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Population Exposure to Air Pollutants in Europe (PEOPLE)

Methodological Strategy and Basic Results

R. A. Field, P. Pérez Ballesta, A. Baeza Caracena, I. Nikolova, R. Connolly, N. Cao, M. Gerboles, D. Buzica, L. Amantini, F. Lagler, A. Borowiak, L. Marelli, G. De Santi and E. De Saeger

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Executive Summary

This report is designed to enable general understanding of the Population Exposure to Air Pollutants in Europe (PEOPLE) project. The methodology and basic results of the PEOPLE project is described. A full interpretative analysis of the data is not presented here. In each city the project required collaboration between a local partner and the Emissions and Health Unit (EHU) of the Institute for Environment and Sustainability (IES). This institute is part of the Joint Research Centre (JRC) of the European Commission. The main mission of the JRC is to provide scientific support to EC policy development, implementation and monitoring.

PEOPLE campaigns were completed in six cities, namely; Brussels and Lisbon (22 October 2002), Bucharest and Ljubljana (27 May 2003), Madrid (3 December 2003) and Dublin (28 April 2004). The first stage of the project was accomplished with benzene as the pollutant considered. In Ljubljana, outdoor measurements were extended to include particulate matter and a number of polycyclic aromatic hydrocarbons. In Madrid, measurements were further supplemented with an assessment of the heavy metal content of particulate matter. In Dublin, particulate monitoring also included human exposure and indoor environments.

Mapping of outdoor measurements indicate areas of highest concentrations being associated with major road intersections. Transportation was identified as the dominant source of benzene in all six cities that were studied. Background levels of benzene measured on the day of the campaign, and the subsequent estimation of the yearly average city levels, revealed that PEOPLE cities are in compliance with the Directive 2000/69/EC, with the exception of Bucharest.

The levels at ambient background sites, situated at the types of locations used for air quality directive monitoring, were comparable to the air quality of the control groups of this study, namely the homes of people that do not smoke and the personal exposure of people who neither commute to a workplace or smoke. City background benzene levels are therefore applicable as an indicator of human exposure for non smoking people that do not commute to work and are not exposed to indoor sources. In general, city background sites represent the lowest level of exposure. Higher levels of exposure were related to the different categories that were used in the project. The smoking group had the highest level of exposure. For the commuting categories the car user group has the highest exposure levels. The level of exposure of children was similar to that of the commuting categories. Some individuals and locations reported extremely high concentrations. Further analysis of the movement diaries from individuals whose measurements were identified as outliers could not always explain the elevated benzene concentrations. In these cases either the presence of unknown sources or unusual proximity to known sources are possible explanations of elevated exposure levels.

The basic results have revealed that human exposure, of commuters and smokers, to the air pollutant benzene is higher, by a factor of two, than concentrations reported at urban background monitoring sites. This is due to the influence of traffic and smoking emission sources. When the commuters are considered together as a group, excluding the smoking participants and control groups, comparison with ambient city background data, for all six cities, indicates that a ratio of approximately 1.5 (commuters/background) for the median benzene concentrations.

Citizens that are exposed to indoor emissions such as smoking, or move and work in proximity to traffic, can be expected to receive much higher pollutant exposures. Indoor locations that were influenced by smoking sources reported relatively high concentrations. While indoor pollution levels are usually determined by the external air quality, it is clear that the presence of indoor sources, such as smoking, can elevate pollution concentrations. This was evident for a number of individual sites. The highest indoor concentrations were measured in bars and inside taxis that travelled within traffic for the sampling period.

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Nomenclature and Abbreviations

APHEIS	Air Pollution and Health: and European Information System
As	Arsenic
B[a]P	benzo[a]pyrene
CAFÉ	Clean Air for Europe
C_{BG}	median 24 hour spatial background concentration level
C_{BGN}	median 12 hour spatial background concentration level from 8:00 pm to 8:00 am
Cd	Cadmium
C_{EX}	Exposure concentration level for 24 hours
$C_{EX(12M)}$	Exposure concentration level for 12 hours from 8:00 am to 8:00 pm
$C_{EX(12N)}$	Exposure concentration level corresponding for 12 hours from 8:00 pm to 8:00 am
C_{HP}	Maximum outdoor 24 hours ambient concentration level
CITIDEP	Research Centre on Information Technology and Participatory Democracy
CO	Carbon monoxide
CONCAWE	Conservation of Clean Air and Water in Europe
COMEAP	Committee on the medical Effects of Air Pollution
Cr	Chromium
CRSP-LVT	Public Health Regional Centre for Lisbon and Tagus Valley
Cu	Cupper
DCEA	Department of Environmental Sciences and Engineering (Portugal)
DMAEV, CML	City Department for Environment and Green Spaces, the Lisbon Municipality
DRAOT-LVT	Regional Administration of Environment and Land Use Planning for Lisbon and Tagus Valley
EC	European Commission
EHU	Emissions and Health Unit
EN	European Norm
EPAQS	Expert Panel on Air Quality Standard
EU	European Union
FCT-UNL	College of Science and Technology, the New University of Lisbon
F	Fahrenheit
Hg	Mercury
IC	Institute for the Consumer
JRC	Joint Research Centre
LV	Limit values
MACBETH	Monitoring of atmospheric concentrations of benzene in European towns and homes
MCOTA	Ministry of Cities, Land Use Planning and Environment. Portugal
METROPOLIS	Air pollution distributions of adult urban populations in Europe
Mph	Miles per hour
MS	Ministry of Health, Portugal
Ni	Nickel
NO_2	Nitrogen dioxide
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PEOPLE	Population Exposure to Air Pollutants in Europe
PM_{10}	Particulate matter less than 10 microns in diameter
QA/QC	Quality Assurance and Quality Control
QUERCUS	National Association for the Conservation of Nature
R	Coefficient of correlation
WHO	World Health Organisation
Zn	Zinc

1. PROJECT OVERVIEW

1.1. Introduction

Air quality continues to be at the centre of efforts to reduce environmental pollution. In recent years improved understanding of the importance of particulate pollution has emphasised the need for control of air pollution levels. The Clean Air for Europe (CAFE) strategy of the European Union is aiming to improve the quality of air we breath. At the centre of recent policy review is the emerging understanding of air pollution impacts upon human health. The CAFE strategy has in recent years focussed upon the importance of traffic emission sources. While ambient air concentrations can be assessed with routine monitoring at urban background sites, population exposure requires a different approach that involves personal monitoring and knowledge of movement through different environments.

1.1.1. Air Quality Directives and Health Impacts

In the European Union, most ambient air pollution measurements are performed for compliance with EC Air Quality Directives. These directives require, by force of law, that member states undertake measurements at outdoor locations in order to assess compliance with prescribed standard levels. Directives are intended to protect human health from adverse impacts that should be avoided if the standards are not exceeded [Council of the European Union, 1996a]. The time period selected for a given pollutant is derived from consideration of particular health impacts. Limit values (LV) are set with respect to whether acute (short term) or chronic (long term) exposure is considered. EU legislation has established a series of LV, which are shown in Table 1. These values are of particular importance for the protection of individuals that are sensitive to affects of air pollutants. Susceptible people include, for example, those with lung or heart disease, asthma, diabetes, children and the elderly [Annesi-Maesano et al. 2003, Harrison R.M. et al. 2002]. The human health associations of these pollutants are briefly summarised below.

The absorption of sulphur dioxide by the nose and upper respiratory tract can impair various respiratory functions. Sulphur dioxide acts as an irritant by stimulating nerves in the lining of the nose, throat and the lung's airways. This causes a reflex cough, irritation, and a feeling of chest tightness, and may lead to narrowing of the airways. It is also suspected that exposure to sulphur dioxide may enhance sensitisation to inhaled allergens or increase the sensitivity to allergens of some patients with asthma [Rusznak C. et al. 1994]. The mechanism by which nitrogen dioxide acts is most probably related to its properties as an oxidising agent that can damage tissue, including cell membranes. Nitrogen dioxide causes acute inflammation of the airways. Short-term exposure can also affect the immune cells of the airways in a manner that increases the risk of respiratory infections and heighten sensitivity to the inhalation of allergens. Repeated inflammatory reactions may act to decrease the resistance of individuals to infection [Devalia J.L. et al. 1994]. The effects of high concentrations of ozone may be noticeable as a slight irritation of the eyes and nose, with potential damage to the airway lining followed by an inflammatory reaction. Ozone is a powerful oxidising agent, able to release free oxygen radicals that damage normal tissue. This inflammation has the potential to cause short term respiratory symptoms. Measurable decline in lung function may occur on exposure to concentrations of ozone greater than about 100 ppb. The evidence suggests that these effects are only transient [McDonnell W.F. et al. 1991].

Carbon monoxide interferes with the processes whereby oxygen is utilised of the cells in the body. This effect comes from the formation of carboxy-haemoglobin, and also by blocking essential biochemical reactions. At ambient levels, the greatest concern is for possible effects on the heart and the brain, since these two organs are crucially dependent upon a high rate of oxygen. Carboxy-haemoglobin levels of 3-4% shorten the duration of exercise needed to induce both changes in the electrocardiogram record and also the onset of angina pain. It has been suggested that the increased risk of hardening of the arteries, arteriosclerosis, in cigarette smokers is due to raised levels of carboxy-haemoglobin [Chaltman B.R. et al. 1992].

Benzene is readily absorbed into the body upon breathing. About half of it is retained and distributed to fatty tissues including the brain and the bone marrow where blood cells are made. The effect of long-term exposure to benzene is of most concern for non-lymphocytic leukaemia. Benzene affects the genetic material of the cells with a genotoxic action. It is generally accepted that it may cause malignant disease even at low concentration levels. While this could be strictly interpreted as meaning that there is no safe concentration to which people can be exposed, a realistic view is that the risks become increasingly small as the cumulative exposure of an individual is reduced and that, for all practical purposes, there is a concentration at which the risks are exceedingly small and unlikely to be detectable by any practicable method [EPAQS, 1994]. The risk of non-lymphocytic leukaemia, in the form of acute myeloid leukaemia, is increased substantially in cigarette smokers; the risk of this disease is almost doubled in those who smoke 20 cigarettes daily. This effect of smoking is not related to benzene alone, but to the mixture of carcinogens found in cigarette smoke. Benzene is classed as a carcinogenic compound and a risk level established by the World Health Organisation ranges between 3.8 and 7.5 cases of myeloid leukaemia per one million people exposed during lifetime to 1 $\mu g/m^3$ of benzene [WHO, 2000]. Benzene is the first carcinogen to be regulated by EU air quality directives[Council of the European Union, 2000].

In recent years the influence of even low concentrations of pollutants on human health has re-emerged as an important scientific issue [Dockerty D.W. et al., 1993]. The health impact from low concentrations of particulate pollution has been established in a variety of cities with considerable demographic and geographic situations [Pope C.A. III et al., 1995, Laden F. et al., 2001]. When large numbers of people are considered, the mortality rate of the population is directly linked through epidemiological research to the particulate pollution level. Similar studies in European cities have reached consistent findings to those documented for the United States [APHEIS, 2004]. Epidemiology has consistently demonstrated an association between adverse health effects and particles. Increasingly, particles are being measured as the mass of the fraction that is considered most likely to be deposited in the lung. These particles are called PM_{10} (Particulate Matter less than 10 µm in aerodynamic diameter) and are thought to be more harmful than coarser matter. Particles exert their effects by causing oxidative stress which leads to inflammation. This drives the associated respiratory and cardiovascular effects. In the case of ultra-fine particles, this may include systemic effects from their direct transfer into the vascular system. A mechanism responsible for development of cancer is more complex. There is considerable evidence for adverse human health effects associated with both acute or short term (days) and chronic or long term (many years) exposure to ambient PM_{10} [COMEAP, 1998; WHO, 2000; WHO, 2003; USEPA, 2004]. They include respiratory morbidity and mortality, cardiovascular morbidity and mortality, and cancer. Quantitative estimation of health impacts from exposure to PM_{10} assumes linearity in the relationship between exposure and responses. It is also not possible to discern whether there is a threshold particle concentration below which there are no adverse effects on health for the whole population. Estimates of population exposure-response relationships indicate that deaths and hospital admissions due to respiratory disorders are either brought forward or additionally caused. Thereby the impact of air pollution episodes on mortality is relatively small. However, in some cases deaths may be brought forward by weeks or months rather than days. Data indicate that life expectancy gains from reduction of exposure to particles in the long-term are about an order of magnitude greater than for a similar magnitude reduction of exposure in the short-term. The long-term health effects appear to be dominated by cardiovascular rather than respiratory mortality [APHEIS, 2004].

Ambient PM_{10} is physically and chemically diverse. The relationship with total PM_{10} inhaled is used, in part due to a lack of data for specific components. Carbon and organic compounds are major constituents of combustion-generated particles and together with secondary organic aerosol, comprise a substantial proportion of PM_{10}. The evidence suggests that it is combustion-derived components of PM_{10}, which are comprised predominantly of fine and ultra-fine particles and may have a high content of heavy metals and PAH (and other organic compounds), that are believed to be most responsible for the harmful effects. Some PAH and their oxy- and nitro-derivatives are known to exert inflammatory, mutagenic and carcinogenic effects. Plausible mechanisms therefore exist to link organic components of PM_{10} with both acute and chronic adverse health effects. Given the evidence emerging for the importance of exposure to traffic-related particles, the public health burden of exposure at such road-side “hot-spots” may be inadequately assessed by using population exposure derived from background urban concentrations. Research on mechanisms that link particle exposure with a variety of health effects has placed considerable emphasis upon combustion derived carbonaceous particles [WHO, 2003].

Most carcinogenic PAH occur almost exclusively in the long-lived particulate phase. Their effect depends upon conversion in the body into compounds that can react with and damage the genetic material in the nuclei of cells. The activation process for such genotoxic compounds is mediated by various enzyme systems in susceptible target tissues. It is known that PAH are rapidly absorbed, and can be activated in the lung [IARC, 1983]. The International Agency for Research on Cancer (IARC) has classified Benzo[a]Pyrene, Benz[a]Anthracene and Dibenz[a,h]Anthracene as classified as '*probably* carcinogenic to humans'. Benzo[b]Fluoranthene, Benzo[k]Fluoranthene, Indeno[1,2,3,c,d]Pyrene are classified as '*possibly* carcinogenic to humans. The unit risk level as a carcinogen of a lifetimes exposure to a mixture of PAH represented by 1 ng/m^3 B[a]P is estimated by the WHO to be 87 cases per one million people [European Commission, 2001].

Heavy metals are known to negatively affect human health. Once absorbed, lead accumulates particularly in bone, teeth, skin and muscle tissues. Around 2% of absorbed lead is found in blood and it is this fraction that is biologically active and leads to harmful effects. The toxic effects of lead are attributed to its ability to inhibit the actions of certain enzymes and to damage chemicals in the nuclei of cells. Lead is associated with a number of health effects. The most substantial evidence relates to effects on the central nervous system and, in particular, on the developing brain of children [EPAQS, 1998].

There are different limit values for arsenic, cadmium and nickel in ambient air [Council of the European Union, 2004] as these metal species differ considerably in respect to their toxicity, carcinogenic potency and uptake mechanisms. The unit risk of a lifetime exposure to 1 ng/m^3 of arsenic is estimated by the World Health Organisation to be 1.5 cases per one million people. The corresponding value for nickel is 1.8 cases per million.

Table 1.- Limit and Target values of EU regulated pollutants for the protection of human health

Compound	*Limit/Target value, µg/m^3*	*Reference period*	*Application period*
Sulphur dioxide	350	1 hour	2005
	125	24 hour	2005
Nitrogen dioxide	200 (NO_2)	1 hour	2010
	40 (NO_2)	1 year	2010
Ozone	120	8 hour	2010
Carbon Monoxide	10 mg/m^3	8 hour	2010
Benzene	5	1 year	2010
PM_{10}	50	24 hour	2005
	40	1 year	2005
Lead	0.5	1 year	2005/2010
Benzo[a]pyrene	1 ng/m^3	1 year	2007
Arsenic	5 ng/m^3	1 year	2007
Cadmium	6 ng/m^3	1 year	2007
Nickel	20 ng/m^3	1 year	2007

**Concentrations are expressed at 20 ºC and 101.3 kPa. Lead, B[a]P, As, Cd & Ni are measured in PM_{10}.*

1.1.2. Emission Control

In tandem with air quality standards are Directives that require emission reduction [Council of the European Union, 1996b]. In recent years the reduction of emissions from motor vehicles has received considerable attention across the developed World. In Europe, a number of revisions to limits required for motor vehicle emissions have resulted in increasingly stringent standards [Council of the European Union, 1998]. The legislative approach adopted by the European Union with respect to air pollution has seen air quality improvements in the air quality of urban areas, in particular since the 1980s [Field et al. 1996]. The implementation of control strategies has proved to be successful at urban locations in developed nations where emissions from motor vehicles are the dominant pollution source [Field et al. 1992]. The control of emissions from light duty vehicles was instigated by the 1970 Type Approval Framework Directive 70/156/EEC, when standards were proposed through EU Directive 70/220/EEC. Over the past 30 years, a progressive reduction of emissions from light duty motor vehicles has been implemented. Prior to the establishment of the EURO 1 standard implemented in 1992, a number of revisions to the superseded ECE R 15 limits were made in 1974, 1977, 1978, and 1983. The EURO emission standards were based upon EC Directive 91/441/EEC. The EURO emission limits have also been reduced through a number of steps since EURO 1 was established. New emission limit values were implemented in 1996 for EURO stage 2, in 2000 for EURO stage 3 and in 2005 for EURO stage 4. The present culmination of actions toward the reduction of emissions from light duty vehicles has seen closer collaboration between the United States, Europe, Japan and China [European Commission, 2004].

1.1.3. Population exposure to air pollution

Research on the health implications of air pollution has highlighted the importance of the pathway that links the given biological impact with dose and exposure. To gain a full understanding of the impact of pollution upon health, an approach that uses total human exposure has shown the importance of considering all routes of exposure, whether through water, air, food or by contact [Pellizari E. 1992, Clayton C.A. et al., 1993, Pellizari E., 1999, Monn C., 2001]. This approach showed the importance of understanding the relationship between pollutant, uptake route and health effect. Ambient air is an important pathway for volatile pollutants to enter the body [Lioy P.J., 1995]. As such, ambient air is of concern for the general population. Workplace air is controlled under different legislation that meets far less stringent standards than those for ambient air. For example in the United Kingdom a 12 hour exposure level of 1 ppm for benzene is orders of magnitude higher than the levels required for ambient air quality [HSE, 2003]. While it is essential to understand mechanisms of response to pollution, a prerequisite is to have the best possible estimates and understanding of exposures and doses [Lioy P.J., 1995].

Air pollution measurements that are used to determine compliance with air quality directives must meet certain siting criteria. Such sites should be selected within areas of higher population density, in order to be representative of the air pollutant concentrations that people are exposed to. These sites are broadly classified as background sites, as the sampled air is usually well mixed and away from emission sources. However the exact approach to national monitoring network design may differ between member states of the European Union. In general, e.g. United Kingdom, stations are sited away from the direct influence of emission sources. For pollutants that present acute health impacts, like NO_2 and carbon monoxide, hot-spot sites are needed for legislative compliance. A direct translation of ambient air measurements as exposure is not necessarily the best approach [Field et al., 2004]. Ambient air measurements are generally performed at fixed sites that are elevated above the breathing zone. Such sites are also selected to ensure that good temporal data can be collected in order to determine the longer-term air quality trends. The influences of meteorology and emission sources are easier to understand in such data-sets. Interpolative maps of city background ambient air give spatial understanding of city scale pollution levels. While showing the interaction of prevalent atmospheric conditions and emission strengths these maps give qualitative information [Perez Ballesta et al. 1997]. However the population experiences a greater variety of exposure situations than those of city background monitoring sites. Information on how people spend their time is essential to determine the relative importance of different locations and activities (Klepeis N.E. et al., 1996). As such, understanding the population we are considering is important. Considerable differences of meteorological conditions and pollutant emission profiles exist between cities. In recent years two main exposure studies have assessed the European situation [Cocheo V. et al., 2000, Jantunen M.J. et al., 1998], MACBETH and EXPOLIS.

Air pollution exposure is the average concentration of air pollutants in the air that a person breathes. It is very different from background air quality; the latter is determined from a fixed site while human exposure includes a multitude of environments. It is necessary to consider indoor air, both at home and in the workplace, as well as all the movements throughout the day, in particular commuting to work. For human exposure, the following classification shows the importance of the multitude of environments, sources and behaviours that should be considered.

The pollution level in many environments is to a large extent determined by outdoor emission sources. However, when indoor sources are present, concentrations in enclosed locations can be highly elevated in particular with respect to smoking. Indeed personal behaviour can have a significant influence upon exposure levels. Besides smoking, the time of and duration of travelling is of prime importance. Commuting by car in slow moving rush hour traffic may significantly increase exposure levels, depending on the pollutant.

We can measure and/or model exposure to air pollution. However, given the size of populations it is often necessary to use a composite approach that would include the following aspects:

- Measurements of actual human exposures
- Measurements and modelling of time activity patterns
- Measurements of environmental concentrations (indoor and outdoor)
- Quantification of factors that contribute to human exposure

While some of these approaches can be used independently it can be useful to use them together. In this way, better estimates of the most important exposure pathways can be obtained. Measurements of human exposure are performed close to the breathing zone to give a good estimate of inhaled concentration. It is clear that the breathing zone is much closer to the main emission sources of motor vehicles than city background fixed site monitors. This is true for most transport users and pedestrians alike. Historically, widespread human monitoring was difficult due to the necessity to carry pumps and expensive equipment. The improvement of the diffusive sampling technique has made cost effective assessments of large groups of people for gaseous pollutants possible.

