Moderately worried	Very worried	Extremely worried
a	**Health & social services**					
b	**Law & order**					
c	**Education**					
d	**Unemployment**					
e	**Local environment**					
f	**Rising population**					
g	**Rising prices**					
h	**Housing**					
i	**Old age pensions**					
j	**Global environment**					
k	**Air pollution from road traffic**					

2 Table 2 lists some possible environmental concerns in your area.

Using Table 2, please tick the box which indicates how bothered or disturbed you personally feel about each of the issues listed in Column B *when you are out walking in this area.*

TABLE 2.

2	**Column B**	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	**Graffiti**					
b	**Litter & rubbish**					
c	**Smoke, fumes and odour**					
d	**Amount of road traffic**					
e	**Dog mess**					
f	**Ugly \ disused buildings**					
g	**Noise**					
h	**Dust & dirt**					
i	**Smog**					
j	**Blackening of building walls**					

3 Using Table 3 below, please tick the box which indicates overall, how often you are bothered or disturbed by each of the effects listed in Column C *when you are out walking in this area?*

TABLE 3

3	**Column C**	Never	Occasionally	Frequently	All the time
a	**Smoke, fumes and odour from road traffic**				
b	**Dust & dirt from road traffic**				
c	**Noise from road traffic**				
d	**Smog**				
e	**Blackening of building walls**				

4 Please consider now smoke, fumes and odour from road traffic in this area.

Using the scale below, please circle the number which indicates overall, how much you are bothered or disturbed by smoke, fumes and odour from road traffic *when you are out walking in this area.*

NOT AT ALL BOTHERED **0 ...1... 2 ... 3 ... 4 ... 5 ... 6** **EXTREMELY BOTHERED**

5 Please consider dust and dirt from road traffic in this area.

Using the scale below, please circle the number which indicates overall, how much you are bothered or disturbed by dust and dirt from road traffic *when you are out walking in this area.*

NOT AT ALL BOTHERED **0 ...1... 2 ... 3 ... 4 ... 5 ... 6** **EXTREMELY BOTHERED**

6 Using Table 4 below, please tick the box which indicates overall, how much you are bothered or disturbed by each of the problems listed in Column D *when you are out walking in this area?*

TABLE 4

6	**Column D**	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	**Sore or runny eyes**					
b	**Sneezing**					
c	**Dirt on your clothes**					
d	**Dirt on your skin, nails or hair**					
e	**Irritated throat**					

7 Look at the items listed in Column E of Table 5 below. Choose the item which causes you personally the most bother or disturbance *when you are out walking in this area*. Place the number 1 in the box next to this item. From the remaining items in Column E, choose the item which causes you personally the next most bother or disturbance *when you are out walking in this area*. Place the number 2 in the box next to this item. Continue this process until you have ranked the items in Column E from 1 to 6.

TABLE 5

7	Column E	
a	Noise from road traffic	
b	Dust & dirt from road traffic	
c	Smoke, fumes & odour from road traffic	
d	Vibrations from road traffic	
e	Danger from road traffic	
f	Splash & spray from road traffic	

8 Thinking now about *when you are inside the shop\office*.

Using Table 6 below, please tick the box which indicates overall, how often you are bothered or disturbed by each of the effects listed in Column F *when you are inside the shop\office?*

TABLE 6

8	Column F	Never	Occasionally	Frequently	All the time
a	Smoke, fumes and odour from road traffic				
b	Noise from road traffic				
c	Vibrations from road traffic				
d	Dust & dirt from road traffic				

9 Please consider again smoke, fumes and odour from road traffic in this area.

Using the scale below, please circle the number which indicates overall, how much you are bothered or disturbed by smoke, fumes and odour from road traffic *when you are inside the shop\office.*

NOT AT ALL BOTHERED **0 ... 1 ... 2 ... 3 ... 4 ... 5 ... 6** **EXTREMELY BOTHERED**

10 Please consider dust and dirt from road traffic in this area.

Using the scale below, please circle the number which indicates overall, how much you are bothered or disturbed by dust and dirt from road traffic *when you are inside the shop \ office.*

