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20-21 April 2009, Cranfield University

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1 Introduction

The twelfth in the series of annual review meetings on outdoor and indoor air pollution research in the UK was held on 20-21 April 2009 at Cranfield University and was hosted once again by the Institute of Environment and Health (IEH) on behalf of the Department of Health (DH) and the Health Protection Agency (HPA). As with previous meetings, the principal intention was to facilitate the exchange of information between UK-based research groups and between researchers and those involved in policy and regulatory development. To further strengthen links with researchers elsewhere in Europe, several invited speakers representing leading European centres presented their recent findings and participated in both the formal and informal discussions that are an important part of this annual conference series.

The particular themes of this year's conference were the topical and growing area of research to improve understanding of the toxicology on nanoparticles, the risks of carbon monoxide exposure, modelling of population exposure, and controls and effects of indoor pollution - as well as studies of outdoor pollution. The HPA Annual Air Pollution Research Lecture was presented by Professor Ross Anderson on 'Air pollution and health: putting together the evidence'. The invited keynote address was by Wolfgang Kreyling on 'Toxicokinetics of inhaled particles' and we are grateful to the CORGI Trust for sponsoring a further keynote address on 'Central nervous system effects of carbon monoxide' presented by Dr John Ross

This report of the meeting provides the available abstracts of papers presented under five main themes, together with notes of discussions. In addition to the 19 oral presentations over the two day meeting a further 13 poster papers were viewed. Poster sessions involved an author of each poster giving a short oral presentation to the conference and then being available for further discussion with delegates during a 'viewing period'. Available abstracts of posters are also included in these proceedings. In a few instances, for example because the presentations included preliminary or as yet unpublished information, it has not been possible to include the abstract in this report. PowerPoint presentations of most of the oral papers are available on the IEH website. The proceedings of a number of previous meetings have been published (IEH, 2000, 2002, 2004a/b, 2005, 2007& 2008) and are available to download from the website.

The meeting opened with a welcome from Professor Robert Maynard CBE of the HPA, who noted the continuing support from the Department of Health for research into the health effects of air pollutants and the more recent programme under the Health Protection Agency concerning nanoparticles. He welcomed the opportunity the meeting gave to review and discuss progress in this important area of public health.

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2 Nanoparticles

2.1 Presentations

2.1a Toxicokinetics of inhaled nanoparticles

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Nanoparticles are increasingly used in a wide range of applications in science, technology and medicine. Since they are produced for specific purposes which cannot be met by larger particles and bulk material they are likely to be highly reactive, in particular, with biological systems. On the other hand a large body of know-how in environmental sciences is available from adverse effects of ultrafine particles after inhalative exposure. Since nanoparticles feature similar reactivity as ultrafine particles adverse health effects cannot be excluded and a safe and sustainable development of new emerging nanoparticles is required.

Cardio-vascular effects observed in epidemiological studies triggered the discussion on enhanced translocation of ultrafine particles from the respiratory epithelium towards circulation and subsequent target organs, like heart, liver, spleen and brain, eventually causing adverse effects on cardiac function and blood coagulation, as well as on functions of the central nervous system. There is clear evidence that nanoparticles can cross body membranes and reach and accumulate in the above mentioned secondary target organs.

To determine accumulated fractions in such organs the ultimate aim is to quantitatively balance the fractions of nanoparticles in all interesting organs and tissues of the body and include the remainder body and total excretion collected between application and autopsy. Otherwise substantial uncertainty remains if only selected organs are analyzed. Since these gross determinations of nanoparticle contents in organs and tissues do not provide microscopic information on the anatomical and cellular location of nanoparticles such studies are to be complemented by electron microscopy analysis as demonstrated for inhaled titanium dioxide nanoparticles.

Based on quantitative biokinetics analysis in a rat model we found small fractions of nanoparticles (iridium, carbon, gold, titanium dioxide) in all secondary organs studied including the brain, heart and even in the foetus. Fractions in each of the secondary target organs were usually below 0.1 % of the administered dose to the lungs but depended strongly on particle size in an inverse fashion. However, nanoparticle fractions in soft tissue and skeleton (without blood content) increased total translocated fraction to 5-10 % of the administered dose. Also negatively ionic surface charged nanoparticles translocated more rapidly than positively charged nanoparticles of the same size. Furthermore, nanoparticle accumulation in the rat brain results from both pathways: via the olfactory bulb versus circulation.

These data suggest nanoparticle parameters such as material, size, hydro- / lipophilicity, surface charge, surface ligands and their possible exchange in various body fluids needs to be considered. The current knowledge on systemic translocation of nanoparticles in man and animal models and an estimate of accumulating particle number, surface area and mass in secondary target organs during short-term and chronic exposure will be presented in order to demonstrate the relevance of translocated fractions of nanoparticles.

While acute effects resulting directly from translocated nanoparticles in secondary target organs are likely to be rather low because of the rather low accumulation fractions of nanoparticles tested so far, chronic exposure will lead to cumulative accumulation of insoluble nanoparticles in some secondary target organs which may well mediate adverse health effects including inflammatory diseases in those secondary target organs. In addition, beyond the direct effect of translocated nanoparticles it appears worthwhile to investigate the effects caused by mediators released from the lungs as the primary organ of intake to blood as a result of the nanoparticle interaction with lung tissues.

2.1b Transport of carbon nanotubes across pulmonary epithelium using an isolated perfused rat lung preparation

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Carbon nanotubes (CNTs) are produced in commercial quantities, annual worldwide production in the range of several hundreds tons, and this level of manufacture is expected to increase rapidly over the next decade. There is a growing potential for CNTs to be inhaled in the work place and future potential for inappropriate exposure of the general public if CNTs are released from various consumer products. We are undertaking experiments using an isolated perfused rat lung (IPRL) to investigate the possibility of CNTs translocating across the lung epithelial barriers into the systemic vascular compartment. The IPRL model comprises a rat lung suspended within a glass artificial thorax which is perfused via the pulmonary artery using a physiological Krebs-Heinseleit buffer containing 4% albumin, providing nutrient and oncotic support. The lung tissue is ventilated continuously by positive pressure through a tracheal cannula connected to a ventilator delivering atmospheric air. Suspensions of single-walled and multi-walled CNTs are prepared in a suitable dosing solution and more than 95% of the CNT dose can be delivered to the peripheral lung airspaces of the IPRL by actuation of a propellant – only pressurised metered dose inhaler.

The concentration of CNTs in the dosing solution and, following dosing, in the vascular perfusate is determined using a Nanosight LM20 nanoparticle characterisation instrument. This instrument uses light scattering in combination with the known parameters of Brownian motion of particles in liquid to obtain a particle count. We will be addressing the extent of CNT transport across lung epithelium into the pulmonary perfusate – a parameter in our model correlative to systemic delivery. In all experiments the integrity of the lung epithelial barrier and its permeability will be monitored by measuring the transport of a probe molecules e.g. sodium fluorescein.

2.1c Nanotoxicology of PM: Particle interactions with lung surfactant polymers

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Background and objectives

Exposure to fine particulate matter (PM, e.g. tobacco smoke, air pollution, nanoparticles) has been consistently linked with the development of disease, especially of the heart and lung. Yet the primary interactions of PM-lung surfactant system, and the mechanism(s) by which particles affect the lungs and heart, remain unclear. PM with small aerodynamic diameters – including nanoparticles (NPs), and PM of specific length to diameter ratios, or low density – access the lower lung in greater quantities than PM with larger aerodynamic diameters and initially impact on the surfactant lung lining liquid layer. This layer enables oxygen exchange, lung expansion and also provides primary host defence against depositing foreign material, such as solid and biological particles. Following lung deposition, some particles may then translocate to the circulatory system and other organs (Oberdorster et al., 2005).

A project to examine the primary interactions of particles and lung surfactant was funded in 2007 under the UK Joint Environment and Human Health Programme, and was recently completed (Kendall et al., 2009). The aim was to examine the physical interactions of particles with lung surfactant polymers and the consequences for downstream clinical effects. This paper reports findings from the in vitro studies sub-project. The study objectives were:

1. To test whether lung surfactant polymers are sequestered to particle surfaces.

2. To characterise physical interactions between lung polymers and particles in vitro, using state-of-the-art analytical techniques.

3. To examine the aggregation kinetics of different particles.

Study description

Briefly, we took several particle types, mixed them with lung surfactant polymers and then observed changes caused by sequestering of the polymer molecules on the PM/NP surfaces. The results for fibrinogen are presented here.

The project was based in Chemical Engineering at the University of Birmingham, where state-of-the-art particle and NP characterisation techniques were available. Unique polymer materials were supplied by Southampton University Medical School, and previously developed experimental methods were used (Kendall, 2009). We used a Malvern laser scattering instrument to accurately measure changes in the size distribution and zeta-potential of mono-disperse polystyrene and silica particles and nanoparticles (approx. 100 nm: Polyscience, Germany; Deggusa, Germany). Particles were measured in suspension in nanopure water, saline or PBS, before and after the introduction of fibrinogen. Calculated surface area concentrations based on the measured particle size were used as the dose/concentration metric. A list of particles used in these experiments is given in Table 1.

Table1 Particle and nanoparticles used in these experiments.

Particles	Primary particle size (nm)	Measured particle size, d_p (nm)	Density (g/cm³)	RI
Polystyrene (Ps)	81	81	1.05	1.59
	231	231		
	465	465		
Amine (A-Ps)	91	91		
	241	241		
Carboxylate (C-Ps)	85	85		
	215	215		
	489	489		
Hydroxylate (H-Ps)	196	196		
Sulphate (S-Ps)	210	210		
Silica (200V)	12	106	2.2	1.46
Silica (R816)	12	106	2.2	1.46

Results

At low concentrations of nanoparticles (0.125cm^2/ml), a bimodal size distribution was observed with the first peak (around 20nm) corresponding to the fibrinogen molecules and larger peak for the particles. At higher particle concentrations (1.25mg/ml), the first peak around 20nm disappeared and only the second peak remained. At both particle concentrations, particle size (dotted line, measured at time = 0) increased with time once mixed with fibrinogen, indicating particle aggregation in the fibrinogen solution. Aggregation rate increased at higher particle concentrations. The morphology of S-PS aggregates formed in a fibrinogen-saline suspension was investigated in and bridging was observed between particles. The length of these bridges was from 40nm to around 110nm - approximately twice the length of a fibrinogen molecule (6×6×45nm; Lassen and Malmsten, 1996). Similar flocculation was observed in silica nanoparticles, and with polymer surfactants (Rubio and Kitchener, 1976; Ding and Pacek, 2008), but not in control samples of particles suspended in saline alone. All particle types increased in size over time in fibrinogen and had a similar structure.

For polystyrene particles, an empirical aggregation kinetic model demonstrated differences in aggregation rates for different particles with amine surface groups (A-Ps). Comparing different particle types, silica particle aggregation was much faster than PS particles at the “same” surface concentrations. We suggest that the apparent differences in aggregation rate are in fact due to the method of calculating surface area. Our silica aggregates (~120nm) for which we calculated a surface area, consisted of aggregated primary particles of 12nm. Measurements by the BET (nitrogen adsorption) method report a higher surface area because it includes the entire surface area, including accessible pores in these aggregates. These pores are not included in the calculated surface area based on a perfect sphere, which would underestimate real surface area. Since the fibrinogen molecular size is relatively large (6×6×45nm) we may predict that the effective surface area of silica particles should be between the values generated by BET measurement and by calculation. We therefore concluded that the biologically available surface area is not measured accurately by either method, an explanation consistent with the experimental data.