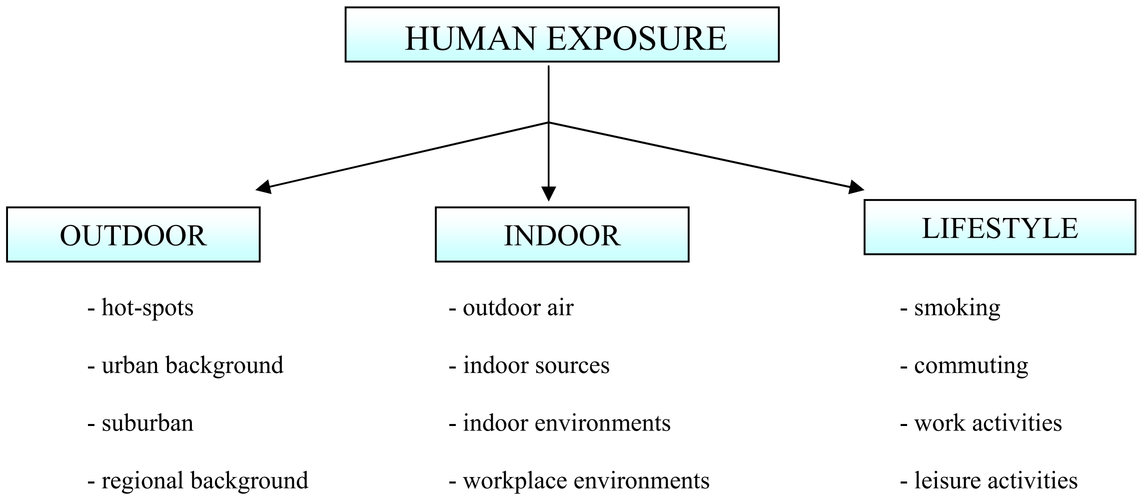


Figure 1.1.- Human Exposure Pathway

As people move through a typical day they encounter a number of different situations that in broad terms are; moving or stationary, indoors or outdoors [Jantunen M.J. et al., 1998]. Assessments of modern urban lifestyles have shown the dominance of time spent indoors. By considering the movement of people we can define and label different environments. A profile is established that consists of a matrix of activities and loscations [Wallace L.A. et al., 1986]. The major problem with this approach is the high temporal variability for most situations and the lack of consistency between similar situations. The label may be clear and concise but it may bear little relation to the environment itself, for example one office may be located at the first floor of a busy street; another may be on the city outskirts upwind of the city centre next to a quiet pedestrian square. Notwithstanding exchange mechanisms, the ambient air is expected, in the absence of indoor emission sources, to define the levels of pollution measured inside a given microenvironment. The relationship may however be unique and controlled by a number of factors. Even two offices in the same building may be difficult to relate to ambient data from the same street [Phillips L.J. et al., 1993].

The information that can be gained from given micro-environments has utility as a screening tool [Field R.A. et al., 2004]. Bars and restaurants that allow smoking are likely to have far higher air concentrations of combustion derived pollutants than non-smoking equivalents. However, a wide range of concentrations can be expected based upon factors including dimensions of the environment and ventilation rate. It can be more useful to use information from the movements of a large population combined with exposure monitoring data to understand the important factors [Cocheo V. et al., 2000]. This approach also has limitations; first, the selection of representative participants and second, the accurate recording of movement information. The latter problem is accentuated with longer sampling times [Jantunen M.J. et al., 1998].

Much work has focussed upon smoking as it has well established health impacts; its presence is known to elevate pollution levels in confined spaces, and it is an issue of major importance in modern societies. Smoking has been banned inside the buildings of some countries, in particular the United States of America. Europe has generally been much slower to control environmental tobacco smoke as a pollution source. Landmark legislation was implemented on March 31st 2004 in Ireland and January 11th 2005 in Italy with the banning of smoking in public places. The movement toward restricting smoking behaviour in workplace and public environments is an important aspect of the issue of the responsibility of emissions that cause elevated exposures.

1.1.4. Selection of Pollutants

Benzene is the first known carcinogen to be controlled by European Air Quality Directives [Council of the European Union, 2000]. While the risk of developing leukaemia from ambient air is low, the estimated number of occurrences is reduced with lower air concentrations [WHO, 2000]. The PEOPLE project measured outdoor, indoor and personal exposure levels of benzene with the goal of supporting the entry into force of the EC Directive 2000/69/EC on air pollution for benzene and carbon monoxide [Council of the European Union, 2000]. Benzene was selected as the first pollutant to be measured as it is relatively easy to measure while being an excellent indicator of emissions from both transport emission sources and smoking. The second step was to include an assessment of particulate matter, PM_{10}. The latter class of pollutant is at the forefront of current concern with respect to air pollution and health. The compound classes that are believed to be of particular importance for health impacts were measured, namely PAH and heavy metals. Ambient levels of B[a]P were measured in the last three cities of the project.

As a collaborative pan-European project managed by the European Reference Laboratory of Air Pollution, the project was designed to meet a number of objectives. A core mission for the European Commission is to ensure that measurements in all member states are both comparable and of the highest quality. This project is part of this mission, while assessing population exposure to air pollutants in Europe.

1.2. Objectives

The PEOPLE project measured outdoor, indoor and human exposure levels of selected air pollutants. The project was initially designed to meet a number of objectives given the entry into force of the EC Directive 2000/69/EC on air pollution for benzene and carbon monoxide.

1. Assessment of outdoor benzene concentrations for city scale monitoring network support; The importance of this objective depends on the city that is participating. For those that already possess established networks or regularly perform large spatial background mapping exercises, this objective will be less important than for cities where little high quality ambient data have been reported. For some cites this objective is of prime importance as a first step towards a commitment to long term monitoring as is required by EU Directives.

2. Understanding human exposure to air pollutants, in particular for benzene; Good information with respect to actual exposure to air pollution from divergent emission sources is important for improved health impact assessments of urban populations in Europe. The project intends to make generalised comparisons between categories of exposure related to both different modes of transport and smoking. The movements of the sampled population are recorded to enable an assessment of the relative importance of different activities and places. Exposure data are further complemented with monitoring at a variety of indoor locations. The project assesses all environments that people experience as part of urban life.

3. Raising the awareness of citizens with regard to air quality in general and in particular to the impact of personal behaviour; Education of the public with respect to environmental issues is of prime importance for both citizens and policy makers. The use of the media to involve citizens in a scientific project enables greater understanding of how air pollution is a part of daily life. While smoking is known to cause higher exposures for both the smokers themselves and those proximate to this pollution source, it will be put in the context of exposures for people that commute to work when traffic levels are highest. The project compares how polluted the air is around a smoker compared to a non-smoking city commuter.

4. Support to decision making; The modelling and prediction of exposure to pollutants from air is important for the protection of human health. The relationship between outdoor air, indoor air and human exposure concentrations is needed for improved health impact assessments. The data from the project is applicable for estimation and validation of city scale exposure models. This approach indicates the significance of applying of control policies at both local and European scales. Where smoking is banned from indoor locations it reduces exposure to many pollutants.

5. Comparative assessment of the air pollution by benzene in various European cities; There are many factors that influence air pollution levels in a given city, for example meteorological conditions, emission sources, infrastructure, size and air quality management. Air quality and emission directives are important tools for reducing air pollution levels in European cities. The snapshot of the day in the life of the given city is placed in context with the pollution levels measured over a year.

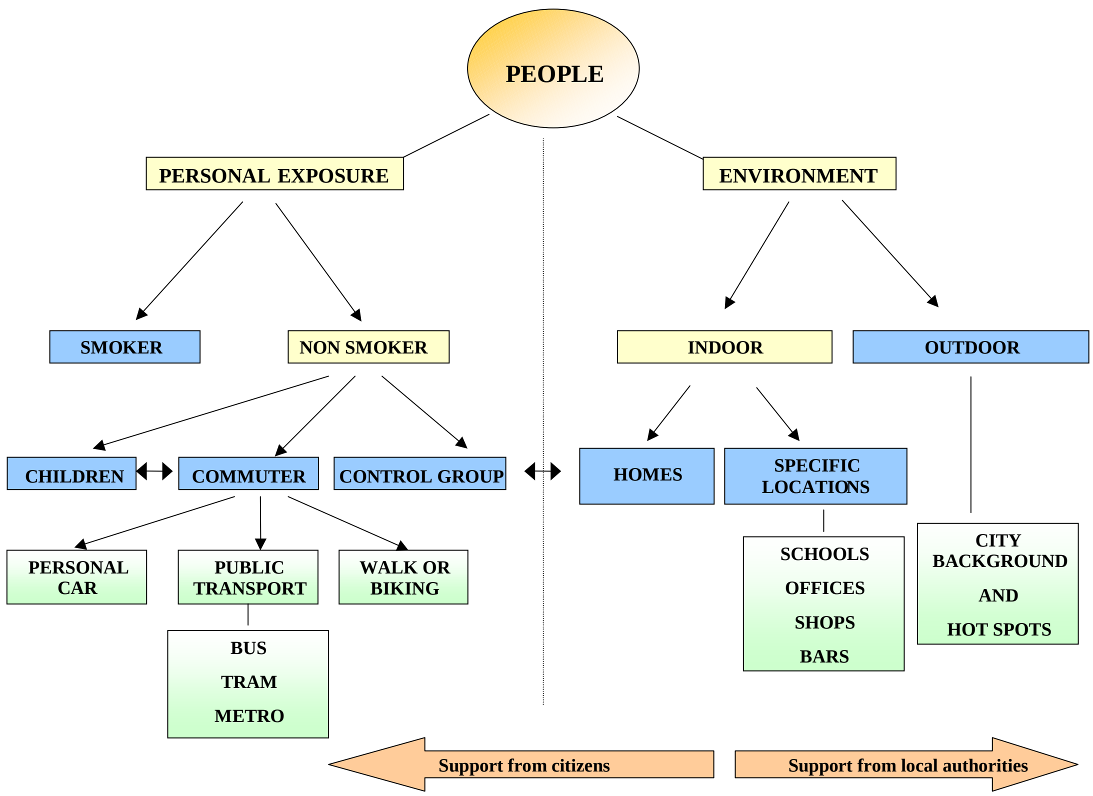


Figure 1.2.- Project schematic

1.3. Milestones and division of work

The following bullet points were the main project milestones:

- Definition of project with collaborating parties;
- Set-up and implementation of media campaign;
- Selection of environmental sites;
- Selection of personal exposure volunteers;
- Measurement campaign;
- Sampler analysis and QA/QC;
- Data analysis and interpretation.

The following milestone schematic indicates the timing of critical events required before, during and after the sampling campaign.

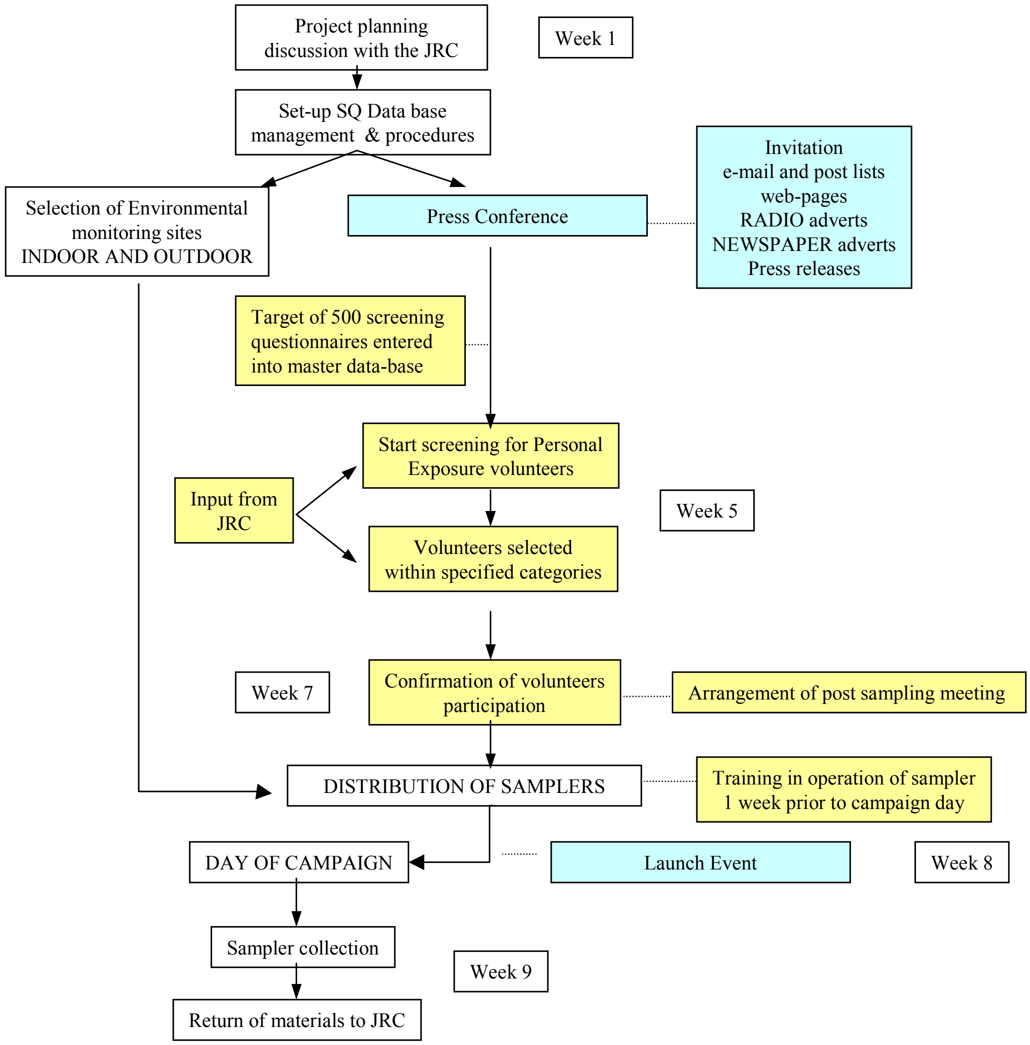


Figure 1.3.- Project milestones

The use of volunteers and the media as project partners is highlighted. These aspects were essential for the success of the project and required the set-up of a number of linked management activities.

1.3.1. Work performed by Emissions and Health Unit

- Overall project management;
- Supply of samplers and shelters;
- Selection criteria for volunteers;
- Data input for movement diaries;
- Analysis of samplers, validation and QA/QC of measurements;
- Final data ratification;
- Transport of materials to city project management;

1.3.2. Work performed by City project management

- City project management;
- Data input for screening questionnaires;
- Selection of volunteers using agreed criteria;
- Selection of environmental monitoring sites using agreed criteria;
- Informing volunteers how to participate using agreed criteria,
- Distribution and collection of samplers;
- Return transport of materials;
- Checking of data outliers.

1.3.3. Work performed jointly by Emissions and Health Unit and City project management

- Definition of project including sampler numbers and measurement categories;
- Interpretation of results;
- Organisation and co-ordination of press conferences.

2. MEASUREMENT STRATEGY

Benzene was sampled with a diffusive sampler that had been previously validated in laboratory experiments to control factors such as air humidity, temperature, wind velocity and pollutant concentrations. The estimated total uncertainty of the use of the samplers was calculated as ± 30 %. This measurement method is equivalent to the reference method of the EC directive (pumped sampling onto an adsorbent cartridge). The European Standardisation Committee has standardised methods based on diffusive sampling for the measurement of benzene in ambient air, which achieves the EC Directive criteria for fixed measurements [EN14662 (2005)].

The following are approximate sampler numbers for benzene measurements in each city:

- Personal Exposure 150 (25 in each of the following categories: Smokers, Control group, Personal car, Public transport, Walk/Biking and Children)
- Environments 110 (40 in city background, 50 in specific indoor locations and 25 in indoor homes)
- Quality control (10 travelling blanks)

The finer details were agreed upon depending on the data needs and structure of the participating city. For instance commuting by public transport in the city centre of Ljubljana is limited to buses, by contrast in Bucharest trolleybus, metro, tram and train are also options. The total number of samplers was circa 270 for each city.

2.1. Outdoor pollution and city background sampling

City background maps display the spatial distribution of the selected pollutant, in order to:

- assess pollution levels with respect to the established air quality standards;
- check or recommend locations suitable for use in air quality monitoring networks;
- yield data to assist in the assessment of human exposure of participating volunteers.

To meet these aims, it is necessary to assess:

- urban background concentration levels and their distribution over the city and at urban sites;
- level of pollution in a number of sites exposed to high traffic emissions (hot-spots).

Locating the sites for a city background mapping exercise required the derivation of a grid for the area of investigation. The grid consisted of cells that were sized to enable sufficient measurements considering variables such as population or traffic density. Most samplers were placed in the city centres. The grid size depended on the layout of the given city as well as meteorological conditions (wind direction, wind speed, atmospheric stability, etc.) and emission sources [Resolution Project, 2000].

Background sampling sites should be representative of "well mixed air" that is not unduly effected by variation in emission fluxes close to the selected site, but that represents emission flux across the whole of a given cell area. The concentrations determined at sampling sites can then be combined by interpolation techniques to yield iso-concentration contour maps. A common criterion of sampling site selection must be used. The following bullet points indicate the key steps for site selection:

- Collection of existing information on population density, traffic density and emission sources;
- Derivation of grid taking into account the maximum number of samplers to be installed;
- Selection of the location most representative of the background pollution in that cell;
- Priority should be given to well-ventilated locations, such as large squares or public parks;
- Sites along busy traffic roads or congested roundabouts should be avoided;
- If in the vicinity of busy roads, secondary streets perpendicular to the main road should be selected.

The following table indicates the relationship between traffic flow and distance required from road edge for a sampling location to be considered as a city background site for nitrogen dioxide (ADEME, 2002). This is useful as a guide for sampler placement. If traffic flow data are not available, estimation can be made.

Table 2.1.- Site Criteria for background monitoring

Vehicles per day	*Distance from road edge (metres)*
< 1000	-
1000 to 3000	10
3000 to 6000	20
6000 to 15000	30
15000 to 40000	40
40000 to 70000	100
> 70000	250

2.1.1. Micro-sitting criteria

Samplers should be exposed inside supplied shelters that are designed to protect the sampler from rain. The presence of water can lead to the formation of a thin film of water on the diffusive surface of the sampler and prevent it from functioning properly.

The shelter and sampler should be affixed to surfaces that allow free circulation of air around the container. Metal poles (e.g. lamp-posts) are the best choice, except when they are located close to buildings, avoiding those treated with tar. The use of trees is not recommended. Samplers should be placed consistently at a height of 3 - 4 m. It is preferable for the samplers to be placed on the North side of the pole; in summer this mitigates sunlight driven heating of the shelter and thus sampler. It is important to avoid contamination of the sample due to the proximity of surfaces capable of adsorbing or emitting contaminants. A distance of 1 m away from any building or similar obstacle is preferred.

If samplers are to be placed for instrument inter-comparison, then the sampler should be attached as close as reasonably possible to the inlet point of air for the sampling duct of the given instrument. The diffusive samplers should be transported in the supplied individual airtight glass vials, to avoid accidental contamination.

2.1.2. Sampler installation, collection and storage

The micro-site selection and the installation of the shelters should be performed before the start of the survey. It is important that the sampler position is known for deriving an iso-concentration contour map. The samplers should be mounted within the same hour, thus attempting to, as far as possible, maintain the same sampling period for all samplers.

The following bullet points indicate the key steps for placing samplers:

- Installation of the samplers during early morning on sampling day (reduced traffic) and collection the day after at the same time.
- The teams responsible for sampler and shelter installation and collection should be composed of a driver and one or two operators;
- The shelters should be installed on the sampling day, if sufficient teams are available and if theft is expected to be a problem. It should be noted that an experienced team will only be able to mount 6 sets of shelters and samplers in one hour;
- It is essential that the operator is equipped with sampling forms that allow the recording of sampler codes, site number, site address, site description and sampling start and end times;
- Use of the same teams and sequences for sample installation and collection is recommended;
- Transport and storage must be performed in the provided glass container and sampler bag (See section 2.4.2).

2.1.3. Urban boundary sampling

A number of additional sampling sites will be selected in the area surrounding the city centre (suburban zone), in order to assess pollution levels in those locations and set the limit of the area considered. These sites should follow the same sampling protocol.

2.1.4. Hot-spot sampling

Background air maps represent ambient concentrations that are associated with well-mixed air. These locations are by definition, as previously indicated, not close to emission sources. It is however also important to gather information on concentrations at locations close to large emission sources, for example busy road intersections or next to standing traffic sites. Measurements at such hot-spots represent maximum urban levels and are usually performed at roads with the highest traffic density in each city (main access roads, busy roundabouts). The traffic density, expressed in average number of cars per day, should be well documented in order to allow some generalization of the measurements to other sites. These sites are not used for mapping. The micro sampling criteria should be respected.

2.1.5. Supplementary information requirements

The following information is required for the sampling day (daily and hourly averages):
- Meteorological data (including wind speed, wind direction, temperature, solar radiation, relative humidity, precipitation);
- Air pollution data;
- Coordinates of sampling sites.

The following information is required from the previous year (monthly and annual averages):
- Meteorological data (including wind speed, wind direction, temperature, solar radiation, relative humidity, precipitation);
- Air pollution data;
- Traffic flow data;
- Characteristics of vehicle fleet: including distribution of vehicle type, vehicle age, fuel type and vehicle speed;
- Population density.

2.2. Indoor Pollution

2.2.1. Homes

The volunteers from the human exposure control category placed samplers in their homes. Nevertheless, in some cities (i.e. Brussels and Ljubljana) homes from other categories were also sampled.

2.2.2. Specific locations

The siting and selection of specific indoor environments was reasonably flexible with respect to local conditions. The selection was by the city project management and aimed to find positions that were representative of the location.

2.3. Human exposure

Human exposure participants were selected according to well defined criteria, set by activities: non-smoking citizens not exposed to automotive sources (control group), smokers, commuters using a personal car as transport means, commuters using various modes of public transport, and commuters using a bike or only walking. The definition of these categories was dependent upon the infrastructure of the city considered. In some cities groups of school children were also included as a category. To determine the influence of commuting upon a baseline condition, it was necessary to control the influence of smoking. Potential volunteers were screened to ensure that they were non smokers and also worked in smoke-free offices. As the project aimed to measure exposure in genuine conditions, some influence of passive smoking was anticipated. While the assessment of the effect of smoking was not a project objective, a smoking category was included in order to discriminate that effect. Most volunteers commuted from home to work and back again after working at an office location.

2.3.1. Human exposure categories

Control

This category acted as the baseline for consideration for the project. This category excluded persons that were affected by smoke and transport activity apart from some walking. Their daytime location was usually inside a house.

Commuters

There were three main categories for commuters: Personal Car; Public Transport; and Walk/Biking.

The stipulation for inclusion was that the given mode of transport is used. This category excluded persons that were affected by smoke Workplace location was usually inside an office.

School children

Children that attended school and were able, either with or without supervision, to complete a movement diary for the sampling period were selected.

Smokers

This category included people who smoked cigarettes or cigars during the sampling period. These volunteers were usually commuters.

The main categories for monitoring human exposure were as follows; control; personal car commuters; public transport commuters (Bus, train, tram, metro); walk or bicycle commuters; school children; and smokers.