NOT AT ALL BOTHERED	**0 ... 1 ... 2 ... 3 ... 4 ... 5 ... 6**	**EXTREMELY BOTHERED**

11 Using Table 7 below, please tick the box which indicates overall, how much you are bothered or disturbed by each of the problems listed in Column G *when you are inside the shop \ office?*

TABLE 7

11	Column G	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	**Sore or runny eyes**					
b	**Sneezing**					
c	**Dirt on your clothes**					
d	**Dirt on your skin, nails or hair**					
e	**Irritated throat**					

12 Look at the items listed in Column H of Table 8 below. Choose the item which causes you personally the most bother or disturbance *when you are inside the shop \ office*. Place the number 1 in the box next to this item. From the remaining items in Column H, choose the item which causes you personally the next most bother or disturbance *when you are inside the shop \ office*. Place the number 2 in the box next to this item. Continue this process until you have ranked the items in Column H from 1 to 5.

TABLE 8

12	Column H	Rank
a	**Noise from road traffic**	
b	**Dust & Dirt from road traffic**	
c	**Smoke, fumes & odour from road traffic**	
d	**Vibrations from road traffic**	
e	**Danger from road traffic**	

13 The list below shows some different types of road vehicles.

In this area, which group of vehicles do you think contributes the *most air pollution* to the overall air pollution?

CIRCLE ONE NUMBER.

Petrol cars 1

Diesel cars 2

Buses\coaches 3

Lorries 4

Vans 5

Motorbikes\mopeds 6

Dustcarts 7

14 How sensitive would you say you are to air pollution in general?

Using the scale below, please circle the number which indicates how sensitive you are to air pollution in general?

NOT AT ALL SENSITIVE	**0 ...1... 2 ... 3 ... 4 ... 5 ... 6**	**EXTREMELY SENSITIVE**

15 Gender ***PLEASE CIRCLE APPROPRIATE NUMBER***

Male 1

Female 2

16 Please indicate which age group you belong to?

PLEASE CIRCLE APPROPRIATE NUMBER

Under 18 1

18 – 24 2

25 – 44 3

45 – 64 4

65 and over 5

17 Please write down below the job title of the main wage earner in your household?

Thank you very much for your cooperation. Please return your completed questionnaire in the prepaid envelope.

THE TRANSPORT RESEARCH LABORATORY

HOUSEHOLD QUESTIONNAIRE

INTERVIEWER NAME ....

LOCATION ....

DATE ....

INTRODUCTION

Good morning/afternoon/evening.

I am <**GIVE NAME**> of Public Attitude Surveys Ltd, contracted by the Transport Research Laboratory.

SHOW IDENTITY CARD. DO NOT WAIT TO BE ASKED.

Would it be possible to ask you some questions about the .... area ***NAME AREA***?

Answering the questionnaire will take 20–30 minutes.

1 Firstly, I would like to ask you a general question.

I'm going to read out a list of issues.

Using one of the statements written on this card, would you please tell me how worried you personally feel about each of these issues.

SHOW RESPONDENT CARD 1 AND READ OUT LIST FROM COLUMN A.

CIRCLE CODE FOR EACH RESPONSE.

1	**Column A**	Not at all worried	Not very worried	Moderately worried	Very worried	Extremely worried
a	**Health & social services**	0	1	2	3	4
b	**Law & order**	0	1	2	3	4
c	**Education**	0	1	2	3	4
d	**Unemployment**	0	1	2	3	4
e	**Local environment**	0	1	2	3	4
f	**Rising population**	0	1	2	3	4
g	**Rising prices**	0	1	2	3	4
h	**Housing**	0	1	2	3	4
i	**Old age pensions**	0	1	2	3	4
j	**Global environment**	0	1	2	3	4
k	**Air pollution from road traffic**	0	1	2	3	4

2 Next I would like to concentrate on some local environmental issues.

I'm going to read out a list of some possible environmental concerns in .... ***NAME AREA.***

Using this card, would you tell me how much these issues bother you when you are out walking in .... ***NAME AREA.***

SHOW RESPONDENT CARD 2 AND READ OUT LIST FROM COLUMN B.

CIRCLE CODE FOR EACH RESPONSE.