Conclusions

These experiments indicated that, under controlled conditions, lung polymers interact with particle suspensions. Zeta potential was altered towards zero and particles aggregated, changing the size distributions of mono-disperse suspensions. Changes in particle and aggregate morphology were confirmed using microscopy. Aggregation kinetic models for particles demonstrated differences in aggregation rates between particles of different surface chemistry. Both calculated and measured surface area values were shown to poorly describe the surface areas involved in interaction with fibrinogen. The morphology of particle surfaces was concluded to influence aggregation rate by determining the biologically available surface area.

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2.2 Discussion

Professor Bob Maynard referred to the on-going and fruitful collaboration between the HPA and Professor Wolfgang Kreyling and his colleagues in Munich. He considered the presented work to be exceptionally important and noted the need to understand the physics of nanoparticles in biological media in order to understand the nature and impact of the particles themselves.

Professor Kreyling was asked about the effect on aggregated particles when they impact the surface of the cells. It was suggested that there is strong evidence that TiO_2 particles do not disaggregate, but there is no direct evidence for any other particles. The difference in iridium translocation behaviour for different sized particles/aggregates suggests that they remain aggregated, but the evidence is indirect. When asked about the quantum effects of primary particles, Professor Kreyling suggested that such effects were possible. This was supported by evidence in 12 cell lines exposed to particles of different sizes: particles of 1.2, 1.4 and 1.8 nm caused cell death but 18 nm particles did not. It is possible that the nanoparticle fits into the groove within the DNA and immobilises DNA, but this is highly speculative. The appropriateness of BET (a technique by which particle surface area is measured by the absorption of gas molecules onto the surface) was questioned. Whilst the limitations of BET were acknowledged, the presented results were supported by electron microscopy observations and considered to be valid.

The measurement of the size and behaviour of nanoparticles was also questioned. Both direct and indirect measurements were used in the inhalation studies, using electric mobility measurements and high resolution electron microscopy (direct observations). The SMPS (Scanning Mobility Particle Sizer)-estimated surface areas were close to others measured. The distribution of particles in target organs was also discussed. Professor Kreyling stated that his current studies investigated the location of particles in target organs but were only able to detect particles in the organ of intake and not the secondary organs. Using a higher dose might have been informative, but the experiments did not go above about 20 ng/animal in order to prevent toxic reactions. There is a possibility that there is a "ferry boat" protein that carries the nanoparticle across the cell membrane and allows passage into cells.

Gastro-intestinal (GI) uptake within inhalation studies was questioned. In reply, Professor Kreyling explained that the data were corrected for intake via the GI tract using results for gold particles; approximately 10% pass into the GI tract and 10 to 20% of those pass into the body, thus the uptake fraction is small. The possible uptake of particles by red blood cells was also mentioned. Whilst it is known that red blood cells have no endocytotic capacity, uptake of particles greater than 70 nm (but not larger than 200 nm) does occur. It is not known whether the uptake is energy-dependent. Previous work by Oberdorster has shown that the majority of nanoparticles in the skeleton fraction are found in the bone marrow, suggesting that other mechanisms are at play. Previous work has also considered uptake into lymph nodes and the lymphatic fraction, but these results were not presented.

Dr Ian Matthews, when asked whether future work would consider the dispersion of carbon nanotubes (CNT) in the airways of the lung, stated that the current project duration was 1 year and involved only the study of macrophages from lung lavage fluid, not CNT dispersion *per se*. The study design would answer the question as to whether CNT were small enough to pass through healthy epithelium intact and in sufficient quantities to measure in lung perfusate. It was suggested and agreed that functionalised single-walled CNT (SWCNT) would increase the likelihood of detection of CNT in perfusate as they are more water soluble.

Dr Michaela Kendall was asked whether the smooth spherical Si particles were the same size as the polystyrene particles previously investigated, and replied in the affirmative that both Si and polystyrene particles were approximately 100 nm diameter. The fibrinogen coating of particles was also discussed, and the possible effects of fibrinogen on the dynamic light scattering device. It was stated that excess fibrinogen will cause coated nanoparticles to precipitate out of solution (visually) and that fibrinogen would not interfere with the device. There was discussion on the different methods of surface area measurement, as great variability was seen in presented results, and also on the accessibility of fibrinogen to the inside of the aggregate, which could be influenced by capillary-like action or charged surface effects.

2.3 Poster

2.3a Nanotoxicology: An emerging branch of toxicology - Introducing the National Nanotoxicology Research Centre

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Background and objectives

Nanotechnology is perhaps the fastest developing technology of the early 21st century and nanomaterials are being used in electronics, construction, pharmaceuticals, cosmetics, foods and medical diagnostic products. Materials can be prepared in nano-form as spheroids, dots, wires, tubes and 'fullerene' balls and are characterized by having at least one dimension of less than 100nm (although nanotubes and wires can be many microns in length).

Rapid developments in the field of nanomaterials has led to concerns regarding their toxicity, based on prior knowledge of the health impacts of particulate air pollution and hazardous materials such as asbestos. For example, it is suggested that the health effects attributed to particulate air pollution might be due to the ultra-fine fraction i.e. particles essentially the same in size as nanoparticles. Recent work has also suggested that nanoparticles can, after inhalation, enter the blood stream and preferentially locate in atherosclerotic plaques leading to destabilization, rupture and occlusion of the coronary arteries. Other studies have shown that inhaled nanoparticles can be transported along nerve fibres and may reach the brain, and there are suggestions that nanotubes may have toxicological properties similar to asbestos fibres. Such health concerns and knowledge gaps clearly need to be addressed and the HPA has responded to this challenge by establishing the National Nanotoxicology Research Centre (NNRC) at Chilton, Oxon.

The NNRC is a joint venture between the Radiation Protection (RPD) and Chemical Hazards and Poisons (CHaPD) Divisions of the HPA, in collaboration with six universities, the Medical Research Council Toxicology Unit in Leicester and the Institute of Occupational Medicine (IOM) at Edinburgh. Inhalation facilities at Chilton are currently being refurbished and re-equipped for nanoparticle studies and experimental work is set to begin in 2009. Initial experiments will focus on the biokinetics of nanomaterials (following inhalation and dermal uptake), followed by research into the health effects of nanotubes and the mechanisms of toxicity, surface reactivity and free radical generating potential of nanomaterials.

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3 Modelling studies

3.1 Presentation

3.1a Ozone, heat, and mortality in England and Wales: epidemiology and modelling

Sam Pattenden[1], Ruth Doherty[2], Ben Armstrong[1], Massimo Vieno[2], Ai Milojevic[1], Ben Barratt[3], Zaid Chalabi[1], Mat Heal[4], Sari Kovats[1], David Stevenson[2], Paul Wilkinson[1].

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Background and objectives

Acute associations between ozone and mortality are largely established, but evidence is sparse on interactions between effects of ozone and heat (Bell et al. 2005). Our project aims to combine epidemiological analyses of present-day mortality patterns with climate-chemistry model simulations in order to quantify the temperature and ozone mortality burdens for present-day and under a range of future emission scenarios across the UK at 5 km by 5 km horizontal resolution.

Here we present results of the first stage: (a) an epidemiological study of ozone, heat, and mortality in 15 UK conurbations (in particular whether ozone effects are worse on hot days) and (b) application and validation of a model to predict daily surface temperature and ozone concentrations at 5 km resolution.

Study description

(a) Short-term effects of summer ozone on mortality were estimated using data from 15 conurbations in England and Wales (1993-2003). Two-day means of daily maximum 8-hour ozone were entered into a case-crossover model, controlling for PM_{10}, natural cubic splines of temperature, and other factors. Interaction terms were added to assess whether ozone effects increased on 'hot days', when the 2-day mean temperature exceeded the 95th percentile.

(b) To predict daily temperature and ozone we use the EMEP4UK chemistry transport model over the UK (Vieno et al 2009). The chemical scheme is identical to the widely used and extensively validated EMEP Unified Model for Europe at 50 km X 50 km but EMEP4UK operates at higher resolution (5 km X 5 km). The chemical mechanism is based on the photo-chemistry of ozone, whereby ozone is produced by the oxidation of carbon monoxide (CO), methane (CH_4) and non-methane hydrocarbons (NMHC) in the presence of nitrogen oxides (NOx). Anthropogenic emissions of NOx, CO, NMHC, and particles $PM_{2.5}$, PMCO (coarse particulate matter) are derived from the UK's National Atmospheric Emissions Inventories. Biogenic emissions of isoprene and monoterpenes are also included. The EMEP Unified Model applied across the European domain of 50 km X 50 km provides the chemical initial conditions and boundary conditions for the EMEP4UK model. The EMEP4UK meteorology is driven by the Weather Research Forecast model.

Results

Adverse ozone effects occurred in nearly all conurbations. The mean mortality rate ratio under a linear model was 1.003 per 10 $\mu g/m^3$ ozone increase (95% CI 1.001–1.005), though there was evidence against linearity in the direction of the threshold at about 50 $\mu g/m^3$ (Figure 1). In London and some other conurbations, ozone effects increased significantly on hot days, and the mean interaction rate ratio was 1.004 (1.000-1.008, p=0.04) per 10 $\mu g/m^3$ ozone increase on a hot day. This was reduced in some sensitivity analyses, though remaining significant in London. The mean mortality rate ratio for a 'hot day' effect itself was 1.04 (1.03-1.05). Ozone and hot day effects were strongest among the elderly, and for respiratory mortality. Ozone-heat interaction was strongest for respiratory mortality, and among those aged 0-64. Ozone effects occurred at concentrations below current guidelines.

The EMEP4UK model estimates were validated against fixed-site monitoring data. For example, hourly July/August 2003 model-simulated ozone compared with monitored ozone from AURN in 34 sites showed mean correlation of 0.78, and mean RMSE of 14 ppb (28 $\mu g/m^3$). Detailed analyses of model-simulated surface ozone during the August 2003 heatwave (Figure 2) illustrate the importance of meteorological conditions, through their transport of regional emissions and import of ozone from Europe.

Conclusions

Ozone and heat showed significant, independent effects on summer mortality, particularly among the elderly and for respiratory mortality. There was some evidence that ozone effects were worse on hot days. The EMEP4UK model is capable of providing reasonably precise daily estimates of temperature and ozone concentrations.

Discussion

In ongoing work, the EMEP4UK simulations of daily temperature and ozone are being used to extend the epidemiological study across all the UK, and to estimate health burdens. Using this methodology, future changes in UK health burdens due to a range of future emission scenarios will be quantified. Future work in collaboration with St Georges UL (Richard Atkinson), funded by the DH, will use the EMEP4UK estimates for epidemiology.

Figure 1: Ozone-mortality relationship for the pooled dataset using two-day mean of daily maximum 8-hour ozone (µg/m3), accounting for PM10, day of week, bank holiday, month, and natural cubic spline of temperature.