The volunteers that were selected into the different personal exposure categories were chosen on the basis of responses to a screening questionnaire. The volunteers were asked to participate through either direct invitation or advertisements. The selection criteria were based on an analysis of the screening questionnaire responses.

2.3.2. Screening questionnaire methodology

The screening questionnaire is given below. The questionnaire was sent to the city management protocol by either: (i) mail, (ii) internet, (iii) telephone or (iv) in person. It was important to enter responses into the database as soon as possible after receipt. The database was sent at regular intervals to determine if the anticipated categories were likely to be achieved. Upon receipt, the responses to each question were entered into a spreadsheet file. The responses were input into a spreadsheet file with the following structure:

Question 1	1 or 2;
Question 2:	age;
Question 3:	specified job title;
Question 4a:	1 or 2 or 3 or 4 or 5 or 6;
Question 4b:	specified location is input according to written response unless 1 is circled then the code "home" is used;
Question 5:	each of the 7 options is input separately (i.e. 7 rows);
Question 6:	distance is coded in km;

Question 7: each of the 5 options input separately (e.g. 5 rows);
Question 8a: 1 or 2;
Question 8b: cigarettes smoked;
Question 9: 1 or 2;
Full Name; Home Address and postcode; Work Address and postcode; Email Address; Home Telephone; Work Telephone; Designation.

PEOPLE project screening questionnaire

Please circle the correct answer and/or fill in the answer (______).

1. Sex: 1 male 2 female **2. Age: (____) 3.Occupation ____________________________**

4. On a weekday between 8 AM and 8 PM I usually spend most of my time:

1 in my own home
2 in one room in a building (e.g. office) specify ____________________________
3 in one building (e.g. school) specify ____________________________
4 outdoors (e.g. construction) specify ____________________________
5 moving in traffic (e.g. delivery driver) specify ____________________________
6 non of the above, where? specify ____________________________

5. On a weekday how much time do you spend travelling using the following?

1 walk (or run), ______ mins.
2 bicycle, ______ mins.
3 motorbike (or scooter), ______ mins.
4 car (or taxi/van), ______ mins.
5 bus, ______ mins.
6 metro, (underground), ______ mins.
7 train ______ mins.

6. Distance approximately from your workplace to your home: ________________ km.

7. On a usual weekday between 8 AM and 8 PM I usually spend my time (12 hours):

1 At home before and after work ____ hour(s)
2 Travelling to work ____ hour(s) and from work ____ hour(s)
3 at work ____ hour(s)
4. Other ____ hour(s)

8. **a) Are you smoker?** 1 yes 2 no
b) How many cigarettes or cigars do you smoke a day? ________

9. Do you share a room at home or work with smokers? 1 yes 2 no

---

If you want to participate in the PEOPLE project, please inform us by completing some or all of the following so that we can contact you

Full Name: ____
Home Address and Postcode: ____
Work Address and Postcode: ____
Email Address:___________________________ Home Telephone: ____________________
Work Telephone: ____________________
Thank you for your help

Figure 2.3a.- Volunteer screening questionnaire

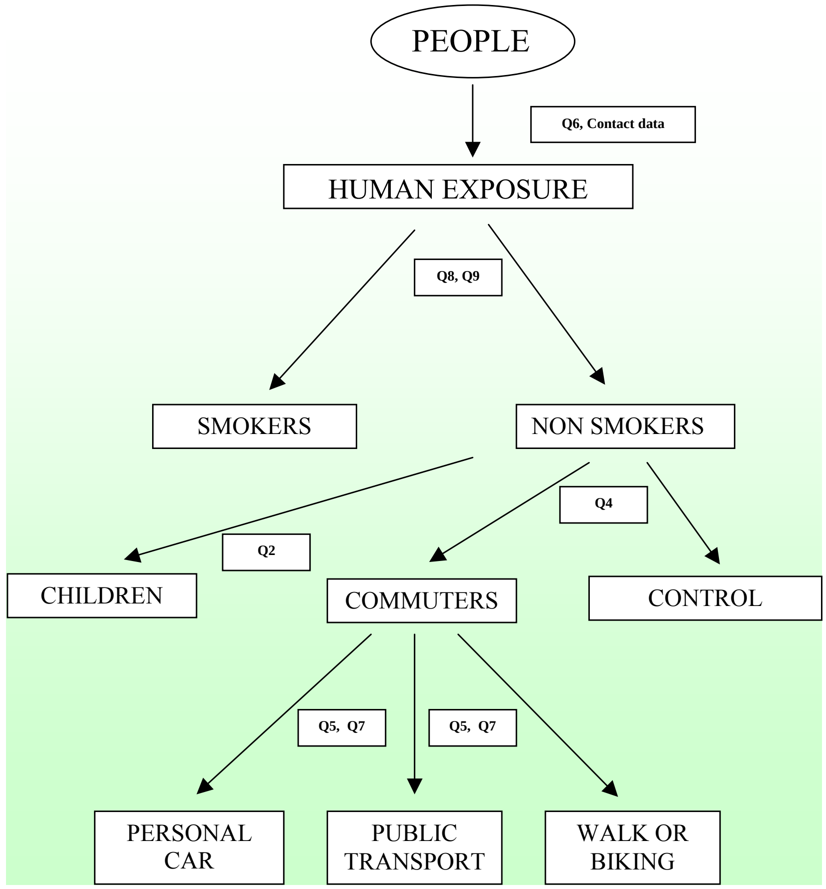


Figure 2.3b.- Flow path for defining sampling category participants

Application of questions to select participants

Questions 1, 2 and 3 were designed to collect information to ensure that the volunteers were reasonably representative of the general population. Questions 6 and final contact data were included to ensure that volunteers are travelling within the area of interest and are reasonably evenly distributed over the city. It also allowed the possibility of straight line mapping of journeys. Question 4 gave the work location type for the volunteer. Office workers were usually selected. Question 5 gave information on the various transport modes that were anticipated to be used, as well as travel time. This question was purposely not framed as transport to or from work. In this way we understood the total transport related activity for the whole exposure period and also if one transport mode dominates or not. This was undertaken as an attempt to get volunteers that did not have excessive mixing of transport modes, i.e. personal car commuters should not go on buses, etc. This question placed volunteers into the various personal exposure categories. Question 7 was designed to determine the length of time the volunteer spent in travelling to and from work. This was used in combination with questions 5 and 6. Questions 8a and 8b were used to determine smoking behaviour. Question 9 was to determine if volunteers were affected by passive smoking.

Assessment of screening questionnaire data-base

The data-base assigned a unique number to each person who replies to a entered screening questionnaire. Approximately 500 were required in each city. From this pool, 125 personal exposure volunteers were chosen to meet the project design. Volunteers were included or excluded from the study according to clear guidelines. Initially, broad exclusion and inclusion criteria were applied. Then, dependent on the numbers of possible volunteers that remained from this procedure, decisions regarding finer criteria were added. The aim was to separate people into distinct categories.

The data-base was assessed for the primary inclusion and exclusion of volunteers. The first sweep removes those people that are heavily influenced by passive smoking. These volunteers were copied into a file named "passive". Next the smokers were removed. These volunteers were copied into a file named "smoker". Next the people that did not commute were removed. These volunteers are copied into a file named "control". This file underwent further screening in particular with respect to amount of walking and daytime location. Next, depending on the number of commuting people further criteria were applied to gain some homogeneity of day-time location. Next, the commuting people were separated into distinct categories. This process of sorting depended on a number of factors including the given commuting behaviour. In most cities, at least three distinct categories were identified.

Designation of commuting mode

The actual protocol for defining the different categories could only be decided upon after investigation of the data base. The categories given earlier represent the expected position for the sampling strategy. Question 5 was designed to reflect the expected main modes of transportation in the given city. When the data base was formed, it was useful to give each person a designation, as indicated below, defined by the answer to question 5 within the master file, e.g. column given term DESIG. The possible responses derived from question 5 are given below:

WALK if they only travel to work by "walk".
BIKE if they only travel to work by "bicycle" or "bicycle plus walk".
MOTORBIKE if they only travel to work by "motorbike" or " motorbike plus walk".
CAR if they only travel to work by "car" or "car plus walk".
BUS if they only travel to work by "bus" or "bus plus walk".
TRAIN if they only travel to work by "train" or "train plus walk".
TRAM if they only travel to work by "tram" or "tram plus walk".
METRO if they only travel to work by "metro" or "metro plus walk".
PUBLIC TRANSPORT if besides walking they travel to work using combinations of different modes of public transport.
MIXED if besides travel by car (and walk) they also travel using one or more other forms of transport

The screening questionnaire data-base files were filled by the city project management, and then emailed to the JRC. Recommendations were then given for the criteria to be applied for selection of different exposure categories. The city project management and JRC together then selected the actual volunteers. If there was a wide choice within the given criteria then tertiary criteria were sometimes applied; for example geographical location of home and work.

2.4. Volunteer training

Once a range of possible volunteers was agreed upon the potential volunteers were contacted to check if they are still interested in taking part in the project. If the volunteer was able to participate, the following arrangements needed to be made:

- A time to meet to receive the sampler and instructions.
- A time to meet to return the sampler and movement diary.

For the distribution of the personal exposure samplers and explanation on how to participate, three general approaches were identified:

Information Day:	On the Saturday prior to sampling, volunteers were invited to attend a large meeting at the offices of the city project management.
Individual Meeting:	At a pre-determined time the volunteers met designated personnel at the offices of the city project management.
Individual Visit:	At a pre-determined time designated personnel visited the homes or offices of the volunteers.

The control category was also required to place samplers inside their homes. Sampling was performed according to the step by step instructions outlined below. It was of special importance that the volunteers recorded the following, ensuring that the duration sampling on the sampling tube and the movement diary matched :

- The start and end times of sampling;
- The start and end times of the movement diary.

Prior to the sampling day the volunteers were shown a sampler, and received a demonstration of how the sampler was assembled as well as how to use the movement diary. On the campaign day the sampler was attached prior to leaving the home. Upon return to the home the sampler was subsequently detached and stored, as directed. The time of sampling was approximately 12 hours, but not less than 11 hours. More than 12 hours was acceptable as it was important that the journey to work and the return journey home were sampled.

2.4.1. Explanation of how to use the movement diary

The movement diary, shown below, was used to follow the movements and locations of people while wearing the sampler. This enabled an estimation of travel time within specified modes of transport, as well as times inside and outside of different buildings or locations. The text below was given to volunteers with the movement diary; sampler and sampling instructions were also distributed.

Travelling:

When you move from one place to another, including going for a walk or taking a roundtrip.

Walk:	By walking or running.
Bicycle:	By bicycle, roller-blades or roller-skates.
Motorbike:	By motorbike or scooter.
Car:	By car, taxi or van.
Bus:	By bus.
Train:	By train.
Tram:	By tram
Metro	By metro or underground

Inside:

When you stay in the same place indoors.

Home :	Rooms inside the house or flat where you live
Work:	Rooms or closed indoor locations where you work
Café or Bar:	Inside a bar or café
Shops:	Inside a shop or shopping centre
Restaurant:	Inside a restaurant
Other In:	Other specified indoor locations, e.g. indoor ice rink or dentist surgery

Outside:

When you stay in the same place outdoors.

Street :	Stationary on a street or road, e.g. outside at a café
Park:	Staying within a park
Other Out:	Other specified outdoor locations, e.g. garden or balcony

Smoking:

If one or more of the following events happens during a 15 minute period:

Self	When you smoke a cigarette, cigar, pipe etc.
Same Room	When somebody near you, inside a closed space, smokes a cigarette, cigar, pipe. Also a room where you can smell smoke.

The recording of smoking information was independent from the recording of movement or location. An "Inside" or "Outside" location is noted when a volunteer is stationary at some place or does not leave a specified location. "Travelling" is moving from one place to another. Since the diary was only used for one working day, accurate time recording was encouraged. For smoking it was assumed that only 1 cigarette is smoked in one 15 minute period; if more are smoked then this was indicated next to the relevant position with the number smoked, e.g. 2. The same applied for smoking with respect to "same room", i.e. if three people are smoking apart from the volunteer, then the bubble would be marked with the number 3 written next to the relevant time circle.

Volunteers filled in the time circles. Mistakes were noted by placing a cross over the error. At least one location was specified for each 15 minute period. It was, however, acceptable to mark more than one circle within 15 minutes. Volunteers could connect bubbles with lines if they stayed for more than 15 minutes at the same location or performed the same activity (e.g. inside office during the morning). It was important that the movement diaries were only completed for the duration of sampling. The data from the movement diary were entered into a spreadsheet data-base file.

Together with the sample kit the following information regarding the handling of the sampler and the movement diary was given to the volunteers.

2.4.2. Handling and using the Sampler Kit

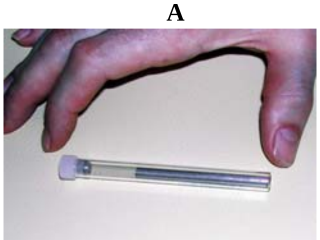
- Read the instructions to check everything is clear.
- When handling the sampler kit ensure that your hands are clean and dry.
- Do not assemble or disassemble the sampler when smoking or in a smoke filled room.
- Avoid handling the yellow membrane and the mesh tube as much as possible as they work best when clean.
- Always wear the sampler on the outer layer of clothing and do not blow smoke onto the sampler.

Using the Sampler Kit

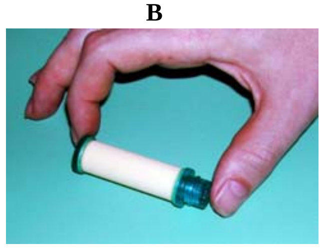
Remove sampler kit from storage bag. You should have the following:

- A glass tube with a white end cap containing a metallic mesh tube (A).
- A yellow (or white) tube with blue end cap (B).
- A blue triangular base plate with clip, sheaf containing a white label and white mounting arm (C).

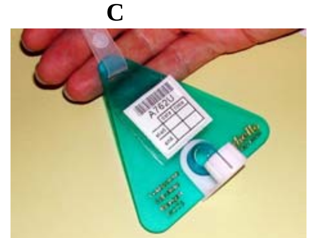
A



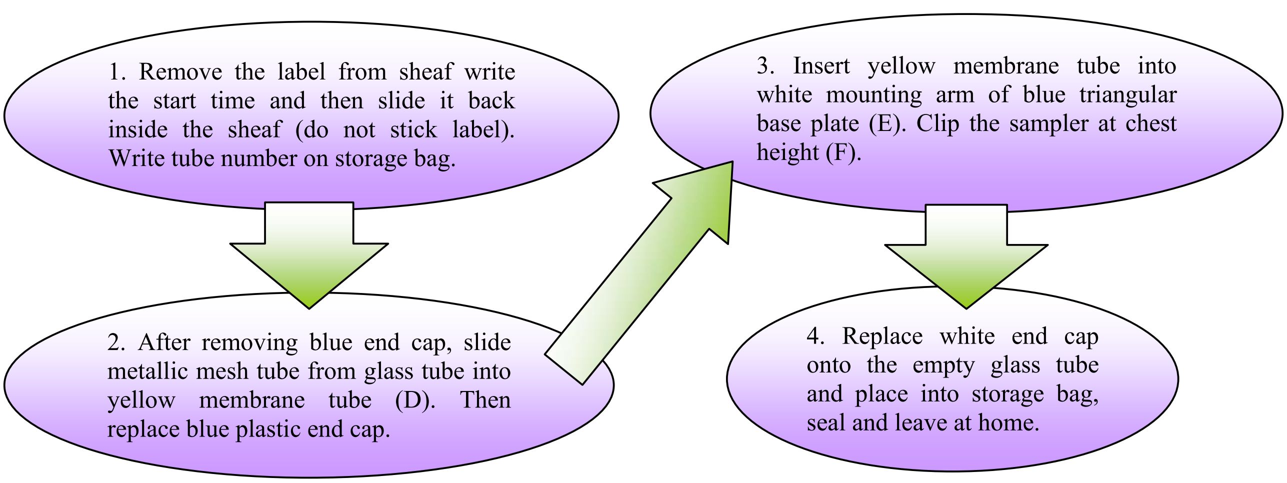
B



C



To assemble the sampler, please follow the instructions given below:



D	E	F
		

To complete sampling**,** please follow the instructions given below:

5. Write the end time on the white adhesive label, peel and place around the glass tube. Reverse the assembly process.

6. It is essential that the metallic mesh tube is sealed inside the glass tube. Fold completed movement diary and place in the sampler kit bag. Ensure that the bag is sealed

2.4.3. Completing the Movement Diary

To complete the movement diary you need to do the following:

- Fill in the circle or circles that correspond to either your activity or location
- You may fill in up to 3 circles for each 15 minute block of time
- If you make a mistake cross the relevant circle.

A portion of the diary day is given below as an example. After installing the sampler at 7.45h, the person remained at home for 15 minutes (until 8.00h). After that the person walked for 15 minutes to a bus stop (8.15h). After waiting at the bus stop for 7.5 minutes, the person travelled by bus for 30 minutes. After disembarking from the bus the person walked for 7.5 minutes, smoked a cigarette, and at 9:00h arrived at the workplace where the person remained inside for the next 60 minutes until 10.00h.

		TRAVELLING					**INSIDE**						**OUTSIDE**			**SMOKING**	
		Walk	**Bus**	**Train**	**Metro**	**Other ***	**Home**	**Work**	**Café Bar**	**Shops**	**Restau- -rant**	**Other ***	**Street**	**Park**	**Other ***	**Self**	**Same room**
7	0	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
	15	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
	30	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
	45	❍	❍	❍	❍	❍	●	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
8	0	●	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
	15	❍	●	❍	❍	❍	❍	❍	❍	❍	❍	❍	●	❍	❍	❍	❍
	30	❍	●	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
	45	●	●	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	●	❍
9	0	❍	❍	❍	❍	❍	❍	●	❍	❍	❍	❍	❍	❍	❍	❍	❍
	15	❍	❍	❍	❍	❍	❍	●	❍	❍	❍	❍	❍	❍	❍	❍	❍
	30	❍	❍	❍	❍	❍	❍	●	❍	❍	❍	❍	❍	❍	❍	❍	❍
	45	❍	❍	❍	❍	❍	❍	●	❍	❍	❍	❍	❍	❍	❍	❍	❍

3. RESULTS

3.1. Brussels

On 22 October 2002, citizens of Brussels participated in the project. The project was performed in conjunction with the Institut Bruxellois pour la Gestion de l'Environnement du Ministère de l'Environnement de la Région de Bruxelles-Capitale (IBGE/BIM).

3.1.1. Outdoor pollution levels

Measurements were performed at a number of urban sites to assess the levels and the distribution of benzene over the city. The city background concentration of benzene measured at 13 sites ranged from 1.5 µg/m^3 to 6.2 µg/m^3 on the day of the campaign, as represented in Figure 3.1a, with a median value of 2.5 µg /m^3.

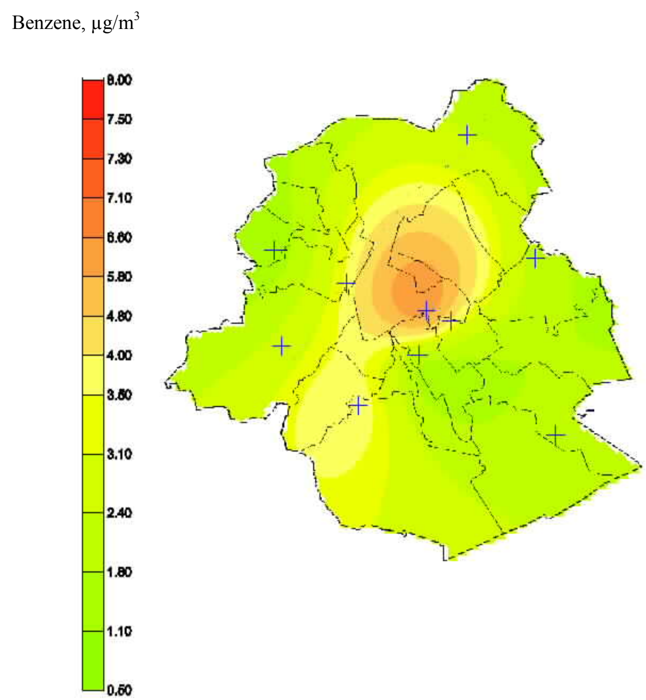


Figure 3.1a.- Benzene concentrations levels in Brussels on the day of the campaign (22 October 2002)

In Brussels, higher concentrations corresponded to the area between Arts-Loi and place Schuman, rue de la Loi and rue Belliard. This area is characterised by dense and bottlenecked traffic. The day of the campaign was consistent in spatial terms with previous longer term monitoring at the city. These results were as expected, according to the traffic profile of Brussels.

3.1.2. Indoor pollution levels

Since many people generally spend most of the day inside buildings, benzene levels were measured in a number of typical indoor locations (Figure 3.1b).

Homes: Benzene concentrations were measured in the homes of 52 citizens. The median value of 6.3 µg/m^3 was twice that of the city background air. However, when indoor sources, including tobacco smoke were not present, the outdoor levels determined the measured concentrations at these locations.

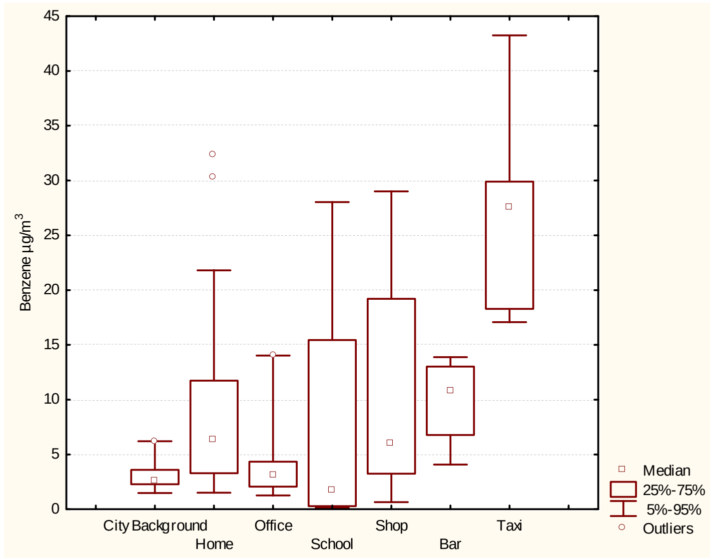


Figure 3.1b.- Indoor and outdoor pollution levels on the day of the campaign. Brussels (22 October 2002)

Offices and schools: In 18 offices and 4 schools, where tobacco smoke was absent, median benzene values of 3.0 µg/m^3 and 1.6 µg/m^3 were calculated. The median value for offices is comparable to the corresponding city background value.