2	Column B	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	Graffiti	0	1	2	3	4
b	Litter & rubbish	0	1	2	3	4
c	Smoke, fumes and odour	0	1	2	3	4
d	Amount of road traffic	0	1	2	3	4
e	Dog mess	0	1	2	3	4
f	Ugly\disused buildings	0	1	2	3	4
g	Noise	0	1	2	3	4
h	Dust & dirt	0	1	2	3	4
i	Smog	0	1	2	3	4
j	Blackening of building walls	0	1	2	3	4

3a For this question, I'd like you to reply using one of the statements written on this card.

SHOW STATEMENTS ON CARD 3.

When you are out walking in .... ***NAME AREA,*** how often are you bothered or disturbed by the following effects?

READ OUT LIST FROM COLUMN C AND CIRCLE CODE IN TABLE BELOW.

3a	Column C	Never	Occasionally	Frequently	All the time
a	**Smoke, fumes and odour**	0	1	2	3
b	**Dust & dirt**	0	1	2	3
c	**Noise**	0	1	2	3
d	**Smog**	0	1	2	3
e	**Blackening of building walls**	0	1	2	3

3b ***DO NOT ASK IF RESPONDENT ANSWERS 'NEVER' IN QUESTION 3a:***

In .... ***NAME AREA,*** what do you think is the main cause of the ....? ***NAME EFFECT FROM COLUMN C.***

RECORD ANSWERS IN TABLE BELOW.

3b	Column C	Cause	Code (office use only)
a	**Smoke, fumes and odour**		
b	**Dust & dirt**		
c	**Noise**		
d	**Smog**		
e	**Blackening of building walls**		

4a I would like you to think now about smoke, fumes and odour from road traffic.

Using this scale ***SHOW SCALE ON CARD 4***, would you please choose a number which indicates overall, how much you are bothered or disturbed by smoke, fumes and odour from road traffic when you are out walking in .... ***NAME AREA***?

CIRCLE RESPONSE. **0 ..... 1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

IF ANSWER IS '0' GO TO QUESTION 5a.

4b ***ASK IF ANSWER TO QUESTION 4a IS NOT '0'.***

What is it specifically about smoke, fumes and odour from road traffic that bothers or disturbs you when you are out walking in .... ***NAME AREA***?

RECORD RESPONSE BELOW:

5a I would like you to think now about dust and dirt from road traffic.

Using this scale ***SHOW SCALE ON CARD 4***, would you please choose a number which indicates overall, how much you are bothered or disturbed by dust and dirt from road traffic when you are out walking in .... ***NAME AREA***?

CIRCLE RESPONSE. **0 ..... 1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

IF ANSWER IS '0' GO TO QUESTION 6a

5b ***ASK IF ANSWER TO QUESTION 5a IS NOT '0'.***

What is it specifically about dust and dirt from road traffic that bothers or disturbs you when you are out walking in .... ***NAME AREA***?

RECORD RESPONSE BELOW.

6a For this question, I'd like you to reply using one of the statements written on this card.

SHOW STATEMENTS ON CARD 5

When you are out walking in .... ***NAME AREA,*** how much are you bothered or disturbed by the following problems?

READ OUT LIST FROM COLUMN D AND CIRCLE CODE IN TABLE BELOW.

6a	Column D	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	**Sore or runny eyes**	0	1	2	3	4
b	**Sneezing**	0	1	2	3	4
c	**Dirt on your clothes**	0	1	2	3	4
d	**Dirt on your skin, nails or hair**	0	1	2	3	4
e	**Irritated throat**	0	1	2	3	4

6b ***DO NOT ASK IF RESPONDENT ANSWERS 'NOT AT ALL BOTHERED' IN QUESTION 6a:***

In .... ***NAME AREA,*** what do you think is the main cause of the\your ....? ***NAME APPROPRIATE EFFECT FROM COLUMN D.***

CIRCLE CODE IN TABLE BELOW.

6b	Column D	Cause	Code (office use only)
a	**Sore or runny eyes**		
b	**Sneezing**		
c	**Dirt on your clothes**		
d	**Dirt on your skin, nails or hair**		
e	**Irritated throat**		

7 Please look at these cards. ***SHOW CARDS A–F.***

Which of these things causes you personally most bother or disturbance when you are out *walking* in .... ***NAME AREA***?

CIRCLE CODE IN APPROPRIATE COLUMN BELOW.