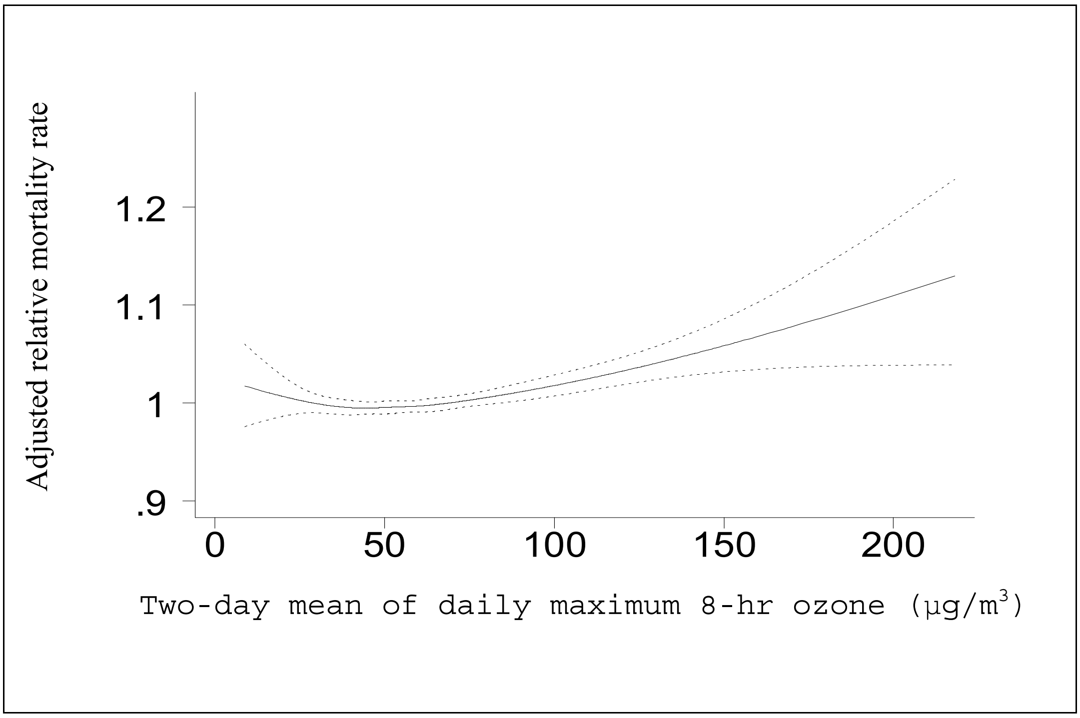
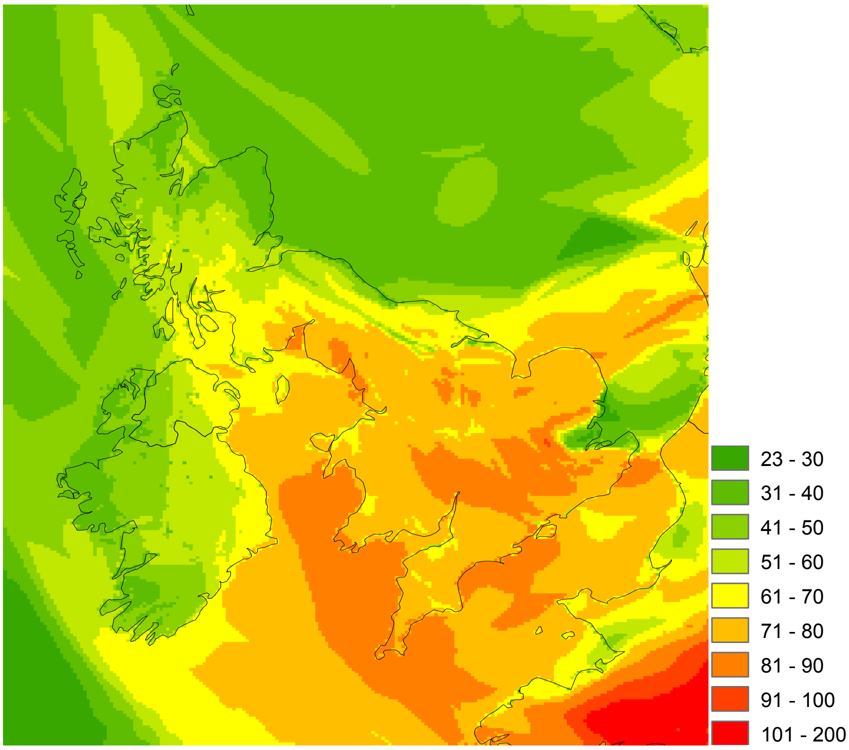


Figure 2: EMEP4UK modelled surface daily-maximum ozone concentrations for the 9th August 2003 Units are ppb (1 ppb ≡ 2 µg/m³).



Acknowledgements

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3.2 Discussion[1]

Areas of discussion included future predictions, hybrid models, effects of ozone, sensitivity analysis and spatial effects.

Professor Ben Armstrong was asked about the bias of his model in rural areas versus urban areas. It was acknowledged that there was reduced accuracy at specific monitoring sites and that the correlation was improved at rural sites, but that the model concentrated on the UK average. Adaptation of the model for the prediction of future conditions (e.g. climate change and urban development) was discussed. The increase in vehicle related pollution was suggested to 'quench' ozone actions and therefore be responsible for the increased mortality in populations. The results were controlled for particulate matter and the results regarding thresholds were suggested to be tentative. The plot of relative mortality rate versus ozone showed an upward inflection at low ozone concentrations; it was speculated whether this could be due to the switching on and off of 'protective genes', but was considered more likely to be due to the statistical fit of the curve, and therefore be artefactual.

Professor Mike Ashmore was asked whether the models, which considered time activity data and outside concentrations, would show the variation in levels in indoor scenarios. Uncertainties within the model were acknowledged, but the box model used was validated in individual homes and offices comparing indoor and outdoor measurements. Important factors were taken into account and the parameters of the model were considered to be representative of air exchange across the city. There was some discussion of the coefficients used in the model that are derived from epidemiological studies using ambient monitoring data. The coefficients used come from the correlation of health outcomes with urban air measurements, and the distribution of exposure is correlated to urban back-ground measurements. Health coefficients have an implicit relationship to the distribution of particle/population exposure in cities, which relate to modelled urban concentrations. The application of studies to policy assessment was commented on, including the issue of roadside concentrations and the need to consider the effect of vehicle emissions on background concentrations.

[1] An additional presentation was given by Professor Mike Ashmore (Modelling personal exposures to PM_{10} in an urban population) for which no abstract is available.

3.3 Poster

3.3a Mass-balance based indoor air quality modelling for PM_{10} sized particulates in naturally ventilated classrooms of an urban Indian school building

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Indoor air pollution is consistently ranked among the top four environmental risks to the public by US-EPA as people spend almost 90% of their time inside the buildings. The school – aged children are especially susceptible to indoor air pollution. In Indian context, most of the school buildings in urban areas are naturally ventilated and located near busy roads. It makes these buildings and its occupants vulnerable to the exposure of pollutants, especially particulate pollution of PM_{10} sized respirable particulate matter (RPM), which is one of the most significant pollutants as a number of health symptoms have been linked to exposure to PM_{10}, including decreased lung function, increased respiratory diseases, cardiovascular diseases, lung cancer etc. (Oberdorster et al., 1995, Pope et al., 1995, Seaton et al., 1995, Peter et al., 1997). Indoor air quality (IAQ) models predict indoor RPM concentrations as functions of their outdoor concentrations, indoor-outdoor air change rates, its indoor *source* and *sinks* (Indoor Pollutants, 1981). The **prime objective** of the present research paper is to analyse the relationship that exists among the indoor-outdoor concentrations of PM_{10} and the influencing parameters i.e. ventilation characteristics, indoor activities, including opening and closing of the windows/doors/ventilators, cleaning practices, occupant's activities, micrometeorology (e.g. wind speed and direction, indoor/outdoor temperature and RH) and traffic conditions (e.g. traffic volume and traffic type) for school hours (8:0 a.m. to 2:0 p.m.) of weekdays as well as weekends during non-winter and winter periods and to develop a single compartment mass balance based IAQ model to predict the indoor concentration of PM_{10} in classrooms of such naturally ventilated urban school buildings.

Site description

A three–storied naturally ventilated school building with total height of 14 meters, located in close proximity to an urban roadway and surrounded by commercial and residential area has been selected for the study. It is rectangular in shape and contains four blocks (figure 1). The pedagogic block towards flyover roadside is occupied by children of junior section (from standard I to VIII) and the other one is occupied by senior section (i.e. standard IX to XII). The junior section pedagogic block has been selected for the study as it is near to an urban flyover road and occupied by children of age group from 6 to 14, which is a more sensitive group of occupants. Figure 2 describes the line sketch of the school building showing the monitoring locations. Locations 1, 2 and 3 are classrooms on the first floor, *herefrom*, named as site 1, 2 and 3, respectively; and location 4 is the classroom on the second floor of the similar block just above the site 1, *herefrom*, named as site 4. The total area and volume of the classrooms are $45.57m^2$ and $177.73m^3$, respectively. The furniture in classrooms (chairs and tables) is mostly wooden type. Every classroom contains one iron almirah, one black board, five ceiling fans, three windows, two ventilators and one door opened into the corridor.

Data description

Indoor and outdoor concentrations of PM_{10} along with occupants activities, ventilation conditions, traffic and meteorological data (temperature, rH, pressure, wind speed and direction), have been monitored during school hours from 8:0 a.m. to 2:0 p.m. for weekdays and weekends during winter (months of November, December, January and February) and non-winter (months of August, September and April) periods. Mass-balance based IAQ model has been coded in C^{++} and the programme code has been named as HEMANYA. Data collected at site-1 has been used for model formulation and data of site 2, 3 & 4 have been used for model validation.

Model description

Principle of macroscopic single compartment mass balance based model developed by Hayes (1989, 1991) has been modified for predicting the indoor concentrations of PM10 assuming isothermal conditions. Equation 1 represents a modified single compartment mass balanced based IAQ model for PM10 (NVIAQMpm10) in naturally ventilated classrooms of a school building.

$$dc_i / dt = ka_M (c_o - c_i) - kK(A/V)c_i + S/V$$

where,

$NVIAQM_{pm10}$ = Naturally Ventilated Indoor Air Quality Model for PM_{10}
$NVIAQM_{pm2.5}$ = Naturally Ventilated Indoor Air Quality Model for $PM_{2.5}$
Co = outdoor concentration
C= indoor concentration
V= room volume
a_M = infiltration flow rate (*the rate at which air passes into a building as a result of structural leakage, e.g. through cracks around windows and doors, through open doors)*. It is expressed in air changes per hour (ACPH or ACH))
k= mixing factor (*the fraction of the pollutant mass that is completely mixed with room air*. Its value ranging from 1/3 to 1/10 and possibly lower value for very large and poorly ventilated spaces. For completely mixed space, value is 1 as reported in Esmen, 1982)
K = particle deposition velocity (for coarse–mode particles of size >2.5 μm to 15 μm, K has been measured as 0.06 m/min by Wechsler et al., 1983)
S = indoor source generation term
A = interior surface area

Following Dockery and Spengler (1981) and later Hayes (1991) approach, mass balance equation has been solved recursively by integrating it over an averaging time period T and assuming that the parameters in the equation remain constants over the averaging period. Proportionality constant R_c has been introduced in the model to represent lump of all activities occurring inside to improve the performance of the model.

Results & Discussion

The findings of exploratory data analysis explains that meteorological parameters show significant linear relationship with outdoor PM_{10} concentrations during both weekdays as well as in weekends, whereas, during weekdays, indoor PM_{10} concentration does not follow the trends with such parameters at particular hours of the school e.g. at start and closing of the school, recess times etc. It happens because, occupants and their activities/movements and classroom activities e.g. chalk board and cleaning become significant indoor sources. During intense indoor activities, PM_{10} concentrations increase substantially. In general, there exists a positive linear relationship between particulates concentration and RH; and negative linear relationship with temperature and wind speed. Indoor PM_{10} concentrations show significant negative linear relationship with ventilation rate. The traffic volume on the flyover road near the school building during weekdays is 9,755 vehicles/ hour during school hours. However, there is a substantial reduction in traffic volume during weekends with average traffic flow of 4,296 vehicles /hour during school hours. Measured concentrations of PM_{10} do not show a significant linear relationship with outdoor traffic volume. However, $PM_{2.5}$ and $PM_{1.0}$ sized particles indoors as well as outdoors show direct linear relationship with traffic volume, which indicates that traffic contributes particulates of <2.5μ in size. Ventilation rates in classrooms change seasonally, daily and even hourly depending on the classroom characteristics, occupants' activities and movements and meteorology. It increases in non-winters and weekdays when windows, doors and ventilators are open and fans running. However, in winters and weekends, it decreases. IAQ model for PM_{10} ($NVIAQM_{pm10}$) has been able to predict the indoor concentrations of these particulates with reasonable accuracy. However, it exhibits a tendency to under predict indoor particulate concentrations at the start of the school hour. Newly introduced proportionality constant, R_c coupled with deposition term in $NVIAQM_{pm10}$ improves the performance of the model with its values within a certain range ($R_c = 0.05$ during weekdays and at $R_c = 0.02$ during weekends). The *d*, R^2 and NMSE statistics of $NVIAQM_{pm10}$ Model validation results indicate that modelled indoor particulate concentrations follow changes in the observed indoor concentrations satisfactorily (except at site -3 during weekdays) and predict concentrations with reasonable accuracy.