Bars and shops: In 4 bars and 10 shops, where tobacco smoke may be present, the median benzene values of 6.0 µg/m^3 and 10.8 µg/m^3 were higher than the corresponding city background value.

Taxis: The highest values of benzene concentration were found inside taxis. The median value of 27.5 µg/m^3 was derived from 5 measurements. Taxis frequently travel through areas with high levels of pollution, hot-spots, and as such are locations that are affected by close proximity to traffic emissions.

3.1.3. Human exposure

The human exposure measurements represent an estimate of the average concentrations to which a citizen is exposed. Figure 3.1c illustrates the categories that were selected as typical for the city of Brussels.

Control group: The control group in the study, with 2 non-smoking citizens, had the lowest median level of benzene exposure with a value of 2.6 µg/m^3. This was expected, as these volunteers did not commute to or from work. If they spent time moving outside they did so by walking. This mode of travel was limited by study design, to an hour and usually less, in order to reduce any bias that may be caused by proximity to emissions from traffic.

Smokers: The smoking category, with 15 participants, had the highest median level of benzene exposure with a value of 7.5 µg/m^3. Variation in concentration levels are expected with both the number of cigarettes smoked and on the confinement space (e.g. indoor, outdoor). The exposure value of benzene that was determined for smokers corresponds to their surrounding area. The inhaled concentration of pollutants when smoking can be expected to be an order of magnitude higher than that measured in the air surrounding the smoker direct vicinity of the smoker.

Commuters: In situations without smoking or other indoor pollution sources, commuting is the main factor affecting human exposure in cities where the main emission source is traffic. The car user category had a median benzene value of 5.0 µg/m^3 derived from 29 samples. The walk and bicycle (bike) category, with 4 and 15 participants respectively, had a median benzene value of 5.1 µg/m^3 and 4.8 µg/m^3 respectively. The median benzene value for the public transport category was 3.9 µg/m^3. The 6 participants in this category travelled using a mixture of bus, tram and metro. Separate categories for bus and metro users were also used. The exposure level was higher for bus users compared to metro users. The median benzene value of 7 bus users, 4.5 µg/m^3, was higher than the corresponding value of 3.6 µg/m^3 for 8 metro users.

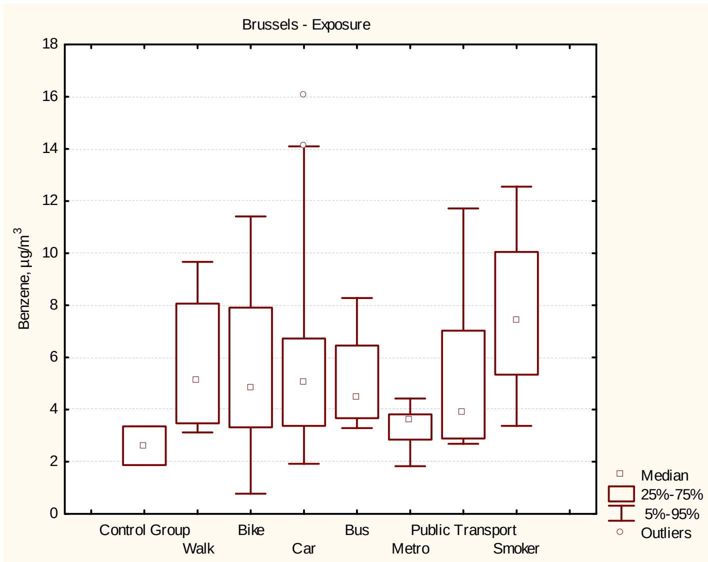


Figure 3.1c.- Personal exposure levels on the day of the campaign. Brussels (22 October 2002)

3.1.4. Outlier and extreme values

Outliers were considered as values that were 1.5 times higher than the 75th percentile of the given group. Extremes were considered as values that were 3 times higher than the 75th percentile of the given group. Extreme values were not included in the calculation of the median values and were considered as not representative of the given sample of population. The values and groups from which they were removed are given below in Table 3.1.

Table 3.1.- Extremes for Brussels

Type	*Benzene concentration (µg/m^3)*
Control Group	27.4
Car user	23.0
Car user	19.5
Smoker	57.3
Home	56.9
Home	68.5
Home	43.2
Office	34.2
Office	96.0*****

**Please note that besides statistical exclusion, values above 75 µg/m^3 were extrapolated from the calibration curve and as such should be considered as estimates.*

While the results presented in Figures 3.1b and 3.1c are representative of typical conditions, there are occasions when individuals or locations report higher levels than expected. While extremes are not considered in the results they are valid measurements in terms of analytical procedures. They often reflect problems of exposure to situations with high pollution levels.

3.2. Lisbon

On 22 October 2002, citizens of Lisbon participated in the project. The project was performed in conjunction with the Institute for the Consumer (IC), Presidency of the Council of Ministers. Other entities participating were the Regional Administration of Environment and Land Use Planning for Lisbon and Tagus Valley (DRAOT-LVT); the Ministry of Cities, Land Use Planning and Environment (MCOTA); the Department of Environmental Sciences and Engineering (DCEA); the College of Science and Technology, the New University of Lisbon (FCT-UNL); the Public Health Regional Centre for Lisbon and Tagus Valley, the Ministry of Health (CRSP-LVT, MS); the City Department for Environment and Green Spaces, the Lisbon Municipality (DMAEV, CML); the National Association for the Conservation of Nature (QUERCUS), and the Research Centre on Information Technology and Participatory Democracy (CITIDEP).

3.2.1. Outdoor pollution levels

Measurements were performed at a number of urban sites to assess the levels and the distribution of benzene over the city. The city background concentration of benzene, measured at 54 sites, ranged from 1.8 µg/m^3 to 7.9 µg/m^{3}on the day of the campaign (as represented in Figure 3.2a) with a median value of 3.8 µg /m^3.

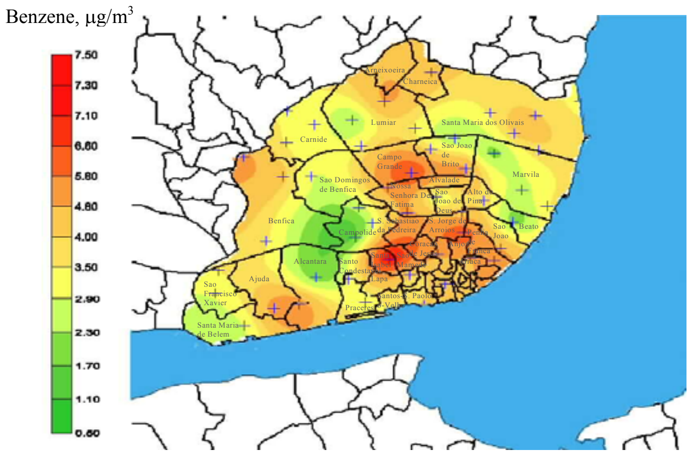


Figure 3.2a.- Benzene concentration levels in Lisbon on the day of the campaign (22 October)

City background sites were distant from busy roads. Measurements in areas of high traffic density revealed higher values. In Lisbon, higher concentrations corresponded to the area between Santa Isabel and Coraçao de Jesus, between S. Jorge de Arroios, Anjos and Penha de Franca, and Campo Grande. The day of the campaign was consistent in spatial terms with previous longer term monitoring at the city. These results were as expected, according to the orography and traffic profiles of Lisbon.

3.2.2. Indoor pollution levels

Since many people generally spend most of the day inside buildings, benzene levels were measured in a number of typical indoor locations (Figure 3.2b).

Homes: The median benzene concentration value of 3.5 µg/m^3 for 18 homes of the control group was similar to the corresponding value for city background air. As expected when indoor sources were not present, the outdoor levels determine concentrations at these locations.

Schools: The highest values reported at schools corresponded to particular situations; in one case a workshop classroom, and in another a teachers' common room. Despite these cases, the median value of 4.2 µg/m^3 from the 9 sampled schools is similar to other indoor environments.

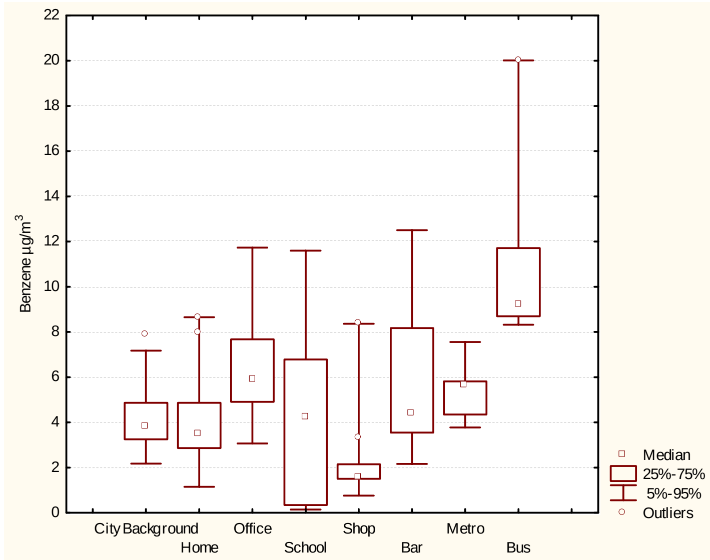


Figure 3.2b.- Indoor and outdoor pollution levels on the day of the campaign. Lisbon (22 October 2002)

Shops, bars and offices: The relatively low median benzene concentration of 1.6 µg/m^3 from 9 shops may be explained by the selection of "clean shops", such as pharmacies, where smoking is prohibited. Nevertheless, in bars and offices where tobacco smoke was often present, the levels were higher. Based on 8 bars and 10 offices, median values of 4.4 µg/m^3 and 5.9 µg/m^3, respectively, were obtained. Over 50% of office workers reported the influence of passive smoking at work.

Metro and buses: The median value of 5.7 µg/m^3 from the 5 sampled metro stations was similar to other indoor environments. The highest values of benzene concentration were found inside buses. The median value of 9.2 µg/m^3 was derived from 4 measurements. Buses frequently travel through areas of high levels of pollution, hot-spot areas, and as such are affected by close proximity to traffic emissions.

3.2.3. Human exposure

The human exposure measurements represent an estimate of the average concentrations to which a citizen is exposed. Figure 3.2c illustrates the different groups that were selected as typical for the city of Lisbon.

Control group: The control group, with 17 non-smoking citizens, had the lowest median level of benzene exposure with a value of 3.0 µg/m^3. This was expected, as these volunteers did not commute to or from work. If they spent time moving outside they did so by walking. This mode of travel was limited by study design, to an hour and usually less, in order to reduce any bias that may be caused by proximity to emissions from traffic.

Smokers: The smoking category, with 23 participants, had the highest median level of benzene exposure with a value of 6.8 µg/m^3. Variation in concentration levels are expected with both the number of cigarettes smoked and on the confinement space (e.g. indoor, outdoor). The exposure value of benzene that was determined for smokers corresponds to their surrounding area. The inhaled concentration of pollutants when smoking can be expected to be an order of magnitude higher than that measured in the air surrounding the smoker (CONCAWE,1999). Therefore, the smoking group could represent the level of exposure for passive smokers in the direct vicinity of the smoker.

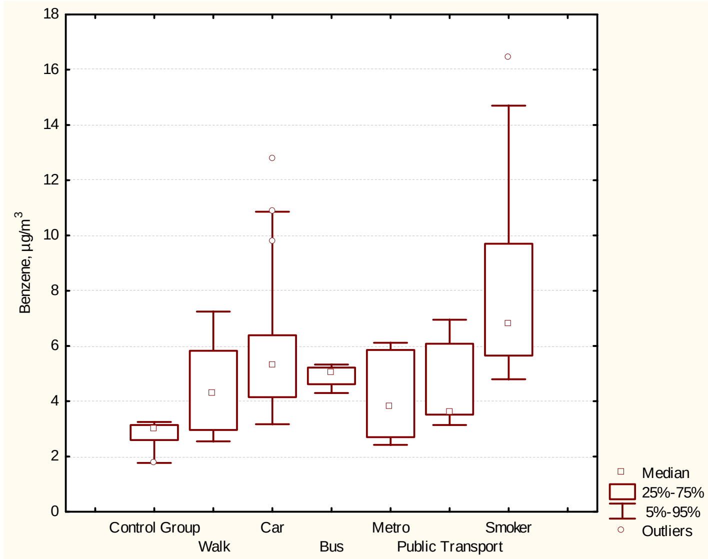


Figure 3.2c.- Personal exposure levels on the day of the campaign. Lisbon (22 October 2002)

Commuters: In situations without smoking or other indoor pollution sources, commuting is the main factor affecting human exposure in cities where the main emission source is traffic. Amongst the categories of commuters, the car user category had the highest level of exposure, with a median value of 5.3 µg/m^3 derived from 29 samples. The walk category, with 11 participants, had a median benzene value of 4.3 µg/m^3. For the public transport category the median benzene value was 3.6 µg/m^3. The 7 participants in this category travelled using a combination of bus, tram and metro. Separate categories for bus and metro users were also used. The exposure level was higher for bus users compared to metro users. The median benzene value of 4 bus users, 5.0 µg/m^3, was higher than the corresponding value of 3.8 µg/m^3 for 8 metro users.

3.2.4. Outlier and extreme values

Outliers were considered as values that were 1.5 times higher than the 75th percentile of the given group. Extremes were considered as values that were 3 times higher than the 75th percentile of the given group. Extreme values were not included in the calculation of the median values and were considered as not representative of the given sample of population. The values and groups from which they were removed are given below in Table 3.2.

Table 3.2.- Extremes for Lisbon

Type	*Benzene concentration (µg/m^3)*
Control Group	6.0
Control Group	6.7
Control Group	6.7
Control Group	6.8
Car user	18.5
School	26.9
Shop	31.9

While the results presented in Figures 3.1b and 3.1c are representative of typical conditions, there are occasions when individuals or locations report higher levels than expected. While extremes are not considered in the results they are valid measurements in terms of analytical procedures. They often reflect problems of exposure to situations with high pollution levels.

3.3. Bucharest

On 27 May 2003, citizens of Bucharest participated in the project. The project was performed in conjunction with the Institute of Public Health of Bucharest of the Romanian Ministry of Health.

3.3.1. Outdoor pollution levels

Measurements were performed at a number of urban sites to assess the levels and the distribution of benzene over the city. The city background concentration of benzene in Bucharest ranged from 4.7 $\mu g/m^3$ to 14.1 $\mu g/m^3$ on the day of the campaign, as represented in Figure 3.3a, with a median value of 7.1 $\mu g/m^3$. While the 13 city background sites sampled the air in park locations, measurements closer to traffic at hot-spot sites revealed higher values of 16.0 $\mu g/m^3$ and 18.2 $\mu g/m^3$.

Figure 3.3a.- Benzene concentrations levels in Bucharest on the day of the campaign (27 May 2003)

Measurements from a monitoring station that was set-up for the project and operated over the period between March 2003 and March 2004, showed that the pollution level on the day of the campaign was below average, and corresponded to the 45th percentile value of the concentration distribution over the measured year.

3.3.2. Indoor pollution levels

Since many people generally spend most of the day inside buildings, benzene levels were measured in a number of typical indoor locations (Figure 3.3b).

Homes: The median benzene concentration value of 7.9 $\mu g/m^3$ for 30 homes of the control group was similar to the corresponding value for city background air. As expected when indoor sources were not present, the outdoor levels determine concentrations at these locations.

Offices and shops: The median benzene value, from measurements in 6 offices, of 10.3 $\mu g/m^3$ was higher than the corresponding value for city background air. In the two shops monitored, the influence of tobacco smoke was suspected and the median benzene value of 22.5 $\mu g/m^3$ was three times higher than the corresponding city background levels.

Bar and school: Only one bar and one school were included in the study. The benzene concentration levels of 17.7 µg/m^3 and 4.6 µg/m^3, respectively are probably related to tobacco smoke that is present at the bar and absent at the school.

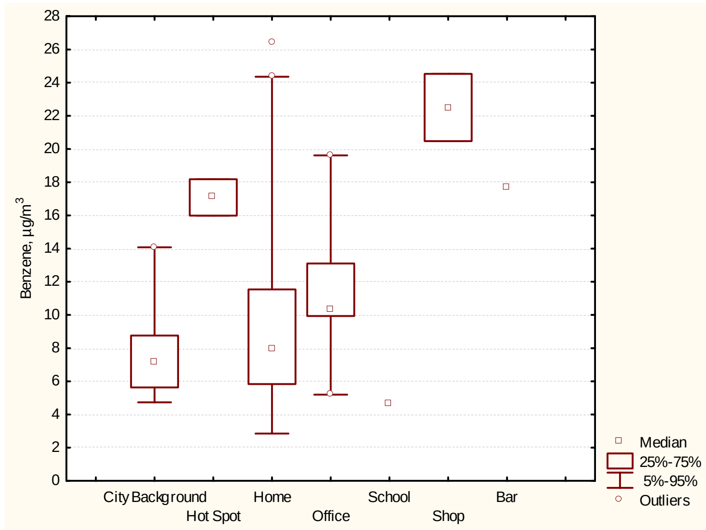


Figure 3.3b.- Indoor and outdoor pollution levels on the day of the campaign. Bucharest (27 May 2003)

3.3.3. Human exposure

The human exposure measurements represent an estimate of the average concentrations to which a citizen is exposed. Figure 3.3c illustrates the different groups that were selected as typical for the city of Bucharest. For Bucharest another category of personal exposure, school children, were included in order to determine if their exposure was comparable to adults.

Control group: The control group, with 12 non-smoking citizens, had the lowest median level of benzene exposure with a value of 11.3 µg/m^3. This was expected, as these volunteers did not commute to or from work. If they spent time moving outside they did so by walking. This mode of travel was limited by study design, not exceeding an hour and usually less, in order to reduce any bias that may be caused by proximity to emissions from traffic.

Smokers: The smoking category, with 19 participants, had the second highest median level of benzene exposure with a value of 16.2 µg/m^3. Variation in concentration levels are expected with both the number of cigarettes smoked and on the confinement space (e.g. indoor, outdoor). The exposure value of benzene that was determined for smokers corresponds to their surrounding area. The inhaled concentration of pollutants when smoking can be expected to be an order of magnitude higher than that measured in the air surrounding the smoker (CONCAWE,1999). In the Bucharest sample, an average number of 8 cigarettes were smoked per person. Therefore, the smoking group could represent the level of exposure for passive smokers in the direct vicinity of the smoker. The smokers with the highest level of exposure were those that travelled by car.

Commuters: In situations without smoking or other indoor pollution sources, commuting is the main factor affecting personal exposure in cities where the main emission source is traffic. Amongst the categories of commuters, the group with 23 car users had the highest level of exposure with a median value of 18.8 µg/m^3. Six participants in the mixed transport group (car and public transport) had a median benzene value of 17.0 µg/m^3. Nineteen participants in the public transport had a median benzene value of 12.5 µg/m^3. The various specific public transport categories were similar in terms of exposure level. Twenty eight bus users had a median benzene value of 13.2 µg/m^3. Seven tram users had a median benzene value of 14.0 µg/m^3. Eight metro users had a median benzene value of 12.7 µg/m^3. The walk category with seven participants had a median benzene value of 13.3 µg/m^3. Walking had the lowest average daily commute time of 80 minutes, 20 minutes less than bus or car travel.

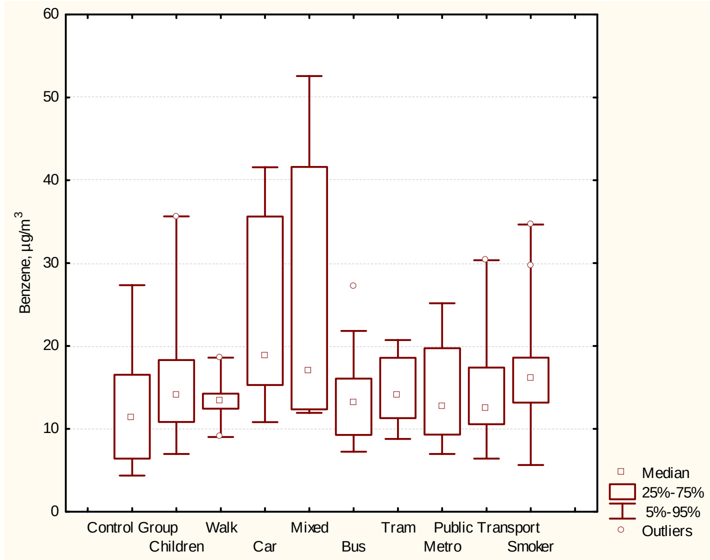


Figure 3.3c.- Personal exposure levels on the day of the campaign. Bucharest (27 May 2003)

Children: A group of 17 children were extracted from the commuting categories. These volunteers commuted to or from school using different means of transport. The median benzene value of 14.0 µg/m^3 is comparable to the commuter categories as illustrated in Figure 3.3c.

3.3.4. Outlier and extreme values

Outliers were considered as values that were 1.5 times higher than the 75th percentile of the given group. Extremes were considered as values that were 3 times higher than the 75th percentile of the given group. Extreme values were not included in the calculation of the median values and were considered as not representative of the given sample of population. The values and groups from which they were removed are given below in Table 3.3.

Table 3.3.- Extremes for Bucharest

Type	*Benzene concentration (µg/m^3)*
Smoker	670.4*
Smoker	240.7*
Mixed transport user	379.1*
Mixed transport user	327.4*
Mixed transport user	201.7*
Car user	70.4
Car user	63.5
Car user	55.7
Car user	51.2
Bus user	30.3

**Please note that besides statistical exclusion, values above 75 µg/m^3 were extrapolated from the calibration curve and as such should be considered as estimates.*

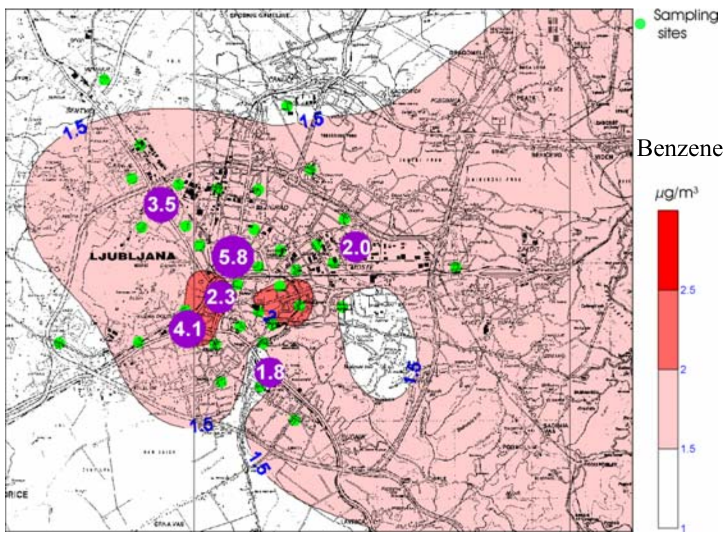
While the results presented in Figures 3.1b and 3.1c are representative of typical conditions, there are occasions when individuals or locations report higher levels than expected. While extremes are not considered in the results they are valid measurements in terms of analytical procedures. They often reflect problems of exposure to situations with high pollution levels.