Which next? ***CONTINUE TO OBTAIN RANK ORDER FOR EACH ITEM.***

7		Most	Next most	Next most	Next most	Next most	Next most
a	**Noise from road traffic**	1	2	3	4	5	6
b	**Dust & dirt from road traffic**	1	2	3	4	5	6
c	**Smoke, fumes & odour from road traffic**	1	2	3	4	5	6
d	**Vibrations from road traffic**	1	2	3	4	5	6
e	**Danger from road traffic**	1	2	3	4	5	6
f	**Splash & spray from road traffic**	1	2	3	4	5	6

8 Thinking now about when you are inside your home. For this question, I'd like you to reply using one of the statements written on this card.

SHOW STATEMENTS ON CARD 6.

When you are inside your home, how often are you bothered or disturbed by the following effects?

READ OUT LIST FROM COLUMN E CIRCLE CODE IN TABLE BELOW.

8	**Column E**	Never	Occasionally	Frequently	All the time
a	**Smoke, fumes & odour from road traffic**	0	1	2	3
b	**Noise from road traffic**	0	1	2	3
c	**Vibrations from road traffic**	0	1	2	3
d	**Dust & dirt from road traffic**	0	1	2	3

9a I would like you to think again about smoke, fumes and odour from road traffic.

Using this scale ***SHOW SCALE ON CARD 7***, would you please choose a number which indicates overall, how much you are bothered or disturbed by smoke, fumes and odour from road traffic when you are inside your home?

CIRCLE RESPONSE. **0 .....1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

IF ANSWER IS '0' GO TO QUESTION 10a.

9b ***ASK IF ANSWER TO QUESTION 9a IS NOT '0'.***

What is it specifically about smoke, fumes and odour from road traffic that bothers or disturbs you when you are inside your home?

RECORD RESPONSE BELOW.

10a I would like you to think now about dust and dirt from road traffic.

Using this scale ***SHOW SCALE ON CARD 7***, would you please choose a number which indicates overall, how much you are bothered or disturbed by dust and dirt from road traffic when you are inside your home?

CIRCLE RESPONSE. **0 ..... 1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

IF ANSWER IS '0' GO TO QUESTION 11a.

10b ***ASK IF ANSWER TO 10a IS NOT '0'.***

What is it specifically about dust and dirt from road traffic that bothers or disturbs you when you are inside your home?

RECORD RESPONSE BELOW.

11a Still thinking about when you are inside your home, using this card ***SHOW CARD 8*** can you tell me how much you are bothered or disturbed by the following problems?

READ OUT LIST FROM COLUMN F AND CIRCLE CODE IN TABLE BELOW.

11a	**Column F**	Not at all bothered	Not very bothered	Moderately bothered	Very bothered	Extremely bothered
a	**Sore or runny eyes**	0	1	2	3	4
b	**Sneezing**	0	1	2	3	4
c	**Dirt on your clothes**	0	1	2	3	4
d	**Dirt on your skin, nails or hair**	0	1	2	3	4
e	**Irritated throat**	0	1	2	3	4

11b ***DO NOT ASK IF RESPONDENT ANSWERS 'NOT AT ALL BOTHERED' IN QUESTION 11a:***

Inside your home, what do you think is the main cause of the\your ....?
NAME APPROPRIATE EFFECT FROM COLUMN F.

CIRCLE CODE IN TABLE BELOW.

11b	**Column F**	Cause	Code (office use only)
a	**Sore or runny eyes**		
b	**Sneezing**		
c	**Dirt on your clothes**		
d	**Dirt on your skin, nails or hair**		
e	**Irritated throat**		

12 Please look at these cards. ***SHOW CARDS A–E.*** [EXCLUDE CARD F]

Which of these things causes you personally most bother or disturbance when you are *inside your home*?

CIRCLE CODE IN APPROPRIATE COLUMN BELOW.

Which next? ***CONTINUE TO OBTAIN RANK ORDER FOR EACH ITEM.***

12		Most	Next most	Next most	Next most	Next most
a	**Noise from road traffic**	1	2	3	4	5
b	**Dust & dirt from road traffic**	1	2	3	4	5
c	**Smoke, fumes & odour from road traffic**	1	2	3	4	5
d	**Vibrations from road traffic**	1	2	3	4	5
e	**Danger from road traffic**	1	2	3	4	5

13 Altogether then, when you are inside your home, how much are you bothered or disturbed by air pollution from road traffic?