4 Indoor air pollution

4.1 Presentations

4.1a Health implications of polycyclic aromatic hydrocarbons in indoor environments

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Background and objectives

There has been extensive research over many years on the concentrations of polycyclic aromatic hydrocarbons (PAH) in outdoor air (e.g. Baek et al. 1991). This continues to this day with considerable controversy over the predominant sources of PAH in the atmosphere. Concentrations have fallen greatly since the time when coal burning was widespread in urban areas, but there continues to be a significant residual concentration arising from sources such as road traffic (Harrison et al. 1996). Application of Unit Risk Factors suggests that this is one of the more important contributors to the carcinogenicity of outdoor air (Harrison et al. 2004).

The main evidence for carcinogenicity of PAH arises from studies in occupational environments such as coke ovens and aluminium smelters where concentrations of PAH are highly elevated above those normally encountered in outdoor air (Armstrong et al. 2004). The UK Expert Panel on Air Quality Standards recommends an upper limit annual average concentration of PAH for outdoor air (and hence public exposure) of 0.25 ng/m^3 of benzo(a)pyrene taken as a marker of a mixture as a whole (EPAQS 1999). One matter which concerned the Expert Panel was to ensure that the proportion of the carcinogenic potency attributable to benzo(a)pyrene was comparable between the occupational environment from which cancer risk had been evaluated and outdoor air. By applying relative potency factors to the different PAH compounds (termed congeners), it was established that benzo(a)pyrene represented a relatively similar proportion of total carcinogenic activity of air within the two environments.

Polycyclic aromatic hydrocarbons are also present in indoor air, sometimes at concentrations well elevated above those out-of-doors (Ohura et al. 2004). This is because of the presence of indoor sources such as smoking and cooking. Additionally, in the absence of such sources, indoor air is polluted by the infiltration of outdoor air. Currently, there is very limited information especially from the United Kingdom on the concentrations and profile of PAH compounds in indoor air.

Data, as well as unanalysed samples, collected during the MATCH study (Measuring and modelling of Air Toxic Concentrations for Health effect studies and verification by biomarker) have been analysed in order to assess typical ranges of concentrations, congener profiles and carcinogenic potency of PAH indoors and compare them with those in ambient air.

Overall aim and specific goals of research

The specific goals of this research were to answer the following questions:

- What are the typical ranges of concentrations of PAH in indoor environments?
- What the profile is of PAH compounds in indoor air and how does this compare with the profile in outdoor air?
- How great is the overall carcinogenic potency of the mixture of PAH indoors compared to that out-of-doors?
- Is the profile of PAH compounds and hence the relative potency of the mixture similar indoors and outdoors?
- Is the current system of estimating the health effects of PAH from the concentration of one marker compounds (i.e. benzo(a)pyrene) an approach that could be used for indoor air, and if so, could the same numerical guideline be applied?

Study description

Microenvironment sample collection

The targeted polycyclic aromatic hydrocarbons are acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, dibenzo(ah)anthracene and coronene.

Using specifically designed pumped microenvironment samplers, samplers were collected in several indoor microenvironments such as homes, workplaces and other public indoor environments (e.g. pubs, restaurants, libraries and museum) as well as in outdoor environments such as roads, background and pedestrian streets and parks. Particle phase polycyclic aromatic hydrocarbons were collected onto a pre-treated quartz fibre filter. Samples were collected for short time periods (e.g. 12 hours for homes, 8 hours for offices and 2 hours for other microenvironments) sampling 4.3 m^3 of air in homes and workplaces and 1.44 m^3 of air in other public indoor environments and outdoors, due to technical restrictions in sampling flow rates (Harrison et al. in press).

Analysis

Particle-phase PAH collected onto pre-treated quartz fibre filters were extracted with solvent, purified and concentrated prior to analysis with a gas chromatograph and mass selective detector. Chromatographic separation was achieved using a HP5-ms capillary column (30 m, 0.25 mm id 0.25 µm film thickness) (Harrison et al. in press).

PAH Profiles

The PAH profile was calculated as the relative proportions of the individual PAHs to the sum of the total PAHs. A second PAH profile was also calculated as the relative proportions of the individual PAHs to the carcinogenic marker benzo(a)pyrene. PAH congener profiles have often been used as a method of determining the relative contribution of different sources to a series of samples.

Total carcinogenic potential of PAH mixtures

There are a number of sources of information on the relative carcinogenic potency of PAH such as those established by the US EPA (1993), the World Health Organization International Programme on Chemical Safety (1998) or the Expert Panel on Air Quality Standards (1999). These data were used to calculate the total carcinogenic potential of typical carcinogenic activity represented by benzo(a)pyrene. These profiles of carcinogenic potency were compared not only between indoor and outdoor samples but also with data derived from PAH profiles from occupational environments which were used in setting the EPAQS standard for PAH.

Results and discussion

Comparison of the measured polycyclic aromatic hydrocarbons concentrations measured indoors and outdoors show that indoor PAH levels are generally higher than those measured out-of-doors whenever Environmental Tobacco Smoke (ETS) is present. Sampling was carried out before the ETS ban on the 1st of July 2007, and in the case of pubs and restaurants levels of benzo(a)pyrene of 0.62 and 0.27 ng/m^3 (geometric mean) respectively were measured, B(a)P levels averaged 0.09 ng/m^3 in ETS-free environments such as homes. Levels measured in streets (i.e. 0.21 ng/m^3 for trafficked roadsides) are higher than home indoor levels, although lower compared with ETS-exposed environments.

EPAQS proposed benzo(a)pyrene as a marker for the carcinogenic potential of the PAH mixtures on the basis that the percentage contribution in ambient air was similar to that in occupationally exposed environments, where high concentrations were linked to excess cancer incidence. The current results derived from a partial dataset show that the percentage contribution of benzo(a)pyrene to the total carcinogenic potential of the mixture in outdoor and indoor environments is similar, ranging between 50-56%, to that in occupational environments (i.e. 47%), independent of the presence of environmental tobacco smoke. The results also imply that in recent data B(a)P is representing a slightly higher proportion of the overall carcinogenic potency compared with the aluminium smelter and with 1990s outdoor air.

Conclusions

The results generated from the comparison of polycyclic aromatic hydrocarbon concentrations show these to be generally higher in those indoor environments exposed to Environmental Tobacco Smoke.

In the partial dataset, as a proportion of total PAH, benzo(a)pyrene is similar outdoors, indoors (ETS-free) and in ETS indoor environments. Combining the relative concentrations with the relative carcinogenic potencies, benzo(a)pyrene shows a similar contribution to the carcinogenic potential of the PAH mixture independent of the environment assessed or the presence of ETS. This contribution represents a similar proportion of the carcinogenic potential of the mixture as in PAH samples from the aluminium smelter and from outdoor air used in setting the EPAQS standard for PAHs.

These results suggest the suitability of benzo(a)pyrene as a marker for the carcinogenic potential of the PAH mixture, but also emphasize the effect of Environmental Tobacco Smoke as an indoor PAH source with carcinogenic potential.

Acknowledgments

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4.1b Issues in indoor air quality: insights for policy development in Europe from the EnVIE project

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The European Union is increasing the efforts towards developing efficient policies for reduction of health hazards associated with indoor air (IA). The co-ordination action on Indoor Air Quality and Health Effects (EnVIE) (EU FP6, 2004-2008) involved in partners 18 European Institutions from 11 countries covering a wide spectrum of scientific themes related to health and the built environment, as well as, with proven ability to disseminate and interface the outcome of the project with policy making.

The main objective of EnVIE was the assessment of the policy relevance of health effects, exposures and pollution sources, accounting for isolated agents and mixtures, and considering the implications for thresholds and safety margins for the general population and for people at work. Specifically it addressed how indoor air quality contributes to the observed rise in asthma and respiratory allergy in Europe as well as in other acute and chronic health impacts. To respond to these objectives, EnVIE identified three major and complementary issues as key questions regarding indoor air, estimated manageable in terms of scientific and technical proximity: health effects, exposure and characterisation of spaces and sources.

EnVIE was the first European indoor air project which chose public health, more specifically the total burden of disease (BoD), as its starting point and assessment criterion – instead of, e.g., indoor air pollutants or sources – and which intentionally focused only on the diseases and their causes which are most important at European level. Because the role of environmental tobacco smoke (ETS) an indoor air pollutant and cause of disease is already well established – and critical where still present – and the ETS policies are straightforward and already advancing across Europe, ETS was not included in the following analyses.

The most important indoor air quality (IAQ) related health effects relevant for all Europe and representing the bulk of the BoD attributable to IAQ was created. For each of the health effects the total national BoDs were first obtained from WHO and national statistics, and the fractions attributable to IAQ were estimated to compute the respective indoor air burdens of disease. The final list consists of cardiovascular diseases (estimated total EU-27 wide IA BoD, 670 thousand DALY/year), asthma [and symptoms of respiratory allergies] (660), sensory irritation [e.g., sick building syndrome, SBS] (520), lung cancer (130), carbon monoxide poisoning (100), chronic obstructive lung disease [COPD] (64) and respiratory infections (48).

Based on the analysis, the most significant causal pollutants in indoor air for the health were identified. Most of these are responsible for more than one disease, so their contributions were assessed as the sum of all adverse health effects for each pollutant. The short list consists of [mostly particulate] combustion products (950), bioaerosols (690), volatile organic compounds [VOCs] (320), CO (100), pathogens (95) and radon (84).

Finally the contributions of the sources of indoor air pollution were evaluated, accounting for that most sources are responsible for more than one contaminant. The BoD associated with the main sources are the outdoor air (1 100), water systems, dampness and mould (360), heating and combustion devices (290), furnishings, interior materials and electric appliances (130), soil at the building site (84), cleaning and other household chemicals (73), ventilation and air conditioning systems (52) and building materials (29). After tobacco smoke the most important source of indoor air pollution and cause of the adverse health effects of contaminated indoor air is outdoor air.

EnVIE also evaluated the public health gain potentials of IAQ policy options. The most beneficial policies include smoking bans, ventilation systems that prevent the penetration of outdoor air pollutants to indoor air, building management [technical standards, training, maintenance, documentation] policies, dampness and mould prevention policies, and policies for harmonised testing and labelling of building and furnishing materials and household products.

Acknowledgement:

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4.1c Development of WHO guidelines on indoor air quality

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The WHO Working Group meeting in October 2006 recommended that WHO develops Guidelines on Indoor Air Quality for the following three groups of factors: a set of specific pollutants, biological agents and products of indoor combustion (1).

The specific pollutants for which the development of the Guidelines was recommended are: benzene, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, particulate matter, radon, halogenated compounds (tri- and tetra-chloroethylene) and PAHs (BaP). Based on the review of evidence on health aspects of these pollutants, initiated in the summer of 2008, WHO Working Group will recommend the guidelines for these substances in mid-2009.