3.4. Ljubljana

On 27 May 2003, citizens of Ljubljana participated in the project. The project was performed in conjunction with the Institute of Public Health of the Republic of Slovenia.

3.4.1. Outdoor pollution levels

Benzene: Measurements were performed at a number of urban sites to assess the levels and the distribution of benzene over the city. The city background concentration of benzene in Ljubljana ranged from 1.3 µg/m^3 to 5.4 µg/m^3 on the day of the campaign, with a median value of 3.1 µg/m^3 derived from 8 sampling sites. Concurrent monitoring over the city of Ljubljana –Air Peco Study [EUR 21649]- between 20 May and 3 June 2003, illustrated in Figure 3.4a shows 39 background sites together with 6 hot-spot sites. The urban background level distribution in the city for two week sampling period was similar to the 27th May. During this day the benzene concentration ranged from 1.5 to 3.0 µg/m³, apart from one hot-spot with a value of 5.8 µg/m^3. In Ljubljana, higher concentrations corresponded to the major roads within the centre of the city that can generally be expected to correspond to higher vehicle flow at lower speeds.



*The values inside the purple circles are benzene concentrations that were measured at hot-spots.
The positions of the sampling sites are shown with green dots.

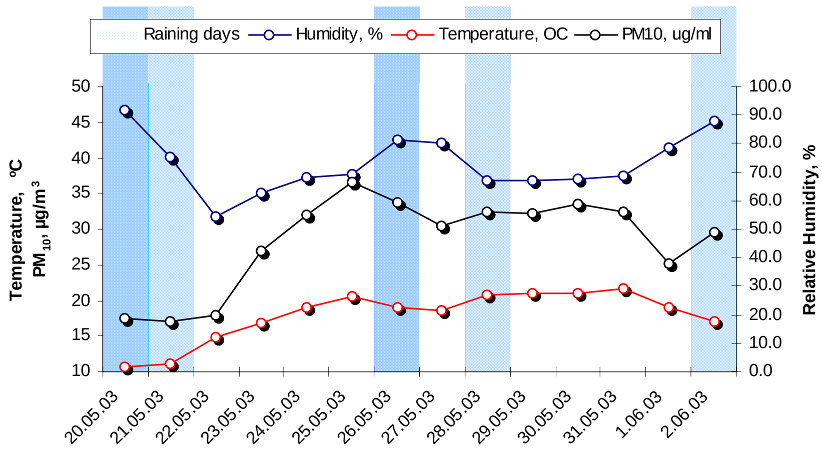
Figure 3.4a.- Benzene concentration levels in Ljubljana from 20 May to 3 June 2003.*

Particulate Matter (PM_{10}) and (Polycyclic aromatic hydrocarbons):

Daily measurements of PM_{10} and particulate phase PAH were performed at 4 outdoor sites during fifteen days, including the day of the PEOPLE campaign.

Figure 3.4b illustrates the trend of B[a]P concentrations along with a number of other parameters at an urban background in a residential area. The concentration levels were low, showing values that are typical for this season. Nevertheless, the B[a]P levels in particles follow the trend of CO; this is probably due to the fact that they both come from the same emission sources.

Based on Figure 3.4b, it is evident that the ambient concentration of B[a]P is related to both temperature and rainfall. During the study period there was a shift from low to higher temperature. With increasing temperature the balance between particle and gas phase PAH shifts. An increase in the volatile phase is observed with a corresponding reduction of the particulate phase. Such an effect is illustrated by Figure 3.4c, which shows the relationship of the ratio between particulate phase B[a]P and PM_{10} with temperature.



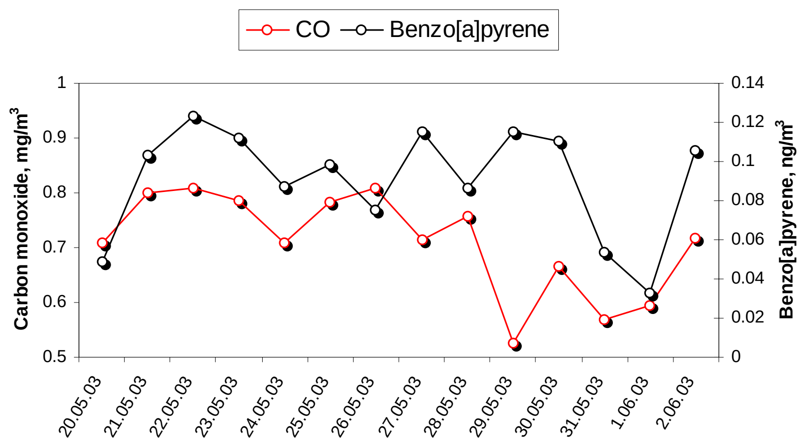


Figure 3.4b.- Time series of daily measurements of B[a]P, CO, PM_{10} and selected meteorological parameters over a 15-day period

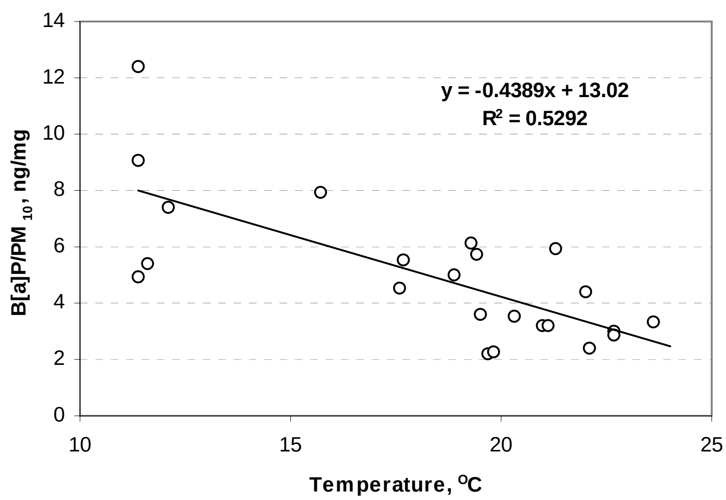


Figure 3.4c.- Ratio between particulate phase B[a]P and PM_{10} versus temperature

Table 3.4a shows that all eleven measured PAH exhibited similar concentrations at the sampling sites selected in the city. Furthermore, the ratios of the measured compounds are reasonably consistent between the four sites, indicating similar emission sources for these locations.

Table 3.4a.- PAH and PM_{10} concentrations at four different sampling sites on 27 May 2003

Compound name	*Concentration (ng/m³)*				*Average*	*STDEV*	*CV,%*
	Station1	*Station2*	*Station3*	*Station 4*			
Phenanthrene	0.223	0.185	0.234	0.247	0.222	0.027	12.1
Fluoranthene	0.103	0.098	0.115	0.122	0.109	0.011	9.9
Pyrene	0.095	0.091	0.104	0.121	0.103	0.013	13.0
Benzo[a]Anthracene	0.056	0.095	0.103	0.147	0.100	0.038	37.4
Chrysene	0.089	0.140	0.177	0.231	0.159	0.060	37.8
Benzo[b]Fluoranthene	0.246	0.527	0.508	0.586	0.467	0.151	32.3
Benzo[k]Fluoranthene	0.097	0.176	0.161	0.193	0.157	0.042	26.6
Benzo[a]Pyrene	0.072	0.117	0.120	0.152	0.115	0.033	28.8
Dibenzo[a,h]anthracene	0.078	0.194	0.115	0.129	0.129	0.048	37.2
Benzo[g,h,y]perylene	0.494	0.917	0.936	1.068	0.854	0.249	29.2
Indeno[1,2,3,c,d]pyrene	0.282	0.443	0.446	0.513	0.421	0.098	23.3
PM10 (mg/m³)	27.5	30.8	32.1	31.3	30.4	2.02	6.6

3.4.2. Indoor pollution levels

Since many people generally spend most of the day inside buildings, benzene levels were measured in a number of typical indoor locations (Figure 3.4d).

Homes: The median benzene concentration value of 2.2 μg/m³ for 21 homes (control group volunteers) was similar to the corresponding value for city background air. As expected when indoor sources were not present, the outdoor levels determine concentrations at these locations.

Schools, restaurants and offices: The median levels of benzene in 10 schools, 5 restaurants and 11 offices were 2.5μg/m³, 2.9 μg/m³and 3.6 μg/m³, respectively. These values are similar to the corresponding value for city background air.

Bars and shops: In 5 bars and 10 shops, where tobacco smoke could be present, the benzene concentration was higher than city background levels with median values of 5.8 μg/m³and 3.8 μg/m³, respectively.

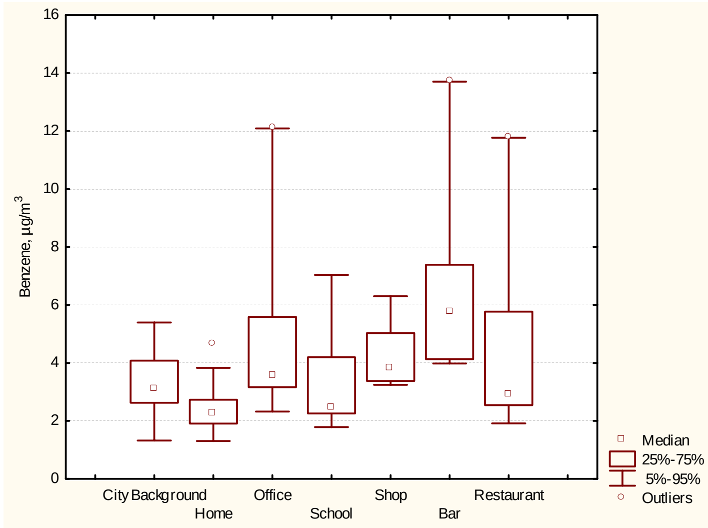


Figure 3.4d.- Indoor and outdoor pollution levels for Ljubljana PEOPLE project. Ljubljana (27 May 2003)

3.4.3. Human exposure

The human exposure measurements represent an estimate of the average concentrations to which a citizen is exposed. Figure 3.4e illustrates the different groups that were selected as typical for the city of Ljubljana.

Control group: The control group, with 18 non-smoking citizens, had the lowest median level of benzene exposure with a value of 2.7 µg/m^3. This was expected, as these volunteers did not commute to or from work. If they spent time moving outside they did so by walking. This mode of travel was limited by study design, to an hour and usually less, in order to reduce any bias that may be caused by proximity to emissions from traffic.

Smokers: The smoking category, with 18 participants, had the highest median level of benzene exposure with a value of 5.7 µg/m^3,. Variation in concentration levels are expected with both the number of cigarettes smoked and on the confinement space (e.g. indoor, outdoor). The exposure value of benzene that was determined for smokers corresponds to their surrounding area. The inhaled concentration of pollutants when smoking can be expected to be an order of magnitude higher than that measured in the air surrounding the smoker (CONCAWE,1999). In the Ljubljana sample, an average number of 9 cigarettes were smoked. Therefore, the smoking group could represent the level of exposure for passive smokers in the direct vicinity of the smoker. The smokers with the highest level of exposure were those that travelled by car.

Commuters: In situations without smoking or other indoor pollution sources, commuting is the main factor affecting personal exposure in cities where the main emission source is traffic. Amongst the categories of commuters, car users had the highest exposure level, with 27 volunteers giving a median benzene value of 5.0 µg/m^3. The 10 participants in the mixed transport category that travelled by bus and car had a median benzene value of 4.7 µg/m^3.The bus category with 8 participants had a median benzene value of 4.0 µg/m^3. The walk category, with 9 participants, and bicycle category, with 13 participants, had median benzene values of 4.0 µg/m^{3}and 3.5 µg/m^3, respectively. These categories also had the lowest average daily commuting time of 80 minutes, 20 minutes less than travel with bus or car.

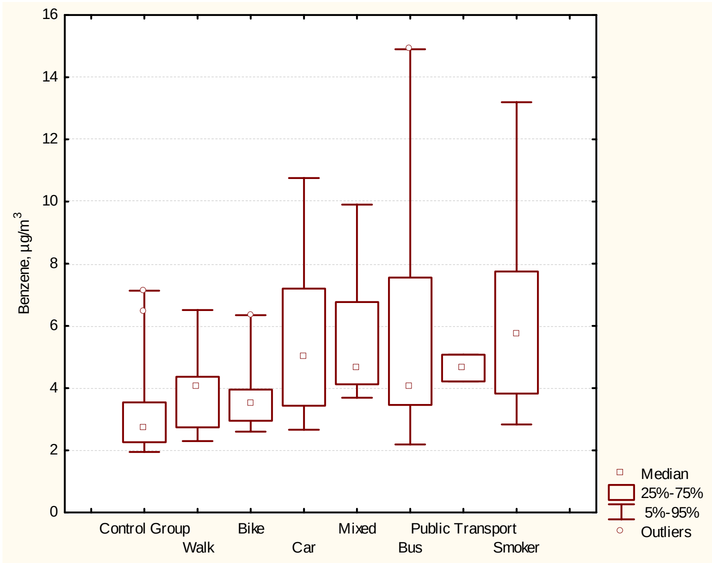


Figure 3.4e.- Personal exposure levels on the day of the campaign. Ljubljana (27 May 2003)

3.4.4 Outlier and extreme values

Outliers were considered as values that were 1.5 times higher than the 75th percentile of the given group. Extremes were considered as values that were 3 times higher than the 75th percentile of the given group. Extreme values were not included in the calculation of the median values and were considered as not representative of the given sample of population. The values and groups from which they were removed are given below in Table 3.4b.

Table 3.4b.- Outliers for Ljubljana

Type	*Benzene concentration (µg/m^3)*
Bus user	29.6
Bus user	59.8
Car user	80.9*
Car user	68.0
Car user	47.0
Car user	35.0
Car user	26.6
Mixed transport user	44.1
Mixed transport user	16.3
Office	120.0*
Office	51.2

**Please note that besides statistical exclusion, values above 75 µg/m^3 were extrapolated from the calibration curve and as such should be considered as estimates.*

While the results presented in Figures 3.1d and 3.1e are representative of typical conditions, there are occasions when individuals or locations report higher levels than expected. While extremes are not considered in the results they are valid measurements in terms of analytical procedures. They often reflect problems of exposure to situations with high pollution levels.

3.5. Madrid

On 3 December 2003, citizens from Madrid participated in the project. The project was performed in conjunction with the Institute of Health Carlos III of Spain.

3.5.1. Outdoor pollution levels

Benzene: Measurements were performed at a number of urban sites to assess the levels and the distribution of benzene over the city. The city background concentration of benzene in Madrid ranged from 0.9 µg/m^3 to 15.0 µg/m^3 on the day of the campaign, with a median value of 4.5 µg/m^3 derived from 36 sampling sites.

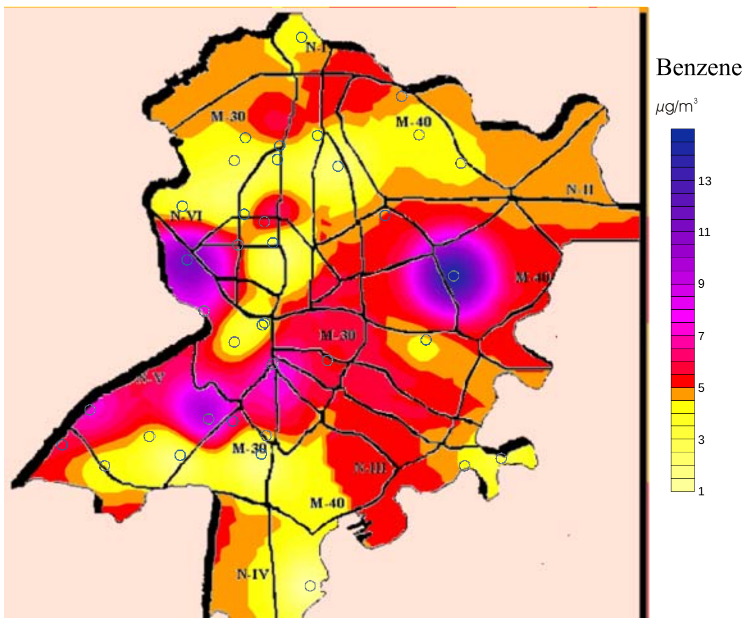


Figure 3.5a.- Benzene concentrations levels in Madrid on the day of the campaign (3 December 2003)

In Madrid, areas of high concentrations were related to streets with intensive traffic and areas of high population density. The day of the campaign was consistent in spatial terms with previous longer term monitoring at the city (Resolution project, 2000).

Heavy Metal, Particulate Matter (PM_{10}) and Polycyclic aromatic hydrocarbons (PAH): The concentrations of heavy metals given in Table 3.5a during the day of the campaign were relatively low. In contrast the PAH concentrations were relatively high in many areas of the city.

Table 3.5a.-. Heavy metals concentrations at fifteen different sampling sites on 3 December 2003

Compound	Concentration, ng/m^3				
	Median	Minimum	Maximum	25 Percentile	75 Percentile
Cr	7.26	6.16	11.8	6.82	8.99
Ni	3.50	2.35	7.00	3.21	3.71
Cu	60.7	37.1	98.2	54.4	80.0
Zn	83.2	59.8	140	74.6	103
As	1.84	0.8	5.65	1.58	2.18
Cd	0.49	0.26	0.98	0.41	0.72
Pb	29.3	23.1	40.0	27.0	32.7

The proposed limit value for B[a]P for an annual average is 1 ng/m^3. In this study a median value of 1.29 ng/m^3 was calculated for B[a]P as given in Table 3.5b.

Table 3.5b.-. PAH and PM_{10} concentrations at seventeen different sampling sites on 3 December 2003

Compound	*Concentration, ng/m^3*				
	Median	*Minimum*	*Maximum*	*25 Percentile*	*75 Percentile*
Phenanthrene	0.36	0.23	0.60	0.305	0.46
Anthracene	0.11	0.08	0.16	0.10	0.13
Fluoranthene	0.93	0.59	1.97	0.82	1.22
Pyrene	1.18	0.71	2.24	0.99	1.45
Benzo[a]Anthracene	1.36	0.73	1.92	1.115	1.65
Chrysene	1.24	0.79	2.2	1.06	1.76
Benzo[b]fluoranthene	1.54	0.92	2.21	1.325	1.93
Benzo[k]fluoranthene	0.70	0.40	0.98	0.58	0.92
Benzo[a]pyrene	1.29	0.73	2.17	0.96	1.45
Dibenzo[a,h]anthracene	0.37	0.17	0.5	0.28	0.42
Benzo[g,h,i]perylene	3.01	1.57	5.59	2.225	3.79
Indeno[1,2,3,c,d]pyrene	1.48	0.80	2.35	1.15	2.03
PM_{10}	51 *$\mu g/m^3$*	37 *$\mu g/m^3$*	78 *$\mu g/m^3$*	46.5 *$\mu g/m^3$*	57.5 *$\mu g/m^3$*

The median PM_{10} level of 51 $\mu g/m^3$ exceeded the limit value of 50 $\mu g/m^3$ already established by the first Air Quality daughter Directive. Figures 3.5b and 3.5c show the spatial distribution of PM_{10} and B[a]P, respectively.

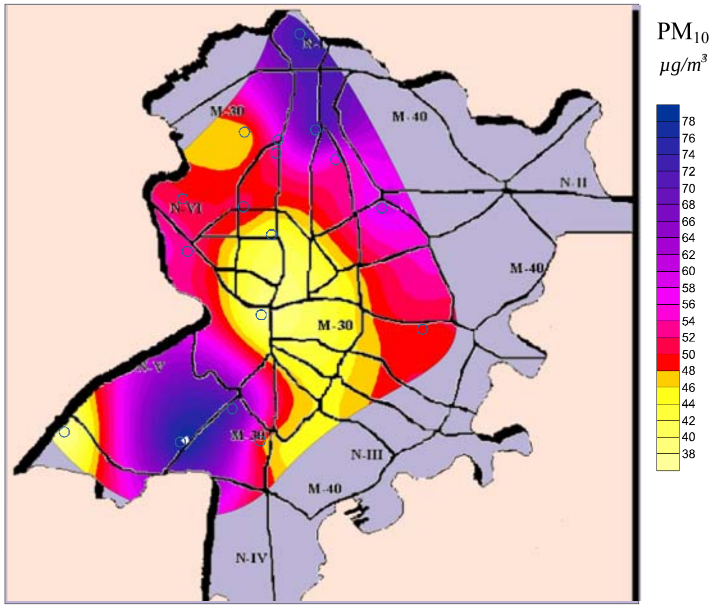


Figure 3.5b.- PM_{10} concentration levels in Madrid on the Day of the campaign (3 December 2003)

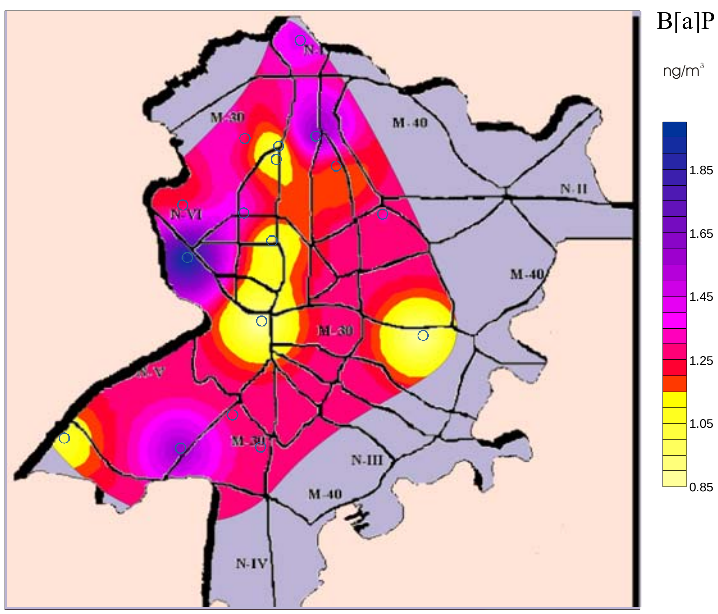


Figure 3.5c.- Benzo[a]Pyrene concentration levels in Madrid on the day of the campaign (3 December 2003)

It appears that ambient concentrations of the measured PAH and heavy metals were controlled by emissions from traffic sources since other emission sources could not be identified from the ambient data. The lowest levels of PAH and heavy metals were associated with open space areas and neighbourhoods with good metro infrastructure.