SHOW SCALE ON CARD 9
CIRCLE RESPONSE. **0 ..... 1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

14a Do you have a garden or yard?

CIRCLE CODE. **Yes 1**

IF RESPONDENT ANSWERS 'NO', GOTO Q15a. **No 2**

14b Is your garden\yard at the back, front or side of the house?

CIRCLE RESPONSE

Back only 1

Front only 2

Side only 3

Back & front 4

Back & side 5

Front & side 6

Back, front & side 7

14c Can you please look at this card ***SHOW CARD 9,*** and indicate how much air pollution from road traffic affects your enjoyment of your garden or yard?

CIRCLE RESPONSE. **0 ..... 1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

IF ANSWER TO QUESTION 14c IS '0' GO TO QUESTION 15a.

14d ***IF ANSWER TO QUESTION 14c IS NOT '0'.***

What is it specifically about air pollution from road traffic that bothers or disturbs you when you are in your garden or yard?

15a Thinking again about dust and dirt and smoke, fumes and odour from road traffic. Some people have told us that sometimes air pollution from road traffic affects the way they and their family live at home.

Do you find that there any jobs that are done around your home which are affected by air pollution from road traffic?

Yes 1

No 2

IF ANSWER TO QUESTION 15a IS 'NO' GO TO QUESTION 16.
IF ANSWER TO QUESTION 15a IS 'YES' GO TO QUESTION 15b.

15b *What are the jobs that are affected by air pollution from road traffic?*

LIST THE JOBS MENTIONED IN COLUMN IN THE TABLE BELOW.

Job name	Code (office use only)

16 This list shows some different types of road vehicles ***SHOW CARD 10.***

In .... ***NAME AREA,*** which group of vehicles do you think contributes the most air pollution to the overall air pollution?

CIRCLE CODE.

Petrol cars 1

Diesel cars 2

Buses\coaches 3

Lorries 4

Vans 5

Motorbikes\mopeds 6

Dustcarts 7

17 Could I ask, how sensitive would you say you are to air pollution in general?

Using this scale, ***SHOW SCALE ON CARD 11,*** please use a number from 0 to 6 which indicates how sensitive you are to air pollution in general.

CIRCLE RESPONSE. **0 ..... 1 ..... 2 ..... 3 ..... 4 ..... 5 ..... 6**

18 How would you describe the amount of traffic passing your home on Mondays to Fridays?

SHOW CARD 12, READ OUT LIST AND CIRCLE RESPONSE. **Extremely heavy 1**

Very heavy 2

Fairly heavy 3

Moderate 4

Light 5

Very little 6

(Don't know/varies) 7

PERSONAL DETAILS

These remaining questions are standard for most questionnaires and are only used for our own classification purposes. Your answers are entirely confidential.

19 Gender ***CIRCLE CODE:***

Male 1

Female 2

20 Using this card ***SHOW CARD 13***, can you please indicate which age group you belong to?

CIRCLE CODE.

Under 18 1

18 - 24 2

25 - 44 3

45 - 64 4

65 and over 5

21a Have you ever smoked a cigarette, cigar or a pipe?

CIRCLE CODE. **Yes 1**

IF RESPONDENT SAYS 'NO', GOTO Q22. **No 2**

21b Do you still smoke?

CIRCLE CODE. **Yes 1**

No 2

22 What is the job of the main wage earner in your household? ***(PROBES?)***

WRITE IN ________________________________

TELL RESPONDENT That is all. Thank you very much for your time.

AFTER THE SESSION COMPLETE THE FOLLOWING:

Distance from nearest wall of building to kerbside\edge of road:

Distance	Circle code
Under ½ yard	1
½ to under 1½ yards	2
1½ to under 3 yards	3
3 yards to under 6 yards	4
6 yards to under 12 yards	5
12 yards to under 24 yards	6
24 yards to under 48 yards	7
48 yards or over	8

I certify that this is a true record of an interview for this survey with a person unknown to me and has been conducted within the code of conduct.

Signature.............................. No.................................... Date..

Respondent Number..