Biological agents in the indoor environment are attributable to dampness and inadequate ventilation. Excess moisture on any material leads to growth of microbes such as moulds, fungi and bacteria, which subsequently emit spores, cells, fragments and volatile organic compounds into the indoor air. Moreover, dampness initiates chemical and/or biological degradation of materials which also causes pollution of the indoor air. Dampness has been therefore suggested to be the strongest and most consistent indicator of risk for asthma and respiratory symptoms. Systematic review of the accumulated evidence indicates that for a number of respiratory symptoms the evidence is sufficient to conclude their association with dampness and mould. Following the review, the guidelines on mould and dampness were recommended by a WHO WG in October 2007 (2). The recommendations say that persistent dampness and microbial growth on interior surfaces and in building structures should be avoided or minimized, as they may lead to adverse health effects. Main approaches to prevention or elimination of damp indoors are also given. Publication of the Guidelines, including background material, is planned for 2009. Separate work is planned on allergens related to house dust mites and pets.

The guidelines on combustion products will refer to particulate matter as well as carbon monoxide as good indicators of a large group of pollutants emitted in combustion of solid fuels. The guidelines will also cover plausible technical solutions to effectively control the sources and exposure pathways, in particular stove venting, household ventilation, combustion quality and fuels quality. The evidence review will be initiated as soon as the necessary resources are identified.

The guidelines will be available on http://www.euro.who.int/AIQ.

(1) *Development of WHO Guidelines for indoor air quality* Report on a WHO meeting, Bonn, Germany, 23-24 October, 2006. http://www.euro.who.int/Document/AIQ/IAQ_mtgrep_Bonn_Oct06.pdf

(2) *Development of WHO Guidelines for indoor air quality: Dampness and mould.* Report on a WHO meeting, Bonn, Germany, 17-18 October, 2007. http://www.euro.who.int/Document/E91146.pdf

4.1d Indoor air quality and ventilation in energy efficient homes: implications for health and well being

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Background and objectives

Housing accounts for around 30% of the UK's total energy use and 27% of its carbon dioxide (CO_2) emissions. As part of policy to combat the effects of climate change, the government intends that all new homes will be 'zero carbon' by 2016, with a progressive tightening of the energy efficiency aspects of the building regulations in advance of that target date. The changes to the building regulations will be complemented by the Code for Sustainable Homes (CSH) which measures the sustainability of a new home against nine categories of sustainable design and construction.

Recent research by the National House Building Council (NHBC) Foundation has highlighted concerns of homeowners and builders about the possible adverse consequences on indoor air quality of the greater airtightness of the building envelope that is required to improve energy efficiency (Davis and Harvey, 2008). The lack of air infiltration could lead to poor air quality because stale indoor air is not replaced at a sufficient rate by fresh outdoor air, resulting in a build up of concentrations of pollutants released by building materials, furnishings and consumer products, as well as those from people and their pets. Associated with this is the risk of high humidity and condensation, with the attendant risks of mould growth, damage to structures and proliferation of house dust mites.

In the case of homes built to Level 4 (and above) of the CSH, it is expected that, to achieve an acceptable indoor climate while satisfying the demands of the CSH with respect to energy use, mechanical ventilation with heat recovery (MVHR) will be applied. There is a very real need to assess whether the MVHR products currently available on the market and being installed are able to maintain good indoor air quality throughout the year in very air tight dwellings.

Moving from largely passive ventilation in most dwellings to a 'sealed' unit relying on mechanical systems is a large step change in terms of culture in the UK, and requires an understanding of the operation of the systems employed to ensure good performance. To facilitate this change, developers and ventilation system manufacturers must render their use intuitive and straightforward.

The operation of mechanical ventilation (MV) systems in very well sealed dwellings during warm periods raises questions about their potential effectiveness at removing heat and minimising overheating. Currently this is not effectively considered in the design or regulatory assessment of systems for dwellings. Evidence of overheating is currently largely anecdotal or based on dynamic thermal modelling predictions, with little real data on the actual extent of the problem.

There is the very great possibility that householders would seek to counteract poor air quality or lack of the feel of 'freshness' by opening windows on a regular basis, and thereby offset the inherent benefits of a structure built to standards of high energy efficiency fitted with a continuously operating ventilation system. This, and other occupant interventions (caused, for example, by concerns regarding noise and elevated energy costs as well as air quality issues) could result in adverse air quality with consequent risk of condensation, mould growth, dust mite infestation and elevated VOC concentrations – all of which could pose a health risk to occupants. This could be compounded by extensive use of composite and other polymeric materials, including those used to achieve high levels of insulation; such materials could provide a stronger source of chemical emissions than traditional materials.

IEH (Cranfield University) and BRE have undertaken a review of the current state of the art of airtight houses in the UK, and elsewhere in the world, with regard to the indoor environment they provide. The report, currently in draft form, has identified aspects of health that could be impacted, either adversely or beneficially, through living in Code 4 to 6 homes. Further research needs are identified, and the NHBC Foundation and the draft report authors would welcome views and contributions from other interested groups.

Possible consequences of highly energy efficient homes

A number of characteristics of highly energy efficient homes can be identified as having a particular impact on indoor air quality and other aspects of the internal environment that could impact on the health and well being of building occupants. It is also possible that some characteristics result in no net change to health and well being relative to less energy efficient homes. If there was no benefit, consideration should be given to whether the current state of the art is acceptable for the future or whether some form of intervention is required to achieve improvement.

There is no published study of highly energy efficient homes in the UK that monitors the range of air quality and other factors that can affect occupant health and well being. Of course, only a limited number of homes currently exist at Code 4 and above and the definition of Code 6 is currently the subject of government consultation. However, it is notable that comprehensive studies of the indoor environment of UK homes are few. The BRE study of 37 homes built following introduction of the 1995 building regulations measured airtightness, ventilation rates and several pollutants (NO_2, VOCs , formaldehyde, CO) over two sampling periods during one winter and one summer (Dimitroulopoulou et al. 2005). These homes were all in southern England and found to be no more airtight than the general building stock and none of the homes were mechanically ventilated. The Indoor Environment Survey of England addressed several pollutants (NO_2, VOCs, formaldehyde, CO) but was carried out over 10 years ago (Coward et al. 2001). The ALSPAC study also covered mites, bacteria and fungi, but this was limited to a particular population group in 174 dwellings in one city and was carried out more than 15 years ago (Berry et al. 1996, Humfrey et al. 1996).

Possibly more informative to our understanding of highly energy efficient homes are studies in other countries with experience of building airtight homes, particularly for very cold climates, such as in Canada, central Europe, parts of the USA and Scandanavia. Certainly these provide experience of mechanically ventilated buildings, often with heat recovery, which is likely to be necessary to meet targets for Code 5 and 6 homes. However there are differences from the UK with regard to climate, local building practice, sourcing of materials, and the economic, cultural and social characteristics of the occupants. It is notable that published studies relating to occupant health and well being have largely addressed thermal comfort and occupant satisfaction, and none have been undertaken in the UK.

Because of its central role in determining the exposure of the population to air pollution, a case could be presented for more research into indoor air quality in homes. For the purposes of this review, however, the following main features of highly energy efficient homes are considered, together with their possible impact on air quality parameters relative to current building regulation requirements.

- Increased airtightness
- Increased winter internal temperature
- Summer internal temperatures

- Mechanical ventilation
- Heat recovery aspect
- Materials for construction
- Ground contaminants.

Recommendations for further research

It is recommended that two broad research areas are urgently required (further detailed in the draft report):

- Addressing the performance of products and designs for high energy efficiency homes and provision of guidance for installers and users.
- Post commissioning and post occupancy evaluation of performance of buildings meeting Code 4 to 6 requirements.

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4.1e Measuring indoor air pollution in homes in Malawi: a methodological paper

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Background and objectives

Exposure to smoke from the burning of biomass fuels is estimated to account for about 1.2 million premature deaths per annum and between 2 and 3% of global healthy life years lost (Smith *et al*., 2004). Biomass smoke is produced by the burning of solid fuels such as coal, wood, charcoal, crop residues and dried cow-dung with more than 80% of homes burning such fuels in large parts of sub-Saharan Africa, India, China and South-East Asia. IARC have classified smoke from biomass fuels as class 2a (probably carcinogenic) and class 1 when coal is used in domestic settings but most of the health burden arises from increased risk of Acute Lower Respiratory Infections (ALRIs) particularly in children and increases in cases of Chronic Obstructive Pulmonary Disease (COPD), asthma and tuberculosis (Fullerton *et al*., 2008).

Exposures to biomass smoke will vary considerably between countries, regions and even households within areas depending on fuel type, stove or heating design, house construction and personal behaviours including the practice of cooking outdoors or on veranda type settings. Characterisation of exposure to biomass smoke within a particular country or region can play an important role in improving our understanding of the relationship between health effects and indoor air pollution and, importantly, can assist in the targeted development of interventions designed to reduce personal exposure to biomass fuels smoke while also considering local conditions together with cultural and practical influences.

The ideal assessment method to gain the most complete picture of exposure variability and determinants would be long-term personal exposure sampling within the breathing zone. This is difficult to achieve in occupational settings and is clearly impossible in domestic settings in the developing world where resources and technological capabilities are often severely constrained. There are many additional problems relating to recruitment of participants, lack of mains electricity to power sampling equipment and the very real possibility of study participants modifying their usual behaviour while instrumentation is positioned in the home are all likely to add further layers of complexity to this type of work.

This paper uses an example of a small study carried out in urban Blantyre and rural Chikwawa in Malawi in order to present details of typical methodological problems encountered carrying out exposure characterisation work in homes in less economically developed countries. Details of particulate matter levels and concentrations of carbon monoxide measured using a variety of methods are also summarised.

Study description

The air sampling study was carried out during April 2008 and was part of a wider study looking at the relationship between exposure to indoor smoke and pulmonary defence mechanisms in a population at risk of HIV-related pneumonia. Ethical approval was provided by the Research Ethics Committee of the College of Medicine, University of Malawi and the Liverpool School of Tropical Medicine

Recruitment and participation

Participants in urban Blantyre were randomly selected from 360 Blantyre residents who had previously volunteered for studies at the Malawi-Liverpool-Wellcome Trust Clinical Research Programme (MLW). In rural Chikwawa homes were selected using a quasi-snowball strategy using established contacts from the local Health Surveillance Officers in the area. Contact was initially made with village elders and the project was explained to the community. As village homes are each very similar; the first home was chosen as closest in a random direction from the village elder's house and a snowball sampling strategy was then used to select the other homes to be sampled within that community.

A small monetary incentive was provided to participants primarily to compensate them for the loss of time while completing our study questionnaire and for the inconvenience of having the air sampling instruments in their home for a 24 hour period.

Air sampling

Sampling was carried out over a typical 24 hour period in the main living area of the home. A mixture of methods was used to characterise indoor air pollution within homes. These were:

- Gravimetric sampling for either total inhalable dust or respirable dust fractions using methods described in MDHS 14/3 (HSE, 2000).
- Photometric methods to measure and log real-time concentrations of fine particulate matter using either a Sidepak Personal Aerosol Monitor (AM510) or a UCB Particulate Matter (UCB-PM) monitor (Chowdhury *et al*., 2007).
- Carbon monoxide measurement using HOBO real-time data loggers.

Results

Practical and logistical difficulties

The main difficulties encountered were:

1. Equipment transportation and customs problems. The equipment required for this work had to be sent from the UK to Malawi and was valued at close to £20,000 for the purposes of insurance. The logistics of arranging this and ensuring the package does not encounter problems with customs should not be under-estimated and input from a logistics specialist dealing with deliveries to that area was beneficial.