3.5.2. Indoor pollution levels

Since many people generally spend most of the day inside buildings, benzene levels were measured in a number of typical indoor locations (Figure 3.5d).

Homes and schools: The median benzene values of the home (control group volunteers) and school groups were the lowest of the different indoor environments that were monitored, with a value of 5.3 µg/m^3 for 13 homes and a value of 6.0 µg/m^3 for 3 schools. Theses benzene concentrations were similar to the corresponding value for city background air. As expected when indoor sources were not present, the outdoor levels determine concentrations at these locations.

Shops, offices and bars: In 4 shops, 4 offices and 5 bars, where tobacco smoke could be present, the benzene concentration was higher than city background levels with median values of 8.8 µg/m^3, 7.9 µg/m^3 and 19.4 µg/m^3, respectively.

Taxis: The median benzene concentration of 14.8 µg/m^3 obtained from 7 taxis was only exceeded by the median of the bar category. Apart from one office extreme, the highest indoor measurement was found inside a taxi. Taxis frequently travel through areas of high levels of pollution (hot-spot areas) and as such are affected by close proximity to traffic emissions.

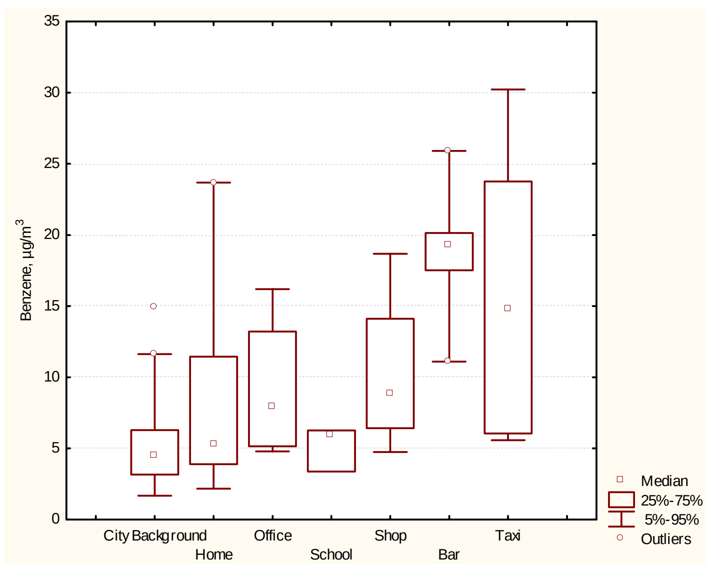


Figure 3.5d.- Indoor and outdoor pollution levels on the day of the campaign. Madrid (3 December 2003)

3.5.3. Human exposure

The human exposure measurements of benzene represent an estimate of the average concentrations to which citizens were exposed during a twelve-hour daytime period that included transit to and from work. Exposure to benzene is anticipated to be related to a person's lifestyle and the types of environments encountered. The main factors that affect benzene exposure for urban populations are the presence of tobacco smoke, and the time, duration and mode of commuting (Figure 3.5e).

Control group: With the exception of a small group of train commuters the control group, with 13 non-smoking citizens, had the lowest median level of benzene exposure with a value of 2.7 µg/m^3. These values were higher than corresponding measurements from inside their homes. These volunteers did not commute to or from work and spent practically all of the sampling period inside their homes, where emission sources were expected to be absent. If they spent time moving outside they did so by walking. This mode of travel was limited by study design, to an hour and usually less, in order to reduce any bias that may be caused by proximity to emissions from traffic.

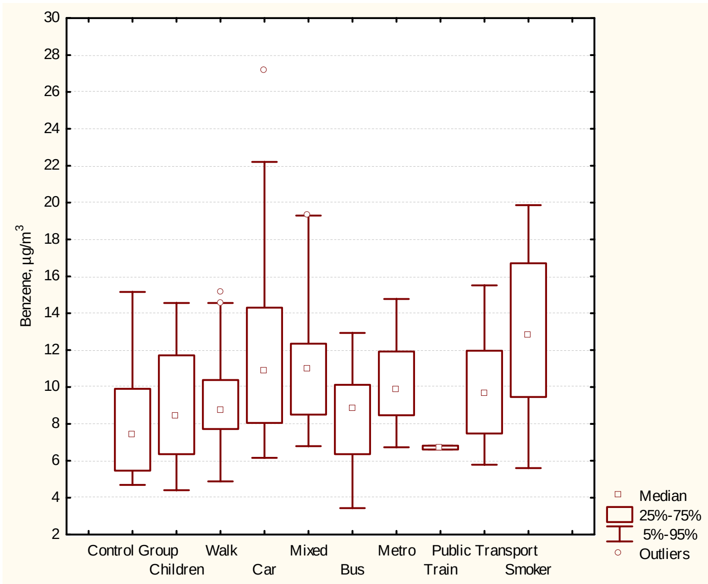


Figure 3.5e.- Personal exposure levels on the day of the campaign. Madrid (3 December 2003)

Smokers: The smoking category, with 28 participants, had the highest median level of benzene exposure with a value of 12.8 µg/m^3. Variation in concentration levels are expected with both the number of cigarettes smoked and on the confinement space (e.g. indoor, outdoor). The exposure value of benzene that was determined for smokers corresponds to their surrounding area. The inhaled concentration of pollutants when smoking can be expected to be an order of magnitude higher than that measured in the air surrounding the smoker (CONCAWE,1999). In the Madrid sample, an average number of 10 cigarettes were smoked per person. Therefore, the smoking group could represent the level of exposure for passive smokers in the direct vicinity of the smoker.

Commuters: In situations without smoking or other indoor pollution sources, commuting is the main factor affecting personal exposure in cities where the main emission source is traffic. In broad terms the commuting categories reported equivalent exposure levels. However, the higher individual exposures were associated with the car use. The 30 car samples and 17 mixed transport (car and bus) samples had median benzene values of 10.9 µg/m^3 and 11.0 µg/m^3, respectively. The public transport category with 10 participants, bus category with 6 participants and the metro category with 8 participants had broadly similar levels of 9.7 µg/m^3, 8.8 µg/m^3 and 9.8 µg/m^3, respectively. The train category with 3 participants had the lowest level of exposure with a median benzene value of 6.7 µg/m^3.

Children: A group of 27 children were extracted from the commuting categories. These volunteers commuted to or from school using different means of transport. The median benzene value for this group of 8.5 µg/m^3 is comparable to the results obtained from the commuter categories as illustrated in Figure 3.5e.

3.5.4 Outlier and extreme values

Outliers were considered as values that were 1.5 times higher than the 75th percentile of the given group. Extremes were considered as values that were 3 times higher than the 75th percentile of the given group. Extreme values were not included in the calculation of the median values and were considered as not representative of the given sample of population. The values and groups from which they were removed are given below in Table 3.5.

Table 3.5c.- Extremes for Madrid

Type	*Benzene concentration (μg/m³)*
Car user	33.8
Control Group	33.5
Smoker	38.2
Mixed Transport user	29.0
Office	375.3*
Shop	63.4

**Please note that besides statistical exclusion, values above 75 μg/m³ were extrapolated from the calibration curve and as such should be considered as estimates.*

While the results presented in Figures 3.5d and 3.5e are representative of typical conditions, there are occasions when individuals or locations report higher levels than expected. While extremes are not considered in the results they are valid measurements in terms of analytical procedures. They often reflect problems of exposure to situations with high pollution levels.

3.6. Dublin

On 28 April 2004, citizens of Dublin participated in the project. The project was performed with the support of Dublin City Council and the Dublin Institute of Technology. Assistance was also provided by the Environmental Protection Agency of Ireland.

3.6.1. Outdoor pollution levels

Benzene: Measurements were performed at a number of urban sites to assess the levels and the distribution of benzene over the city. The city background concentration of benzene in Dublin ranged from 0.5 µg/m^3 to 2.0 µg/m^3 on the day of the campaign, with a median value of 1.1 µg/m^3 derived from 24 sampling sites. In Dublin, higher concentrations corresponded to the centre of the city. This is also reflected by the median benzene value of 0.8 µg/m^3 from 4 city boundary sites. In order to assess areas with high vehicle flows, measurements were made at 8 hot-spot sites. A median value of 1.8 µg/m^3 was reported from these sites.

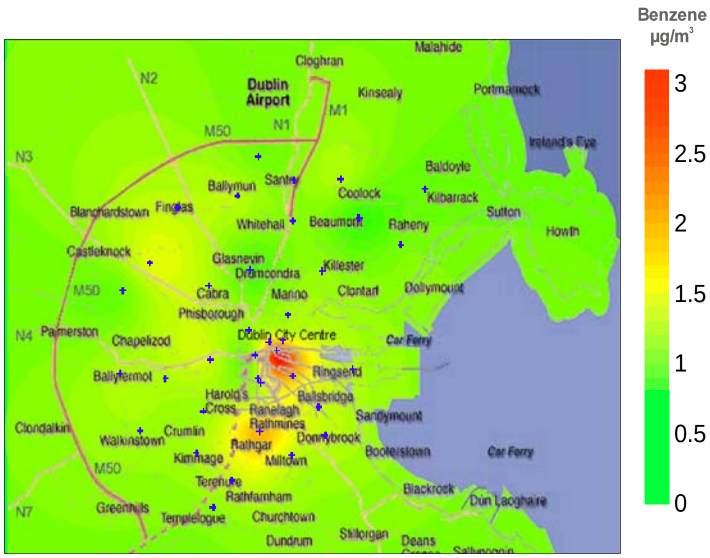


Figure 3.6a.- Benzene concentration levels in Dublin on the day of the campaign (28 April 2004)

Particulate Matter; PM_{10} and Polycyclic aromatic hydrocarbons (PAH): Measurements of PM_{10} and particulate phase PAH were performed at 15 outdoor sites for 24 hours during the day of the campaign. While 12 different PAH were measured, the results for the 9 species that were consistently above detection limits are presented along with the corresponding PM_{10} data. The data are differentiated into background and hot-spot categories, derived from 10 and 5 sites respectively (See Table 3.6a). It should be noted that the different between concentration levels at hot spots and background locations become greater for PAH with higher volatility.

Table 3.6a.- PM10 (µg/m^3) and PAH (ng/m^3) median concentrations

Type	*City Background*	*Hot-spot*
PM_{10}	14.2	21.7
Fluoranthene	0.071	0.148
Pyrene	0.080	0.180
Benzo[a]anthracene	0.073	0.151
Chrysene	0.094	0.213
Benzo[b]fluoranthene	0.132	0.216
Benzo[k]fluoranthene	0.062	0.090
Benzo[a]pyrene	0.057	0.088
Benzo[g,h,i]perylene	0.254	0.334
Indeno[1,2,3,c,d]pyrene	0.124	0.164

Phenathrene, anthracene and dibenzo[a, h]athracene are not reported

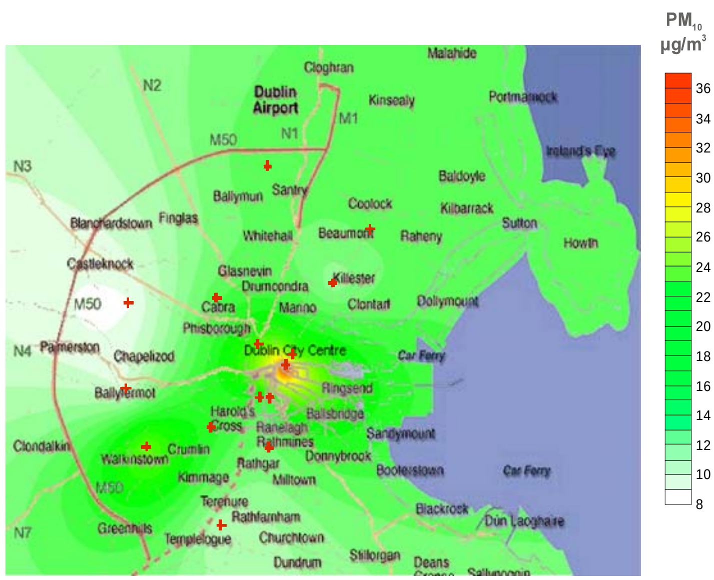


Figure 3.6b.- PM_{10} concentration levels in Dublin on the day of the campaign (28 April 2004)

During the campaign day, concentrations of PAH were consistent with the trends evident for benzene monitoring, with hot-spot sites reporting higher values than city background sites.

3.6.2. Indoor pollution levels

Since many people generally spend most of the day inside buildings, benzene levels were measured in a number of typical indoor locations

Benzene in Homes and Schools: The median benzene concentration value of 1.6 µg/m^3 for 10 homes of the commuting groups was similar to the corresponding value for outdoor air. A median value of 1.5 µg/m^3 was also determined from the 10 sampled schools.

Benzene in Bars and Offices: A median benzene concentration of 1.6 µg/m^3 from 10 offices was consistent with other indoor environments. The highest median value of 2.0 µg/m^3 was reported for the 9 bars that were sampled.

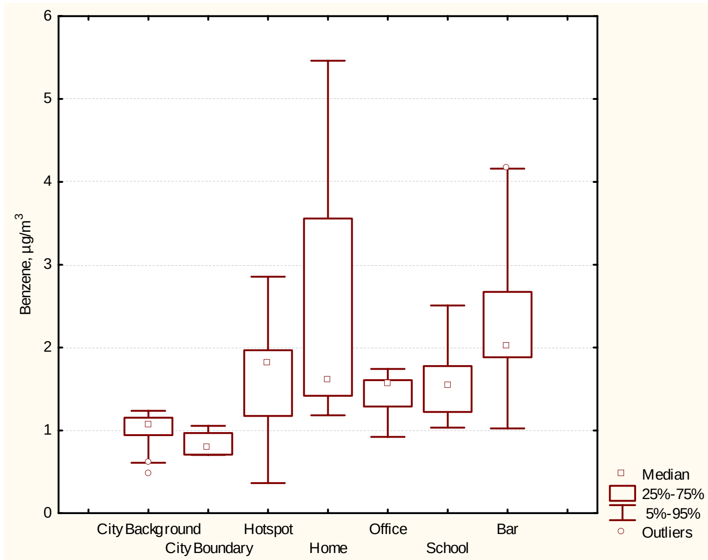


Figure 3.6c.- Indoor and outdoor pollution levels on the day of the campaign. Dublin (28 April 2004)

Particulate Matter; PM_{10} and Polycyclic aromatic hydrocarbons (PAH): Measurements of PM_{10} and particulate phase PAH were performed at 3 offices, 3 non smoking homes and 2 smoking homes for 24 hours during the day of the campaign. The nine species that were consistently above detection limits are given along with the corresponding PM_{10} data. Indoor levels were lower than or comparable to outdoor levels, with the exception of the smoking home category. In this case the values of the PAH were up to an order of magnitude higher. The most abundant species were benzo[a]anthracene, chrysene, benzo[b]fluoranthene and benzo[a]pyrene. The other reported PAH were around 5 times higher in the smoking home category. The level of PM_{10} was also five times higher for smoking compared to non smoking homes and offices.

Table 3.6b.- Particulate matter PM10 (µg/m^3) and PAH (ng/m^3)median concentrations for offices and home categories

Type	*Offices*	*Non smoking Homes*	*Smoking Homes*
PM_{10}	11.1	11.2	57.9
Fluoranthene	0.072	0.045	0.183
Pyrene	0.062	0.053	0.263
Benzo-a-Anthracene	0.053	0.036	0.316
Chrysene	0.064	0.046	0.625
Benzo-b-fluoranthene	0.083	0.055	0.493
Benzo-k-fluoranthene	0.050	0.031	0.170
Benzo-a-pyrene	0.049	0.031	0.475
benzo-g,h,i-perylene	0.229	0.160	0.404
Indeno-1,2,3,cd-pyrene	0.094	0.053	0.261

Phenathrene, anthracene and dibenzo[a, h]athracene are not reported

3.6.3. Human exposure

The human exposure measurements represent an estimate of the average concentrations to which a citizen is exposed. Figure 3.6d illustrates the different groups that were selected as typical for the city of Dublin.

Control group : The control group, with 3 non-smoking citizens, had a median benzene value of 2.4 µg/m^3. These volunteers did not commute to or from work. If they moved outside they did so by walking. This mode of travel was limited by study design, in order to an hour and usually less, to reduce any bias that may be caused by proximity to emissions from traffic.

Smokers: The smoking category, with 9 participants, had the highest median level of benzene exposure with a value of 4.3 µg/m^3. Variation in concentration levels are expected with both the number of cigarettes smoked and on the confinement space (e.g. indoor, outdoor). The exposure value of benzene that was determined for smokers corresponds to their surrounding area. The inhaled concentration of pollutants when smoking can be expected to be an order of magnitude higher than that measured in the air surrounding the smoker (CONCAWE,1999). In the Dublin sample, an average number of 8 cigarettes were smoked per person. Therefore, the smoking group could represent the level of exposure for passive smokers in the direct vicinity of the smoker.

Commuters: In situations without smoking or other indoor pollution sources, commuting is the main factor affecting human exposure in cities where the main emission source is traffic. Amongst the types of commuters, the car category had the widest range of exposure levels. While the median benzene level from 44 samples of 2.4 µg/m^3 is comparable to other categories, the 75th percentile value of 3.6 µg/m^{3}and the maximum value is higher than the corresponding values for other categories. In the other categories, namely; motorbike, mixed transport, bus, bike, walk and train median and 75th percentile values range from between 2.0 and 3.0 µg/m^3. The 5 motorbike users, 11 mixed transport users, 21 bus users, 17 bike users, 14 walk users and 3 train users produced median benzene values of 2.6 µg/m^3, 2.4 µg/m^3, 2.4 µg/m^3, 2.3 µg/m^3, 2.7 µg/m^3, and 2.2 µg/m^3 respectively.

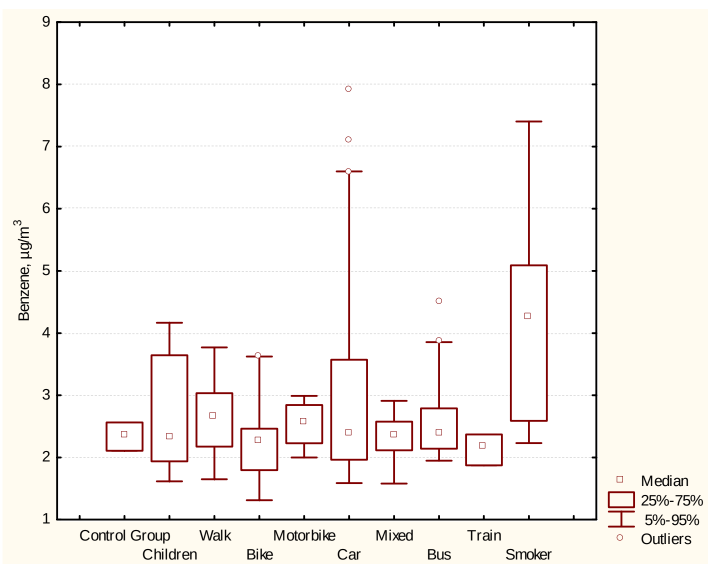


Figure 3.6d.- Personal exposure levels on the day of the campaign. Dublin (28 April 2004)

Children: A group of 14 children were extracted from the commuting categories. These volunteers commuted to or from school using different means of transport. The median benzene value for this group of 2.3 µg/m^3 is similar to the results obtained from the commuter categories as illustrated in Figure 3.6d.

3.6.4. Pilot study for PM_{10} human exposure

Three participants also carried a portable personal sampler for the same sampling period as that for the benzene measurement. The optical sampler was set to report measurements on a one minute frequency. The average concentration values for the sampling period were 15 µg/m^3 for a mixed transport user, 22 µg/m^3 for a car user and 26 µg/m^3 for a walker. The three samplers were operated predominately outdoors, in the city centre and in areas proximate to traffic. Figure 3.6e illustrates the PM_{10} levels that were measured in different Dublin environments. It is clear that the highest concentrations were associated with hot-spot sites and in particular a smoking home.

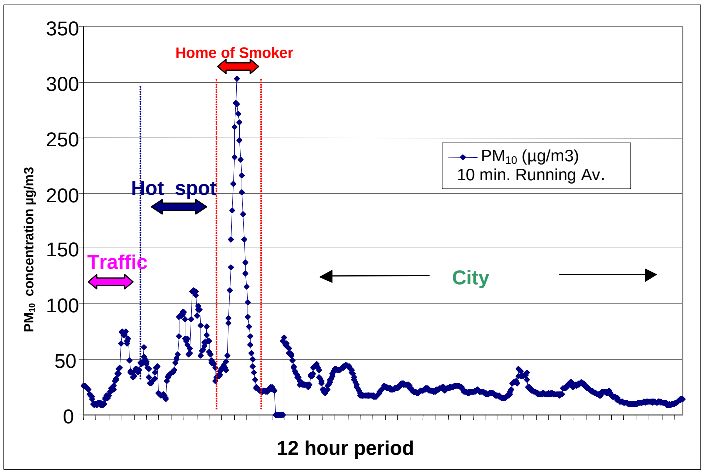


Figure 3.6e.- PM_{10} profile related to activities during PEOPLE campaign in Dublin

3.6.5. Outlier and extreme values

Outliers were considered as values that were 1.5 times higher than the 75th percentile of the given group. Extremes were considered as values that were 3 times higher than the 75th percentile of the given group. Extreme values were not included in the calculation of the median values and were considered as not representative of the given sample of population. The values and groups from which they were removed are given below in Table 3.6c.

Table 3.6c.- Extremes for Dublin

Type	*Benzene concentration (µg/m^3)*
Motorbike user	5.2
Office	11.3
Home	13.3

While the results presented in Figures 3.5d and 3.5e are representative of typical conditions, there are occasions when individuals or locations report higher levels than expected. While extremes are not considered in the results they are valid measurements in terms of analytical procedures. They often reflect problems of exposure to situations with high pollution levels.