2. Travel and personal security. Road travel in LEDCs presents particularly high risks to research staff. Vehicles are often poorly maintained and observance of rules of the road can be limited. Travel in rural areas is often off-road and the risk of injury and/or damage to sensitive equipment should be considered. Local guidance should be sought but in our case it was deemed inadvisable to travel outside the main urban area of Blantyre after dark. There are also personal security issues in entering homes and our protocol always had 2 researchers to place and uplift sampling equipment. Equally, there can be cultural issues about male researchers entering homes where women are at home alone and the ideal is to have a mixed male and female research team.

3. Collecting questionnaire data. Part of the study involved collecting data on the respiratory health of the participant and also details of household possessions in order to quantify the economic status of the home. It is important that this is done as sensitively as possible, in a private place where the participant feels comfortable answering the questions. The skills of an interviewer experienced in conducting this type of data collection are essential in order to identify the most appropriate method of doing this and to put the subject at ease.

4. Use of incentives to recruit participants. We told participants that we would provide a ‘small token of thanks’ on completion of the sampling in their homes. This was partly to reimburse them for their time and the inconvenience of having equipment in their home for 24 hours but also served as a way of ensuring that equipment was stored safely in their home and not damaged during the time there. Some participants had been previously involved with MLW studies and there was some evidence of ‘incentive inflation’. One subject in particular felt strongly that the reward should have been larger than that paid for their involvement in a previous research study.

5. Battery life issues for the pumped samplers. The Apex Sampling pumps employed ran for between 21 and 26 hours. The Sidepak devices also had variable battery life depending on the use of NiMH battery packs or AA alkaline battery options. On the small numbers of occasions where urban homes had electricity supply and we attempted to use this to power our devices this was found to be unreliable. Evening visits to change pump or Sidepak battery packs were attempted on some occasions but often road conditions in rural areas and security considerations made this impossible. Re-charging NiMH units was not reliable due to power outages while sourcing local good quality AA batteries was difficult and expensive.

6. Equipment noise. The Apex sampling pumps and the Sidepak Personal Aerosol Monitors emit a steady hum during operation. This can be annoying particularly at night in quiet rural locations. We placed our pumps in small lockable cash-boxes that we padded with noise-insulating material in order to minimise the disturbance to participants.

7. Modification in personal behaviour. Despite explanation to participants that we wished to collect information of smoke levels in homes over a typical 24 hour period there were concerns that households changed their behaviour. There was evidence that the visit of the study team and presence of the equipment in the home may have attracted more visitors to the home leading to more cooking, smoking or use of lighting/lamps in the home during the sampling period than would normally have occurred. Conversely, one case was identified where the participant reported not cooking indoors as she would normally have done for fear that the smoke would damage the instruments.

8. Personal sampling. Devices were placed in the main living area of the home. It is likely that this will under-estimate personal exposures during cooking activity where the individual lighting the fire and cooking will have higher exposures due to close proximity to the source. The fixed location may over-estimate exposures during periods when the participant spends time outdoors either remote to the home or on the khondi (or veranda) area.

Air sampling results

A total of 3433 hours of data on indoor air pollution levels was gathered from 62 homes. Not all homes had all instruments placed in them. Tables 1 and 2 present time-weighted average levels for particulate matter concentrations in study homes measured using either gravimetric methods or photometric devices. Table 3 presents similar data for carbon monoxide measurement. A more comprehensive description of the air quality data collected is presented elsewhere (Fullerton *et al*., submitted).

Table 1: Time weighted average gravimetric data for respirable and total inhalable dust measurements

	Urban homes (SD)	Rural homes (SD)
N	15	14
Respirable dust (μg/m^3)	185 (197)	268 (214)
Total inhalable dust (μg/m^3)	204 (69)	811 (541)

Table 2: Time weighted average data for respirable dust measurements from Sidepak and UCB-PM devices

	Urban homes (SD)	Rural homes (SD)
N (Sidepak/UCB)	13/24	13/23
Sidepak respirable dust (μg/m^3)	70 (80)	180 (270)
UCB-PM respirable dust (μg/m^3)	150 (360)	250 (400)

Table 3: Time weighted average data for carbon monoxide measurements

	Urban homes (SD)	Rural homes (SD)
N	30	28
Carbon monoxide concentration (ppm)	6.14 (6.48)	1.87 (2.42)

Respirable dust levels in both urban and rural homes using gravimetric methods are approximately 7 to 10 times the World Health Organisation's guideline value for $PM_{2.5}$ concentrations in outdoor air (WHO, 2006). Carbon monoxide concentrations are higher in urban homes than rural homes. This may be due to the more extensive use of charcoal in urban dwellings. Peak concentrations of both respirable PM and carbon monoxide were measured during cooking periods with values of respirable dust exceeding 20,000 μg/m^3 and CO at values of over 100ppm.

Discussion and Conclusions

The practical and logistical difficulties of carrying out studies on indoor air quality in homes in developing countries should not be under-estimated. The logistical problems relating to transport of equipment and having limited access to equipment spares and facilities to repair instruments means that a wide-range of kit may be required. Problems linked to participant recruitment and behavioural modification are important to consider when interpreting the results from such surveys. Consideration of the safety of the research team is paramount and sensitivity to local and cultural norms should be observed at all times when entering participants' homes to collect data.

The World Health Organisation guideline on outdoor air recommends that 24h average $PM_{2.5}$ exposures should not exceed 25 μg/m^3 (WHO, 2006). While our measurements were of respirable dust rather than $PM_{2.5}$ we feel that the size distribution of this combustion-derived biomass smoke is likely to be predominately less than 1μm in size and so we feel it is reasonable to compare our data with $PM_{2.5}$ guidelines. In all Malawian homes we sampled the respirable dust concentrations exceeded the WHO guideline value with 80% being more than 4 times higher. These exposures are likely to result in increased risk of acute lower respiratory infections, lung cancer, asthma and a range of cardiovascular ill-health outcomes. There is a real need for well-designed intervention strategies that combine improved ventilation, efficient stoves, lower emissions from fuel and education on how to reduce personal exposure to biomass fuel smoke. Such interventions should be developed in association with local communities and require evaluation strategies to determine long-term effectiveness in reducing exposure and producing health benefits.

Acknowledgements

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4.2 Discussion

It was noted that *Dr Juan-Maria Delgado-Saborit*'s study took place before the current legislation banning smoking in public areas was enforced. Dr Delgado-Saborit was asked about the possible read-across from smoking in pubs to smoking in homes, which could reinforce the relevance of the study. While acknowledging this possibility, she noted that pubs generally had higher PAH concentrations as there are multiple smokers. The concentration and location of specific PAHs was not considered in this study, although such investigations had been done previously for VOCs. The toxic potential of individual PAHs was described within the presentation, and the interactions between individual PAHs were considered to be synergistic and additive. The possibility of testing the conclusions against another marker of carcinogenicity was raised and would be considered in future work.

Heather Walton responded to a question concerning the use of toxic equivalent factors for PAHs; she explained that the Committee on Carcinogenicity has looked at the issue and in 2002/03 drew up a list of research suggestions, but these were not funded.

In reply to a question about the persistence of PAHs in the environment and in the body, Roy Harrison said that PAHs are surprisingly persistent in the atmosphere but are shown to break down rapidly in laboratory conditions. Wolfgang Kreyling added that it is important to consider the solubility of PAHs as the majority are lipophilic and will enter cell membranes readily, which means they will be taken up into the body and may persist. Bob Maynard clarified that PAHs entering the cell membrane *per se* is not necessarily as important because PAHs become toxic when metabolised. Wolfgang Kreyling considered that PAHs reacting with the cell membrane would indicate that effects are molecular rather than due to the particle on which they are bound. Roy Harrison added that PAHs are generally cleared from the body more quickly than organic chlorines or dioxins.

Professor Otto Hanninen was questioned about the quantification of the impacts of outdoor air quality with respect to mortality but not morbidity. He replied that quantification of morbidity is currently under investigation in collaboration with WHO, but that the overall ranking is robust despite the uncertainties. The order of magnitude of effect size is considered correct even with the assumptions made. The possible role and relative importance of sick building syndrome was mentioned but this is considered to be controversial as causes are clearly not identified.

In response to a question on the meaning of 'classification of sufficient evidence of association', *Professor Michal Krzyzanowski* explained that this depends on the type and strength of evidence and not just whether it is possible to replicate the data. It is dependent on study design and adjustment for confounding.

Dr Derrick Crump, when asked whether the major sources of indoor air pollution in low energy housing will cease to be combustion-related, stated that replacement fuel sources such as wood-based pellets are increasingly used and that this may lead to a change in both indoor and outdoor levels of pollutants.

Dr Sean Semple was asked about the effect of different types of cookers and ventilators used within villages and the effect of individual choice in the household. He stated that there is little variability between the types of stoves used in the village and that the main factor was the lack of awareness of the high exposure to smoke and the related health effects. Educational intervention will probably be the most effective way of reducing exposure.

4.3 Posters

4.3a HealthyAir – Network for actions and policies to address the effect of construction products on indoor air

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Background and objectives

The need to improve indoor air quality (IAQ) to benefit the health and well being of people is recognized in a number of international and national initiatives such as European and national Environment and Health Action Plans, the WHO ministerial declaration, the EU expert group on IAQ, and EU sponsored research (Kephalopoulos et al. 2007).

There are a wide range of sources of indoor pollutants and these include the products used for the construction and furnishing of buildings (Fernandes et al. 2008). Depending on the type of products, on the way they are used in buildings and on the ventilation conditions of indoor spaces, it has been shown that these products can potentially impact IAQ by the release of:

- Volatile Organic Compounds (VOC) and formaldehyde
- Odours
- Particles and fibres
- Radiation
- Mycotoxins (as a result of fungal growth).

Depending on the toxicological properties of the released substances and/or agents and the exposure level of occupants, possible effects can range from discomfort, non-specific symptoms (as reported in 'sick building syndrome'), illness and severe effects (e.g. cancer). In the case of poor IAQ, a lack of productivity in workers or a deficit in learning performance in pupils has also been reported (Carrer et al. 2008).

The European project *HealthyAir* is an EU network project addressing the effects of construction products on indoor air, which started in April 2007 with a three year duration (www.healthy-air.org). The general objective is to define, initiate and develop activities that improve indoor air quality and reduce exposure to indoor air pollution sources, in particular of construction products. This will be achieved by:

- A state of the art review on the impact of construction products on indoor air quality, the effect of indoor air pollution (quality) on occupants, and the sources of the pollution. It will consider methods of emission testing of products, including methods of assessment relevant to occupant's health.
- Information exchange between the different stakeholders through workshops and consultation by interviews, in particular manufacturers of construction products, architects and specifiers of products, and building owners.
- Identification of gaps in knowledge.

- Definition of actions and activities that could improve indoor air quality and reduce exposure to indoor air pollution, such as controls on emissions from construction and furnishing products and other indoor pollution sources. This will include consideration of research required, technology development, education and dissemination, and thereby provide information in support of national and European Environment and Health Action Plans.

In the UK, the Children's, Environment and Health Action Plan and the associated strategy includes discussion of indoor air pollution with respect to risks to respiratory health (HPA 2009). The Plan refers to particular actions on ventilation provision in schools, gas safety with respect to carbon monoxide (CO) poisoning and reducing exposure to environmental tobacco smoke. It refers to a current lack of co-ordinated action to improve IAQ and states that there may be benefits in preparing an action plan to address IAQ. The section on chemical hazards identifies the need for a better understanding about where children are exposed to chemicals (e.g. in the home, schools and outdoor environment).

Progress

The first HealthyAir workshop was held in November 2007 in Rotterdam (Netherlands) and most stakeholders of the building sector were represented, including producers of building products, architects, building owners, consultants, standardization bodies and research organisations. The purpose of the workshop was to present the objectives of the HealthyAir project focussing on the draft state-of-the-art report:

- Documentation of the effects of building products on indoor air quality (IAQ) and on the health and comfort of occupants of indoor spaces.
- Identification of actions and methods to improve IAQ.

The issues raised during the discussion were captured in a summary of the conference (available on the project web site) and include the following;

- In order to obtain good IAQ in buildings, it is necessary to select low emission products, but also to properly design, operate and maintain ventilation systems. Indoor air quality guidelines which can be set as objectives to be reached are also necessary as shown by experience from Finland or Japan.
- People in charge of building product selection during building design are generally not aware of IAQ topics and do not have smart and simple tools for choosing low emission products. It is therefore necessary to transfer knowledge on IAQ to people in charge of the design of indoor spaces.
- While good IAQ is generally not considered as a priority when designing buildings, the building sector has integrated the global concept of "sustainability", which covers a wide range of issues. Several workshop participants, including building owners, suggested that IAQ should be closely linked to "sustainability" since architects and industry already accepts the need for sustainable buildings.
- Energy efficient buildings were regarded as a new challenge for the building sector. The drive to increased energy efficiency will probably lead to drastic changes in building design, to more insulation of the building envelope, to the introduction of new synthetic materials and the reduction of ventilation. Those changes will certainly affect IAQ and therefore this topic should no longer be ignored, otherwise energy efficient buildings will not be "healthy buildings".
- Several workshop participants expressed their wish for simple actions to be adopted based on current knowledge in order to achieve better IAQ now, rather than await the outcome of further research which may recommend other actions at some undefined time in the future.

Further consultation with stakeholders is underway by carrying out interviews in a number of European countries. These take the form of a structured questionnaire based interview, whenever possible undertaken face to face, but valuable feedback can also be achieved by telephone. The interview is used to gauge current knowledge about indoor air quality, the information available to stakeholders and the adequacy of this to meet their needs, including that requested by their clients. It seeks views about the most effective methods of communicating information and the likely effectiveness of labelling products and/or buildings with respect to IAQ criteria. It also explores current knowledge of existing EU and national initiatives on indoor air, and asks about their own policies on sustainable buildings, as well as the main current challenges facing their business sector.

This part of the project is on-going and therefore overall findings are not yet available. Some feedback is available from interviews of representatives of five organisations responsible for rented housing in England. These range from a local authority with about 5,000 dwellings in one region to a housing association with a portfolio of over 20,000 properties across England. The feedback has included the following general themes:

- The overriding concern with respect to IAQ is condensation and mould. This is a source of complaints from significant numbers of occupants, and cases occasionally involve a prolonged period of discussion and actions to resolve the problem. Enquiries from tenants about condensation can be on a daily basis during some periods in winter. As well as providing advice to avoid recurrence of the problem, there is the need to undertake remedial action including cleaning of affected areas, replacement with more appropriate materials that minimise the risk of further mould growth and provision of additional ventilation. Other enquiries from residents include complaints about noise, dust, cooking and smoke odours, dryness of the atmosphere and overheating of communal areas.
- CO, radon and asbestos are other recognised indoor air problems that are considered to be managed by existing practice. Chemicals released during painting and other works are primarily considered to be associated with possible risks to health of maintenance staff, but there are occasional concerns raised by tenants. One interviewee reported that levels of lead in paint are checked in older properties prior to refurbishment. Annual audits of properties by some authorities specifically consider water leaks and presence of mould.
- Problems of condensation can relate to lifestyle and suitability of the property; occupants may not ventilate spaces sufficiently and problems occur because of buildings being sealed and airtight. The increasing use of balanced flues, with fewer properties having chimneys, has contributed to reduced air exchange. Fuel poverty is a real issue for some tenants and this can lead to condensation problems with cold surfaces and a lower moisture capacity of the air. Some occupants dry clothes indoors despite being advised otherwise, but they may have no other practical alternative.
- Information about use of heating appliances is provided to tenants but it is not necessarily read by them. It is important not to overload people with information if it is to be effective. The information provided to new tenants doesn’t cover use of trickle ventilators and extraction fans. Some organisations do include information on risks of condensation.
- A minority of occupants interfere with ventilation provision; this has included cases of occupants removing the fuse from humidistat controlled mechanical ventilators to prevent their operation. This is thought to arise because of the perceived cost of running the fans and because the occupants are unable to affordably heat their home.
- Problems of low ventilation can be due to building design, such as windows on the ground floor that do not offer sufficient security if opened. A housing association may inherit properties from another

organisation and therefore would not have controlled the design and build process. Trickle ventilators may be closed because of draughts and never re-opened.

- Low emitting products are welcome but costs are a paramount consideration during new build and refurbishment. The preference is for standards to be in place that ensure that all products for use in homes are suitably low emitting and will not cause risks to workers or occupants.
- The likely costs of installation and maintenance of mechanical ventilation systems, if they were to be used more in the future in airtight buildings, are of concern.
- They would welcome appropriate advice on IAQ matters including an internet site, some appropriate printed information and being aware of experts to contact.

Conclusions

The HealthyAir project is identifying the impact of construction products on indoor air quality, and through consultation with various stakeholders is seeking to identify actions and policies to minimise adverse effects on occupant health and well being. The recommended actions and policies will be informed by a state of the art review, two workshops and interviews with key stakeholders in a number of European countries.

Interviews with representatives of five organisations managing rented accommodation in England found IAQ to be of considerable concern with respect to problems caused by condensation and mould growth. This problem occurs because of a combination of lifestyle and building design factors. The representatives realise that there could be risks to health from emissions of chemicals, particles and radiation from construction products and considered that these risks should be controlled as part of product standards. They thought that labelling of low emission products would probably promote their development and use. However if the choice of such products was limited and there was an associated additional cost, it is unlikely that they would be specified unless indoor pollution from products was deemed to be a high priority issue.

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4.3b Establishment of the London indoor air quality network

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Background and objectives

In response to increasing concerns over indoor air quality and health a long term monitoring project was set up at two campaign buildings with existing ambient monitoring stations (see Table 1).

The primary purpose of the study was to monitor and analyse indoor and outdoor data to assess meteorological effects and building activity on the transfer of air pollutants into buildings of differing construction. Traffic related pollutant species that are known to be detrimental to health were monitored.

The secondary purpose was to produce a high quality long-term data set for indoor air quality assessment and to evaluate the need for an indoor air quality network within London.

Study description

Continuous indoor and outdoor monitoring was carried out at the 2 campaign sites. NO_X and O_3 were monitored at the Greenwich background location and NO_X was monitored at the Corporation of London roadside location.

At Greenwich the indoor sampling point is in a frequently used classroom. At Corporation of London the indoor sampling point is in the entrance foyer of the local authority offices, permanently staffed during office hours.

Indoor measurement began on 7 July 2008 and for the purpose of these preliminary studies, data was analysed up to the end of 2008.

Diurnal hourly means and maxima were used for data analysis for the whole period and seasonally. Pollutant data was also compared various meteorological parameters. Linear regression analysis was used to compare indoor and outdoor pollutant species.

Results

Investigation of the results from the two study sites showed very different relationships between indoor and outdoor measurements.

At the roadside Corporation of London site variation of outdoor NO_X significantly affected indoor NO_X (maximum 495ppb outdoor, 390ppb indoor). A trace of the mean NO_X levels can be seen in Figure 1. Linear regression analysis confirmed that (R^2=0.9) 90% of the variance of indoor NO_X was influenced by variance in outdoor NO_X concentration. This was also observed for outdoor/ indoor NO_2 levels indicating that most of the indoor sources for NO_X and NO_2 come from the ambient surroundings i.e. the heavily trafficked road approximately 3m from the building entrance.

At the Corporation of London site a comparison between indoor/outdoor levels with wind direction showed that the majority of high level NO_X came from a Westerly to South Easterly direction affected by the building/street orientation (street canyon).

During the study period at Corporation of London indoor levels of NO_2 exceeded the EU Limit Value for NO_2 (105.6 ppb hourly mean) on 11 occasions. The site has since failed the (outdoor) Air Quality Strategy Objective value of 18 exceedences per year.

At Greenwich, data showed low correlation of indoor to outdoor NO_2. Indoor NO_X levels were higher than outdoor on average (22 ppb indoor, 20 ppb outdoor), suggesting an indoor NO_X source. By comparing the indoor source ratio for NO_X/NO_2, a weak correlation (R^2=0.0002) indicates no indoor combustion sources.

In seasonal comparison analysis at Greenwich (Figure 2), we identified indoor O_3 levels exist during summer time, but not in winter or during the weekend. This suggests that human activity and building occupation could play a role in outdoor ozone transportation.

Conclusions

From the results, we observed different concentration patterns for both indoor/outdoor pollutants at the two monitoring sites. At Corporation of London, we conclude that most of the indoor air contaminants (NO_X/NO_2) were transported from outdoor heavy traffic especially during weekdays. Whereas at Greenwich, indoor NO_X could be derived from a mixture of indoor and outdoor sources or indoor chemistry. In terms of seasonal comparison, from Greenwich, data suggested that building activity could play a role of transportation of O_3 from outdoor into the building.

Discussion

What next? Indoor monitoring will continue at both these campaign sites and further analysis will be undertaken. The publication of the WHO indoor air quality guidelines will raise the profile of indoor air quality. In order to make an ongoing assessment of the standard of indoor air across London, similar to the role of the London Air Quality Network, long-term indoor monitoring sites may be required in a range of 'typical' London building types. This study will be presented as a pilot scheme for such a network in the future.

Table 1 Study site details

Site	Site Location	Condition	Indoor Sampling point	Measured parameters
Corporation of London (IC6)	Upper Thames Street, Wallbrook Wharf	A mechanically ventilated office building in a busy roadside location	Ground floor lobby	NOX
Greenwich (IG4)	ECC (Nature Study Centre), Bexley Road, Eltham	A naturally ventilated school building in an urban background location	Classroom	NOX and O3

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Figure 1: Daily mean concentration of outdoor/indoor NO_X at IC6