4. CITY TO CITY COMPARISON

4.1. Meteorological Conditions

The 12 hour human exposure measurements were for a single day, whereas the 24 hour environmental measurements included a second day. Air quality is critically affected by meteorological conditions, hour by hour and throughout the annual cycle. Dispersion is enhanced with lower atmospheric stability that is broadly characterised by higher temperature and wind speeds. By contrast cold conditions coupled with low wind speed are typical for times of poor dispersion. The combination of emissions, that also vary with time, and atmospheric dispersion control the measured ambient air pollution concentrations. Annex I gives a graphical representation of temperature, dew point, barometric pressure and wind speed for all six PEOPLE cities for both the main sampling day and the following day. A summary of the maximum, minimum and averages for the main meteorological parameters are also given in Annex I. With this information it is possible to understand the dispersion conditions during the days of the campaigns. With the exception of Madrid and Dublin, the rest of the cities were characterised by moderated weather conditions. Dublin had high wind speeds above 5 m/s, which enhanced atmospheric dispersion. By contrast Madrid had low wind speeds coupled with low temperatures that was associated with high atmospheric stability and poor atmospheric dispersion.

4.2. Outdoor Measurements

The measurement campaigns were performed at different times. To assess the daily snapshot with respect to the annual pollution level, a comparison was made with data from urban background network sites. When benzene measurements were not available the levels of carbon monoxide or nitrogen oxides were used as a surrogate. Table 4.2 gives the percentile values of the campaign day in the year along with the estimated annual median city background level. As an example, Figure 4.2 shows position of the campaign day in the annual trend as well as the annual mean value for Madrid. With this information it is possible to perform an assessment of compliance with the limit value of the benzene Directive, since annual average levels should be considered instead of daily levels. Table 4.2 shows that the position of the day in the year ranged from low pollution levels for Dublin and Brussels to average pollution levels for Lisbon, Bucharest and Ljubljana to high pollution levels for Madrid.

Table 4.2.- Comparison of PEOPLE Cities

	Brussels	*Lisbon*	*Bucharest*	*Ljubljana*	*Madrid*	*Dublin*
Median spatial city background benzene level (µg/m^3)	2.5	3.8	7.1	3.1	4.5	1.1
Maximum outdoor benzene value (µg/m^3)	6.2	7.9	18.2	5.4	15.0	2.9
Percentile value (reference year)	35 (2002)	55 (2002)	45 (2003)	45 (2003)	90 (2003)	25 (2004)
Reference pollutant	CO	CO	NO_2	CO	Benzene	CO
Estimated annual median spatial city background benzene level (µg/m^3)	3.4	4.1	8.6	3.7	3.4	1.9

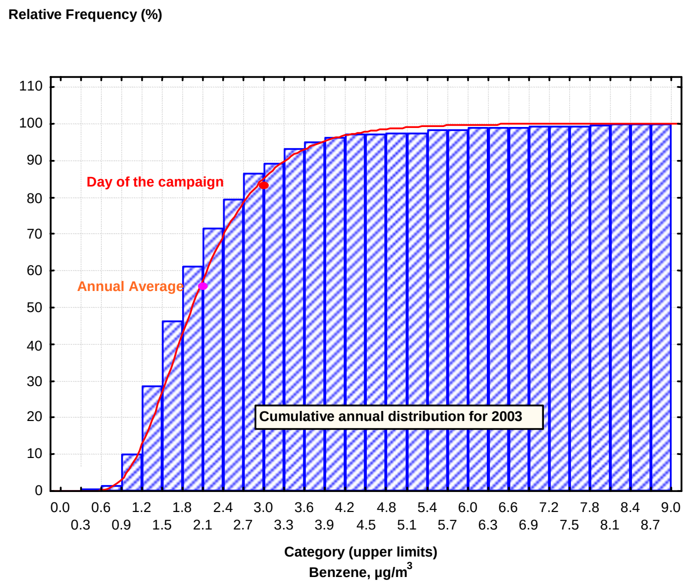


Figure 4.2.- Position of Madrid campaign day in 2003

4.3. Exposure versus Ambient concentration

The estimation of exposure values included only the commuters groups and excluded the control and smoking participants. Therefore, the relationship between the median 24 hour ambient air concentration and the median 12 hour measured exposure concentration considers the commuting population.

As shown in Figure 4.3, the linear correlation between 24h ambient concentration and 12 h exposure are given by the following equations:

$$C_{BG} = 0.52 \cdot C_{EX(12M)} \qquad \text{(Eq. 4.2.1)}$$

with R^2=0.853 and where C_{BG} is the 24h median spatial background concentration measured in the city during the day of the campaign and $C_{EX(12M)}$ is the median of the 12h average concentration measured in the non-smoking commuting sampled population.

$$C_{HP} = 1.36 \cdot C_{EX(12M)} \qquad \text{(Eq.4.2.2)}$$

with a R^2 = 0.955 and where C_{HP} is the 24h highest average concentration measured in the city during the day of the campaign and $C_{EX(12M)}$ is the median of the 12h average concentration measured in the non-smoking commuting sampled population.

On dividing (Eq.4.2.2) by (Eq.4.2.1) it is possible to obtain a ratio between maximum concentration (hot-spot value) and median background concentration of 2.63.

In order to estimate an average exposure value for the 24 hours, it is hypothesised that during the 12 hours, in which the people were not sampled, they did not commute and they were exposed at home to a concentration, $C_{EX(12-N)}$ that was approximately to the corresponding background concentration level C_{BGN}:

$$C_{EX(12-N)} = C_{BGN} \qquad \text{(Eq. 4.2.3)}$$

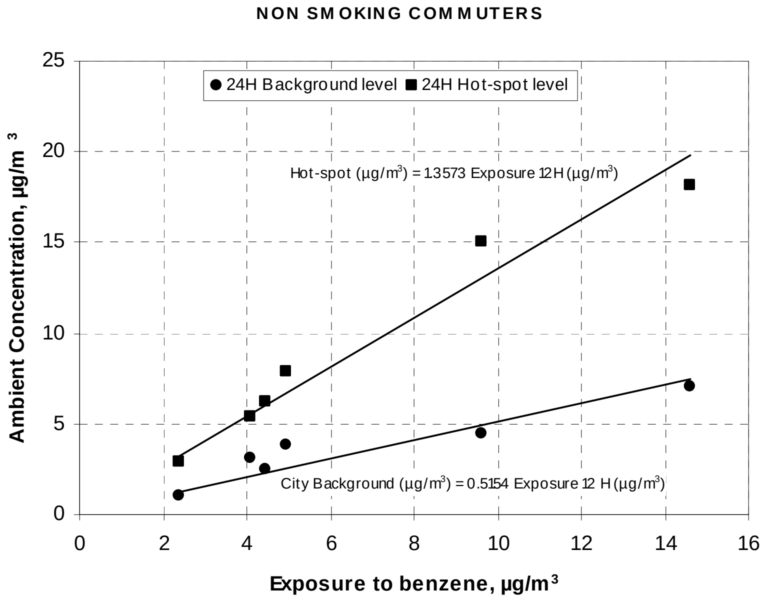


Figure 4.3.- Relationship between ambient air quality and human exposure for PEOPLE cities

However ambient air has a diurnal curve with peaks related to rush hour emissions. An assessment of hourly ambient city background data revealed a ratio of approximately 1.05 between the non-sampled 12 hours and the 24 hour periods. It should be noted the presented ratios are used in all 6 cities as an average approximation. This ratio has an uncertainty of ± 10 % that would be related to emission sources, dispersion conditions and the intrinsic characteristics of the city, which may affect the dispersion of the peak traffic emission across the city after rush hours:

$$C_{BGN} = 1.05 \cdot C_{BG} \qquad \text{(Eq. 4.2.4)}$$

Therefore, By considering Eq. 4.2.1, Eq. 4.2.3 and Eq. 4.2.4, the 24 hours exposure concentration, C_{EX}, can be estimated according to the following expression:

$$C_{EX} = \frac{C_{EX(12M)} + C_{EX(12-N)}}{2} = \frac{\frac{C_{BG}}{0.52} + C_{BGN}}{2} = \frac{\left(\frac{1}{0.52} + 1.05\right)}{2} \cdot C_{BG}$$

$$C_{EX} = 1.5 \cdot C_{BG} \qquad \text{(Eq. 4.2.5)}$$

The exposure concentration can also be expressed as a function of the maximum outdoor concentration by dividing Eq. 4.2.5 by 2.63:

$$C_{EX} = 0.57 \cdot C_{HP} \qquad \text{(Eq. 4.2.6)}$$

Therefore, by applying Eq. 4.2.5 to the annual median spatial city background level estimated for the PEOPLE cities (Section 4.2). It is possible to estimate an annual exposure level for the non-smoker commuter in the corresponding cites as indicated in Table 4.3.

Table 4.3- Estimated annual exposure level for non-smoker commuter in PEOPLE Cities

City	*Annual Exposure level (µg/m^3) for non-smoker commuting population*
Brussels (2002)	5.1
Lisbon (2002)	6.1
Bucharest (2003)	12.9
Ljubljana (2003)	5.5
Madrid (2003)	5.1
Dublin (2004)	2.9

5. CONCLUSIONS

5.1. Outdoor Air

Mapping of outdoor measurements indicates that areas of highest concentrations were associated with major road intersections. Transport was identified as the dominant source of pollution in all six cities that were studied. Urban background levels of benzene, measured on the day of the campaign and the subsequent estimation of the yearly average levels, revealed that PEOPLE cities, with the possible exception of Bucharest, are in compliance with the Directive 2000/69/EC in background ambient air. A combination of factors can be identified that account for the relatively high concentrations and levels of exposure to benzene in Bucharest. Some of the motor vehicles were relatively old and did not conform to the latest European emission standards (Directive 70/220/EEC). Furthermore, the limit of 1% benzene content in petrol (Directive 98/70/EC), imposed within Member States of the European Union, was not implemented in Romania. During the sampling campaign the content of benzene in petrol was 3% of the total volume.

5.2. Indoor Air

While indoor benzene levels are usually determined by the infiltration rate of the external air it is clear that the presence of indoor sources like smoking can elevate concentrations. This factor was evident for a number of individual sites. Elevated indoor concentrations were measured in bars and inside vehicles; this is expected for the former due to the influence of tobacco smoke, and for the latter due to proximity to traffic emissions. The homes of non smokers reported comparable concentrations to the city background sites. However, in homes, ventilation rates and possible internal sources play an important role in the ratio between indoor and outdoor concentrations levels. Some differences between cities were attributed to the prevalent weather conditions.

5.3. Human Exposure

The basic results have revealed that human exposure, of commuters and smokers, to the air pollutant benzene is higher, by a factor of two, than concentrations reported at urban background monitoring sites. This is due to the influence of traffic and smoking emission sources. As expected, the control group had the lowest level of exposure and the smoking category had the highest level of exposure. Of the commuting groups, car users had the highest exposure levels. Children's exposure level was similar to that of the various commuting categories.

Occasionally, some individuals and locations showed extremely high exposure levels. Further analysis of movement diaries could not always explain the extreme values. In these cases, either the presence of unknown sources or unusual proximity to known sources were possible explanations. Citizens who live in indoor environments affected by smoking, or move and work in close proximity to traffic (hot-spots and busy traffic roads), can be expected to receive much higher pollutant exposures.

The city background benzene concentration was comparable to measurements for both the personal exposure control group and non smoking homes. Therefore, city background measurements may be used as a surrogate for human exposure for non smoking people that do not commute to work. It is reasonable to assume that city background sites generally represent the exposure of only part of the general population. However, when considering all the cities together, a linear relationship was calculated between human exposure and ambient levels. Daily median values for commuters, excluding the smoking participants and control groups, were 1.5 times the level of city background and 0.6 times the maximum outdoor ambient value.

6. FUTURE POLICY DEVELOPMENT

The results from the six cities have revealed that human exposure is approximately 1.5 times higher than concentrations reported at urban background monitoring sites. The measured exposure to benzene, in conjunction with the movement diaries of the human exposure volunteers, showed the importance of considering the baseline condition of a given city and the behaviour of the citizens. Ambient air quality data can be used as a surrogate or indicator for human exposure when the main emissions are from external sources, i.e. transportation. While urban background measurements remain essential for compliance monitoring for air quality directives of the European Union, they are also important, along with hot-spot monitoring, for defining human exposure. The use of exposure data to replace ambient air data in epidemiological work is at present in its infancy. Clearly the trend of replacing simple extrapolation of ambient air quality data to more realistic derivations of population exposure is important for the area of air pollution and health.

Most of the exposure measurements could be predicted from knowledge of movements through the different environments encountered. Exposure is critically dependent upon emission sources and personal behaviour, and as such, while extrapolation form air quality information is a useful approach, it needs to respect the dynamics of the city considered. The derivation of factors to define the importance of sources is only possible with the complementary use of movement diaries for human exposure measurements. This approach is key to deriving factors that can be used to predict exposure for larger populations. In this way an approach based on source apportionment of exposure might be possible.

Air Quality legislation can be more successful when it is understood and endorsed by the citizens that it serves. The PEOPLE project helps to link the scientific information that drives policy with the daily lives of citizens. Improved public awareness of the factors influencing air pollution will hopefully lead to environmentally friendly behaviour. The active support of citizens to pollution issues is important for the success of environmental policy. The enthusiastic participation of the volunteers through the PEOPLE project clearly shows that improved environmental quality is a common goal for citizens and policy makers.

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ANNEX - I

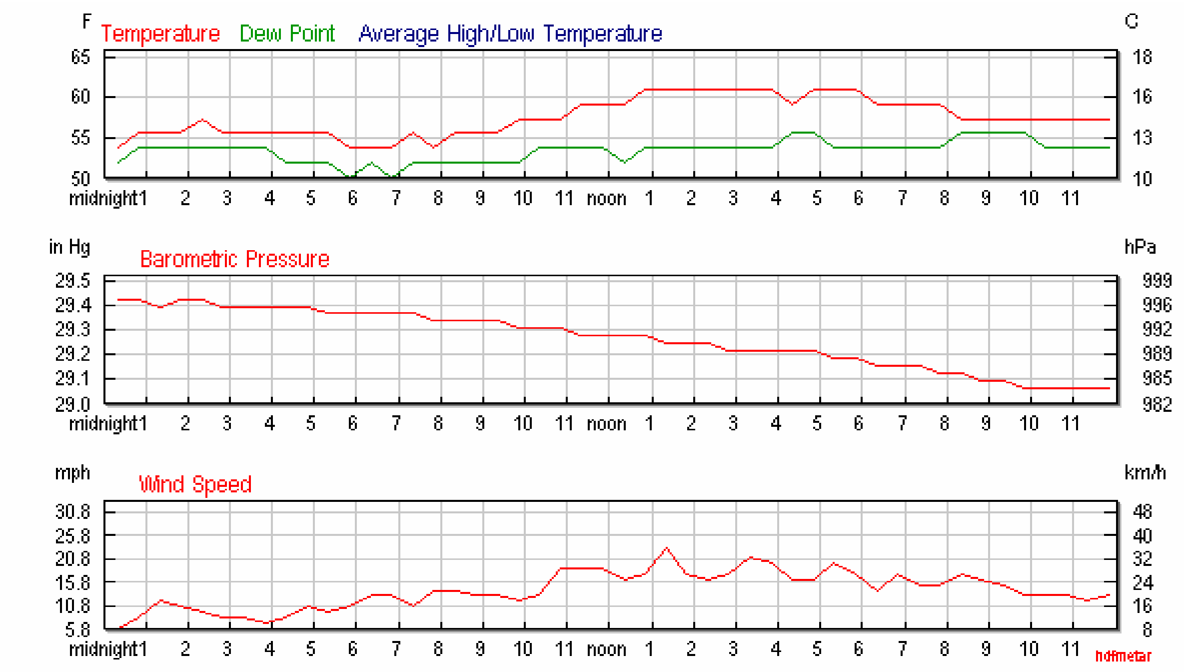
Meteorological conditions during the day of the campaign in the PEOPLE project cities

CITY	*Brussels*		*Lisbon*		*Bucharest*	
	Campaign Day	*Next Day*	*Campaign Day*	*Next Day*	*Campaign Day*	*Next Day*
Date	22/10/02	23/10/02	22/10/02	23/10/02	27/05/03	28/05/03
Temperature						
Mean Temperature	13 °C	10 °C	17 °C	17 °C	20 °C	21 °C
Max Temperature	15 °C	13 °C	20 °C	20 °C	26 °C	25 °C
Min Temperature	11 °C	6 °C	15 °C	13 °C	12 °C	16 °C
Moisture						
Dew Point	11 °C	12 °C	15 °C	15 °C	16 °C	15 °C
Average Humidity	90 %	80 %	85 %	85 %	72 %	66 %
Maximum Humidity	94 %	100 %	100 %	100 %	100 %	94 %
Minimum Humidity	77 %	54 %	64 %	60 %	44 %	39 %
Sea Level Pressure	991 hPa	997 hPa	1013 hPa	1019 hPa	1014 hPa	1013 hPa
Wind						
Wind Speed	13 km/h (South)	24 km/h (WSW)	23 km/h (WSW)	13 km/h (West)	3 km/h (NW)	10 km/h (NE)
Max Wind Speed	37 km/h	34 km/h	34 km/h	16 km/h	11 km/h	32 km/h
Max Gust Speed	55 km/h	60 km/h	53 km/h	-	-	50 km/h
Visibility	11 kilometres	10 kilometres	9 kilometres	11 kilometres	9 kilometres	11 kilometres

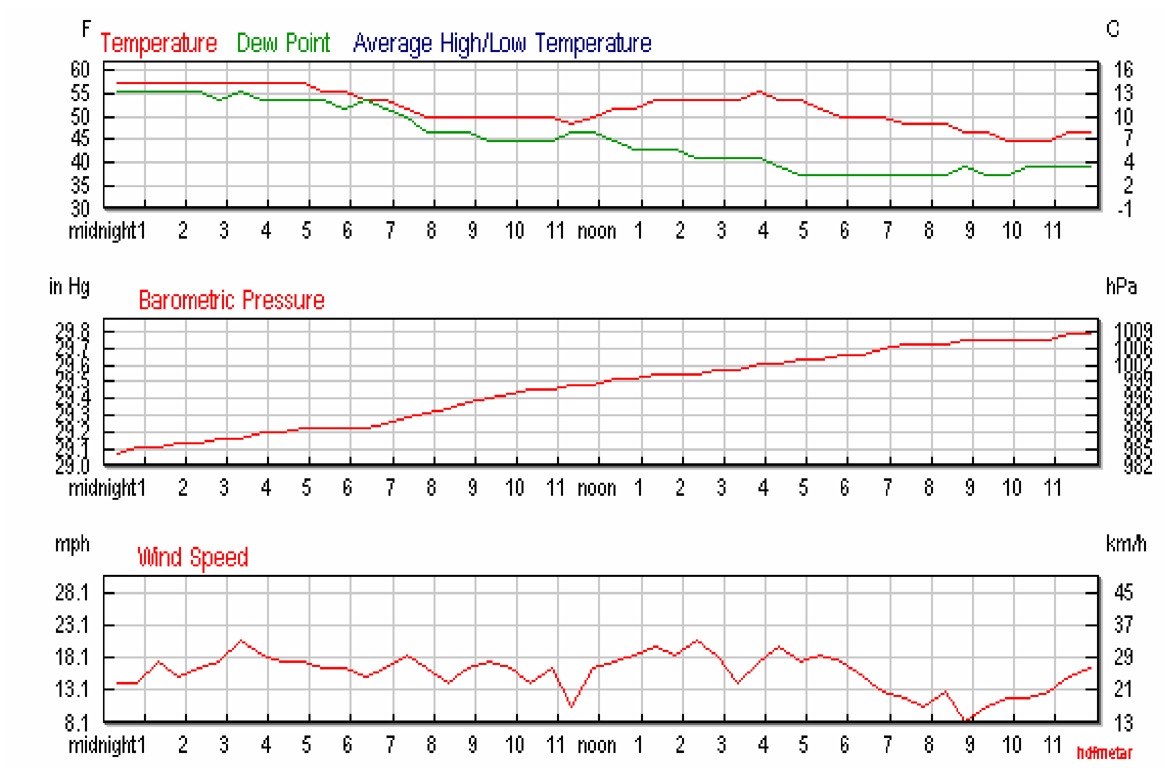
CITY	*Ljubljana*		*Madrid*		*Dublin*	
	Campaign Day	*Next Day*	*Campaign Day*	*Next Day*	*Campaign Day*	*Next Day*
Date	27/05/03	28/05/03	04/12/03	05/12/03	28/04/04	29/04/04
Temperature						
Mean Temperature	20 °C	18 °C	2 °C	1 °C	10 °C	8 °C
Max Temperature	25 °C	26 °C	5 °C	5 °C	12 °C	11 °C
Min Temperature	13 °C	10 °C	-1 °C	-2 °C	6 °C	5 °C
Moisture						
Dew Point	14 °C	12 °C	0 °C	0 °C	5 °C	4 °C
Average Humidity	82 %	80 %	86 %	89 %	72 %	71 %
Maximum Humidity	100 %	100 %	100 %	100 %	93 %	87 %
Minimum Humidity	47 %	45 %	70 %	70 %	51 %	51 %
Sea Level Pressure	1017 hPa	1017 hPa	1014 hPa	1010 hPa	1019 hPa	1014 hPa
Wind						
Wind Speed	0 km/h (WSW)	2 km/h (WSW)	3 km/h (ESE)	2 km/h (NNE)	21 km/h (North)	21 km/h (North)
Max Wind Speed	21 km/h	21 km/h	14 km/h	8 km/h	37 km/h	39 km/h
Max Gust Speed	-	-	29 km/h	-	47 km/h	60 km/h
Visibility	7 kilometres	9 kilometres	9 kilometres	10 kilometres	11 kilometres	11 kilometres

SOURCE: The Weather Underground http://www.wunderground.com/

Brussels



Meteorological conditions on the 22/10/2003



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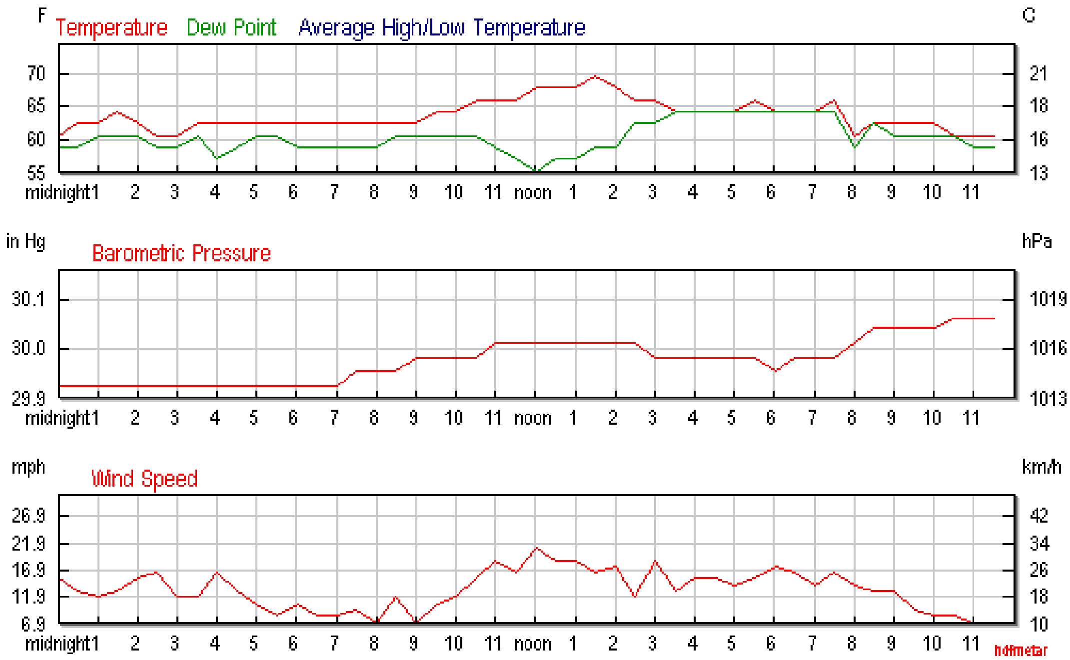
Lisbon



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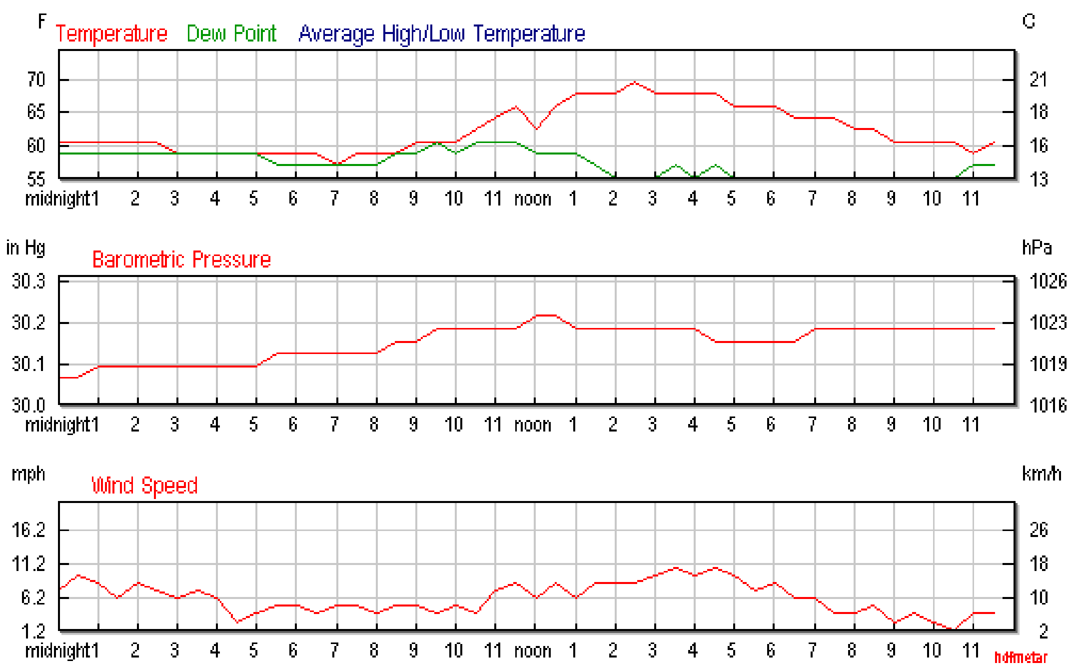
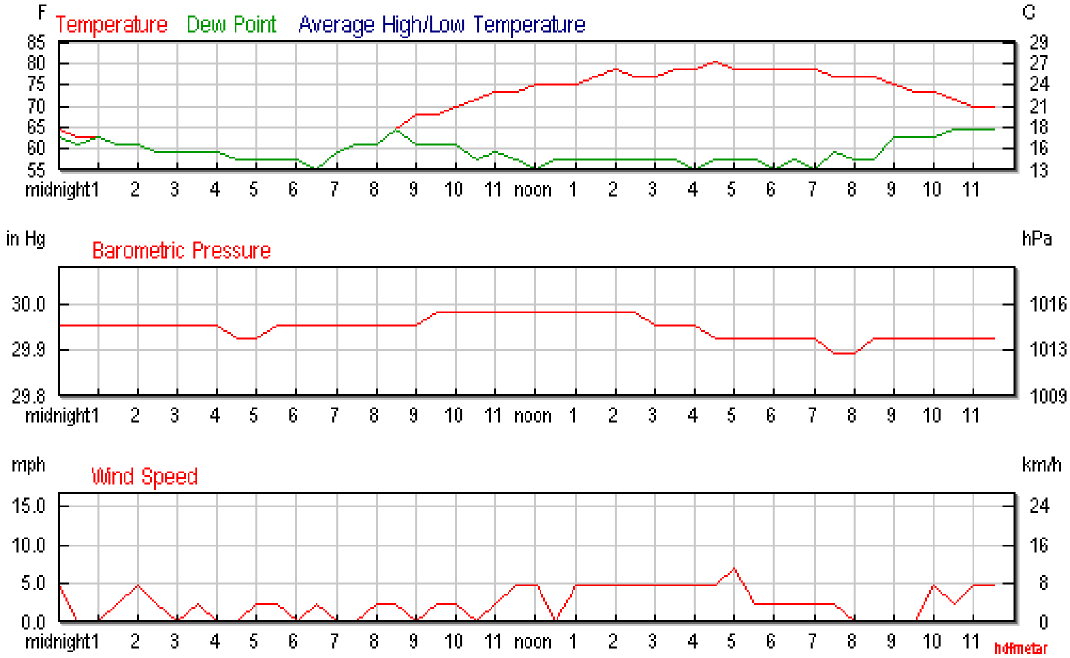


Meteorological conditions on the 23/10/2003

Bucharest



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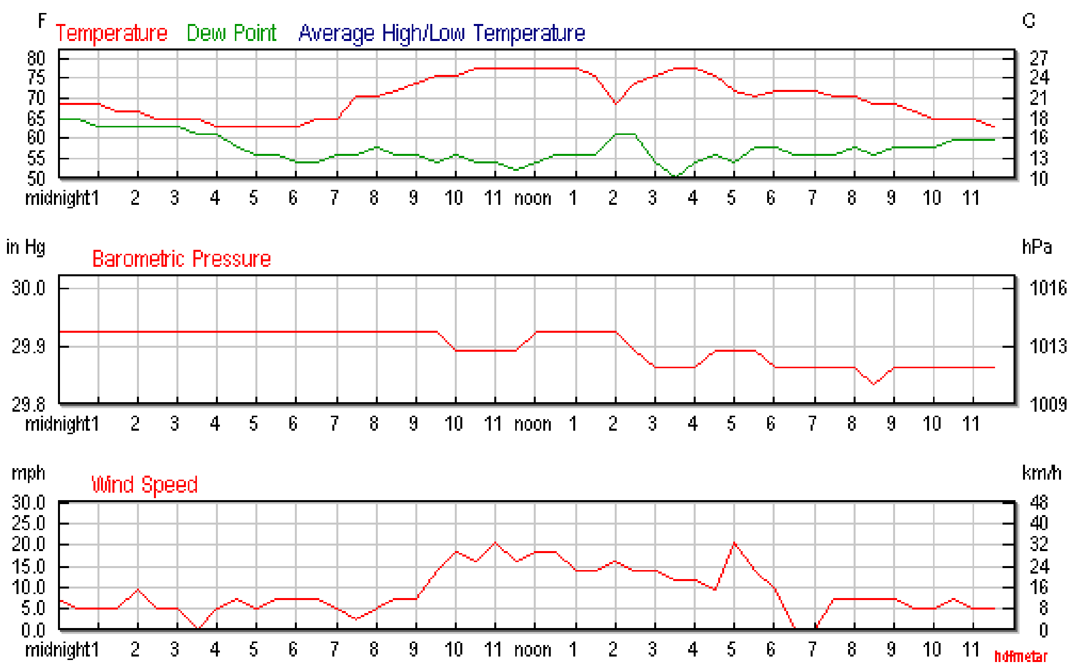
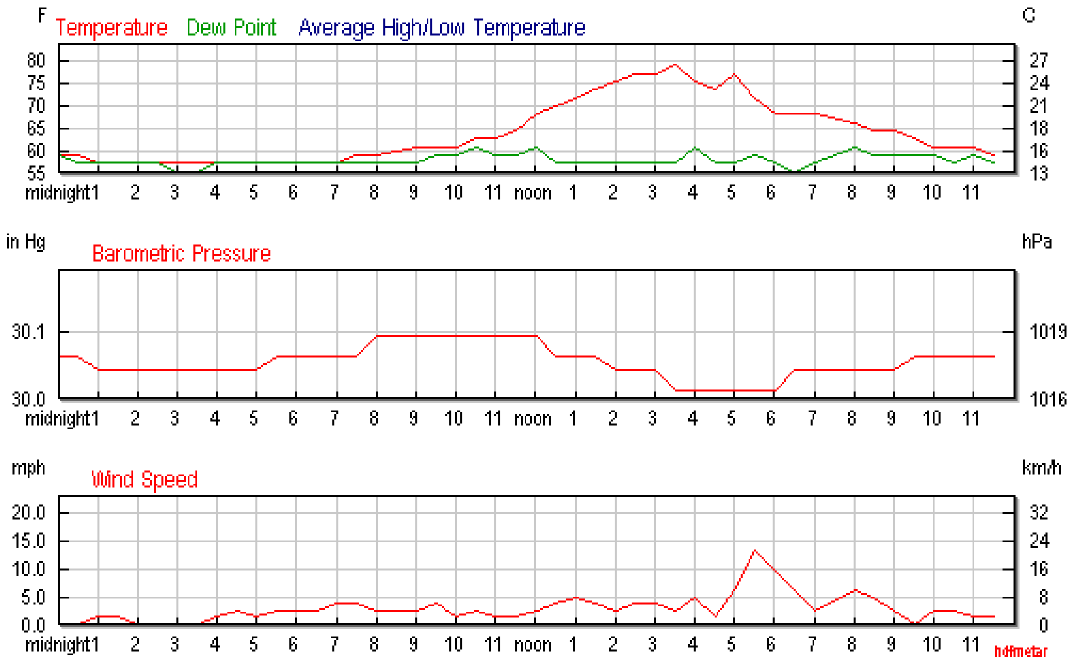
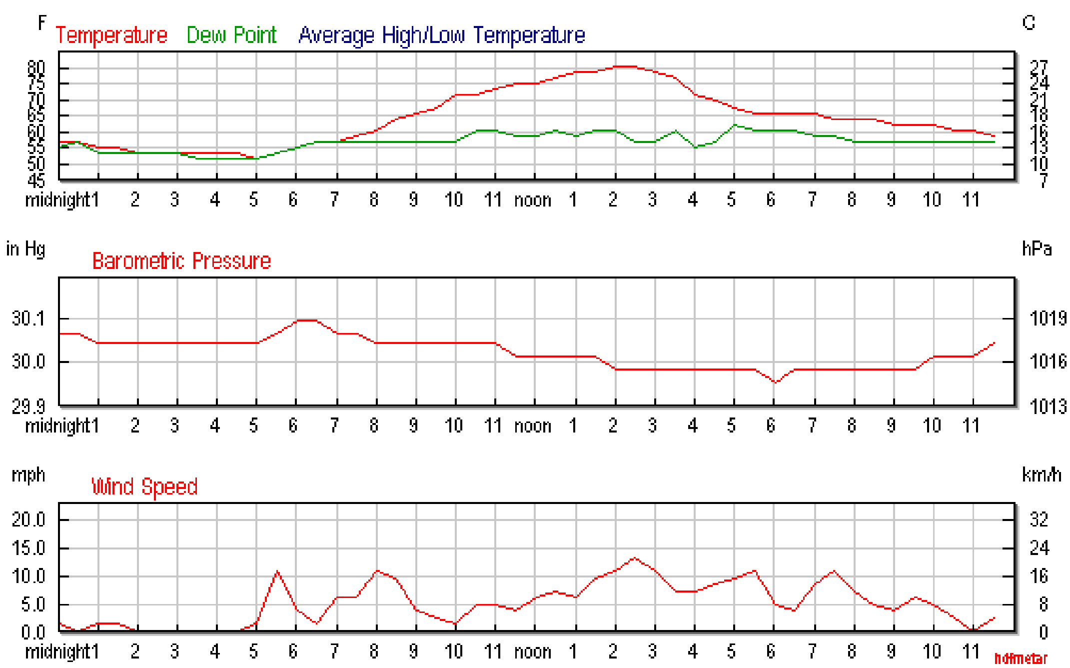


Meteorological conditions on the 28/05/2003

Ljubljana

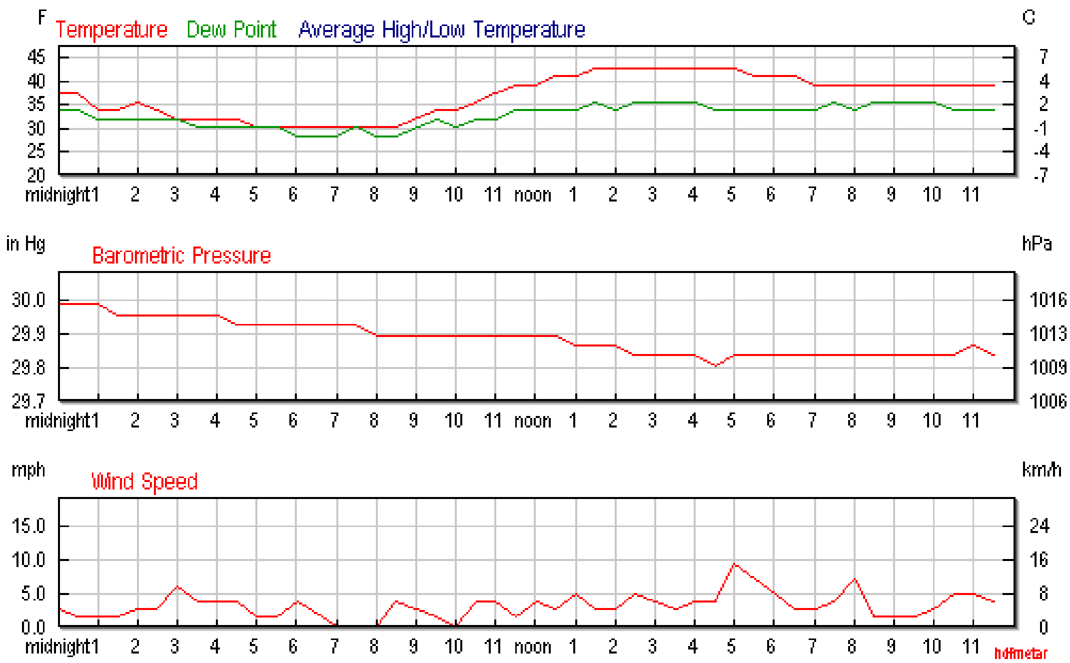


Meteorological conditions on the 27/05/2003

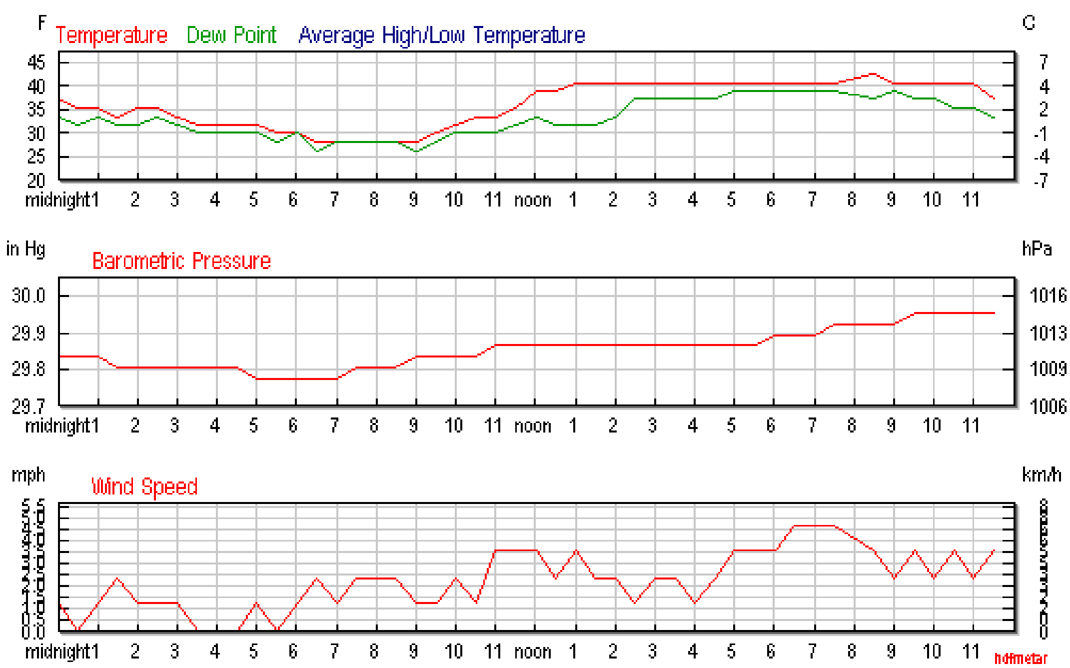


Meteorological conditions on the 28/05/2003

Madrid

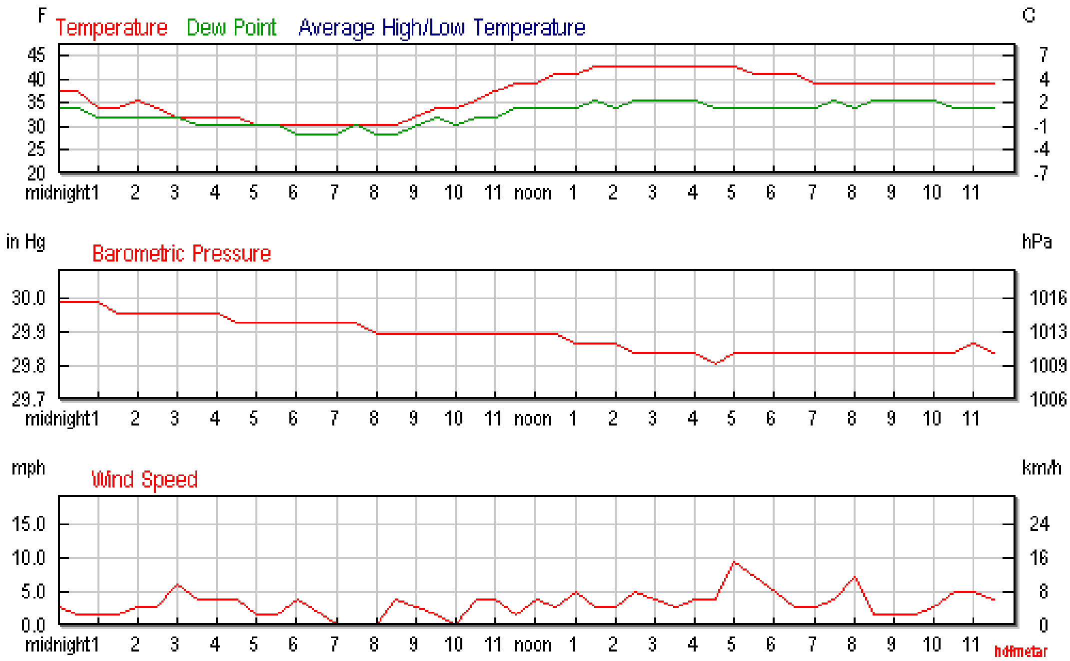


Meteorological conditions on the 03/12/2003



Meteorological conditions on the 03/12/2003

Dublin



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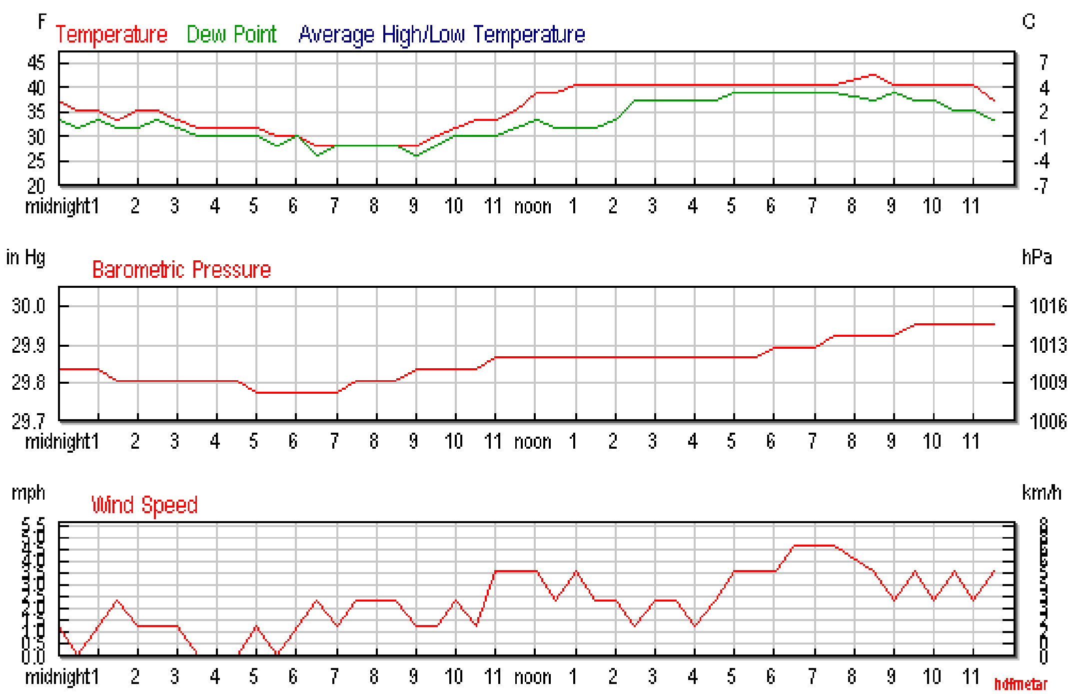

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