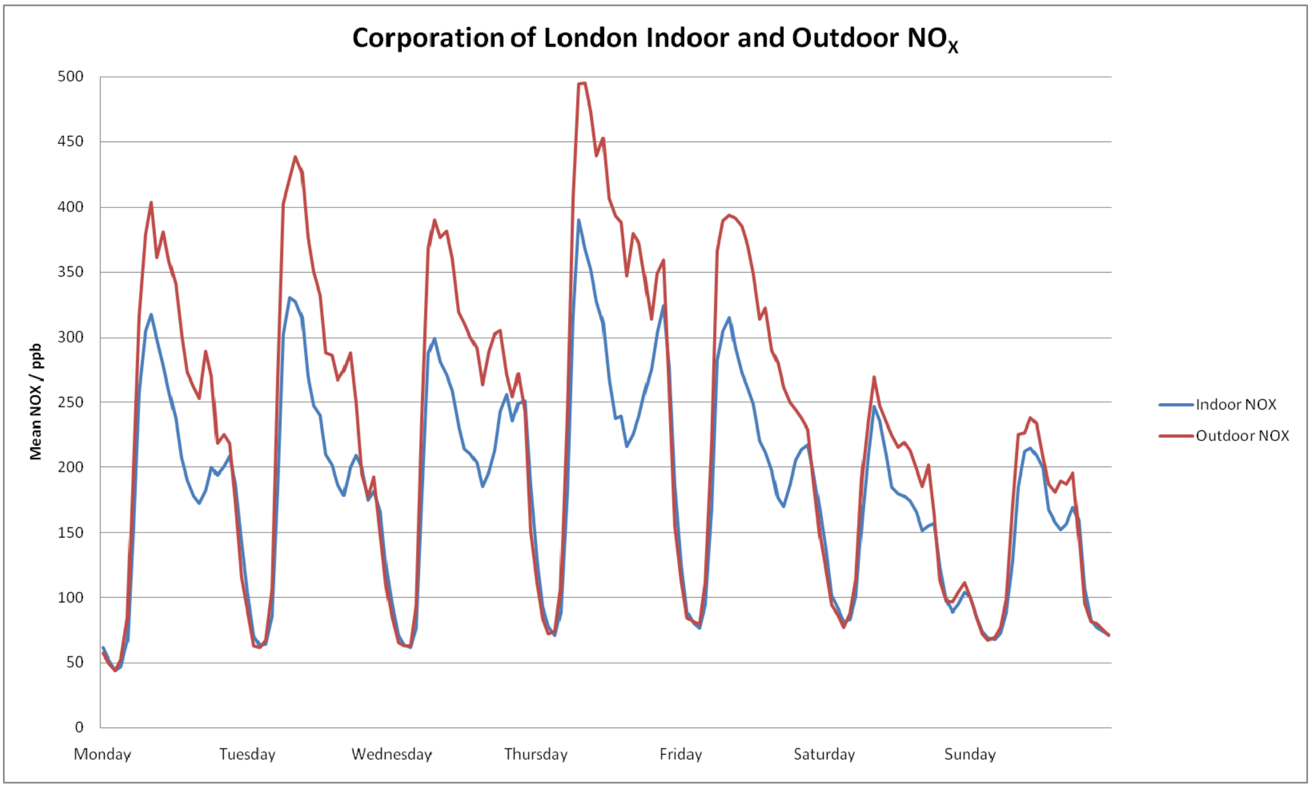
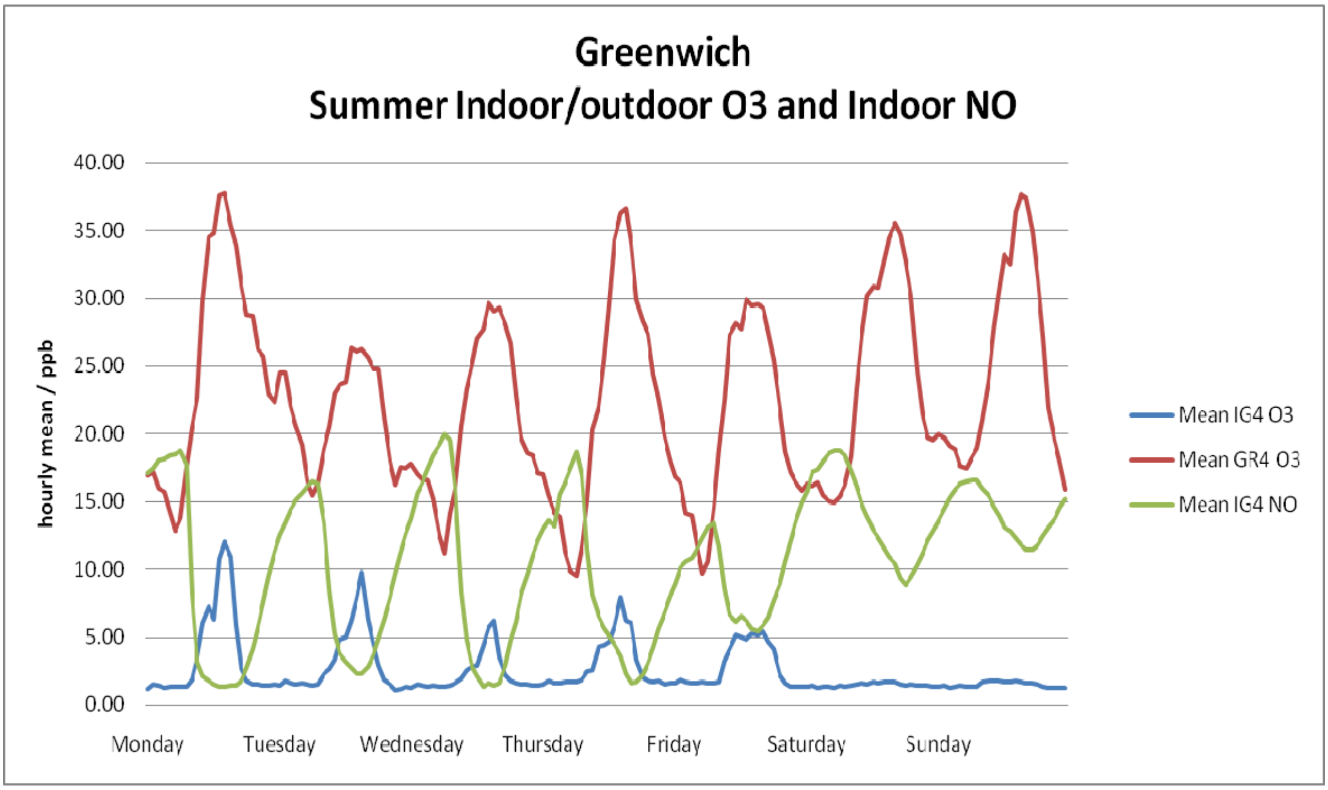


Figure 2: Indoor/Outdoor O_3 and indoor NO during summer at Greenwich



4.3c Indoor levels of particle number and mass concentrations in residential microenvironments

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Introduction

There have been a great number of studies on the association of particulate matter (PM) with chronic and acute respiratory problems. Recently in an review on health effects of fine particulate matter Pope and Dockery, (2006) mentioned that despite important gaps in scientific knowledge and continued reasons for some skepticism, there is a persuasive evidence that exposure to fine particulate air pollution has adverse effects on cardiopulmonary health. In order to control and reduce human exposure to particulate pollution, information on indoor particle characteristics is of substantial importance due to the fraction of time people spend indoors. Most of the current exposure models use outdoor concentrations of pollutants to predict the total human exposure, however, there is growing evidence that indoor air varies significantly from outdoor even if there is no indoor source. A sizeable number of studies have been conducted on various features of indoor particulate matter but most of them are lacking in providing information on continuous spatial and temporal variation in concentration of fine particulates and factors responsible for them. Studies on simultaneous and continuous measurement of mass and number concentration of particulates and factors affecting the indoor levels of PM are limited. Moreover, the indoor levels of particulate matter depends on a range of factors (for example, generation rate of pollutants indoors, outdoor pollutant concentration, air exchange rate, penetration efficiency, deposition rate on indoor surfaces, metrological conditions). Most of these factors vary with building design, indoor activities and geographical locations. Hence, there is a need to evaluate the PM concentrations by considering all those factors, which affect their indoor levels in a wide range of indoor settings.

Methods

The present work was carried out during 2004-2006 to gather quantitative information on the mass concentration of PM_{10}, $PM_{2.5}$ and PM_1 and number concentration in various residences in South East England. Ten single family residences were investigated for particle number concentration and mass concentration. The mass concentration of particles was monitored using two different GRIMM: analysers (Model 1.108 and Model 1.101) while the number concentration was measured with a Condensation Particle Counter (TSI 3010). Ventilation rate and data of inhabitant activities were also recorded. The sampling was carried out in living rooms and kitchens. To understand the indoor /outdoor relationship of PM_{10}, $PM_{2.5}$ and PM_1 the simultaneous measurements were taken both indoors and outdoors.

Results

The 24 hour average of number concentration collected in non-smoking living rooms showed that number concentrations were generally in the range of 2,965 – 37,067/cm^3 (Figure 1). Analysis and comparison of data with diaries of activities maintained by the resident enabled the identification of activities which contributed the elevated levels. The activities identified were, personal presence, normal household activities, cleaning and window openings. While in the kitchen, with electrical hobs, the mean number concentration was 36,325 and a ranged between 6,814 to 52,107 particles/cm^3 (Figure 2). The maximum number concentration was recorded during the frying period.

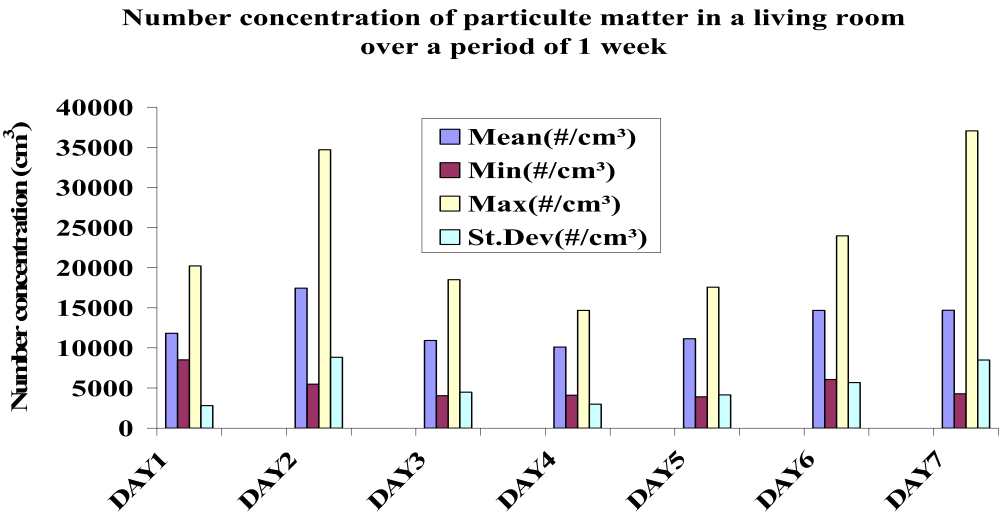

Figure 1. Number concentration in a living room

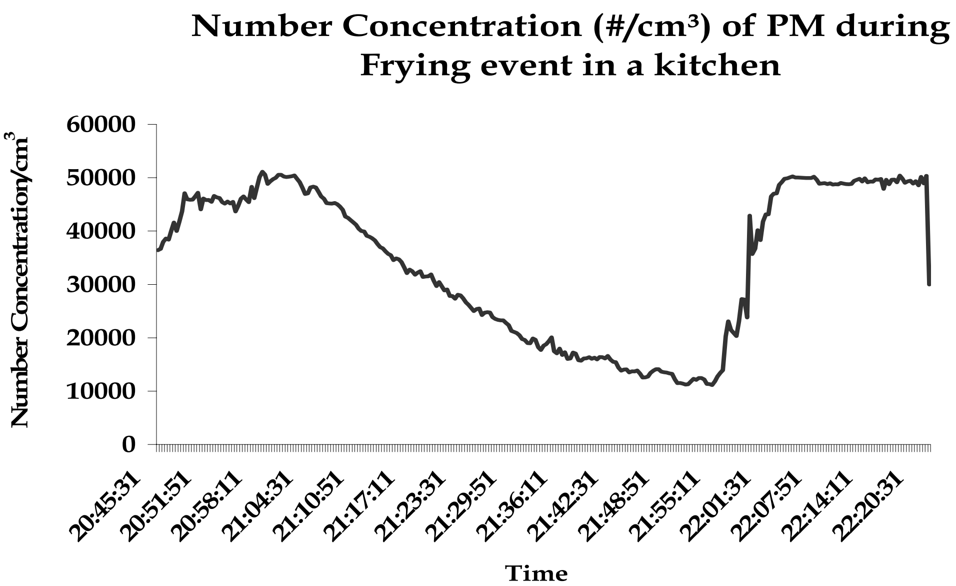

Figure 2. Number concentration during frying in a kitchen

On the other hand, the hourly average mass concentration of particulate matter in non-smoking living rooms ranged from 5 to 35 µg/m^3 and in the smoking rooms the concentration can jump up to 650 µg/m^3 (Figure 3). The simultaneous indoor/outdoor measurements revealed clearly that smoking was the biggest contributor to indoor levels and generally, without any activity, indoors levels were approximately the same as those outdoors (Figure 3). Indoor smoking under normal ventilation conditions had a substantial effect of indoor particulate pollution and the concentrations of $PM_{2.5}$ and PM_1 were 10 - 18 times higher as compare to background residential settings.

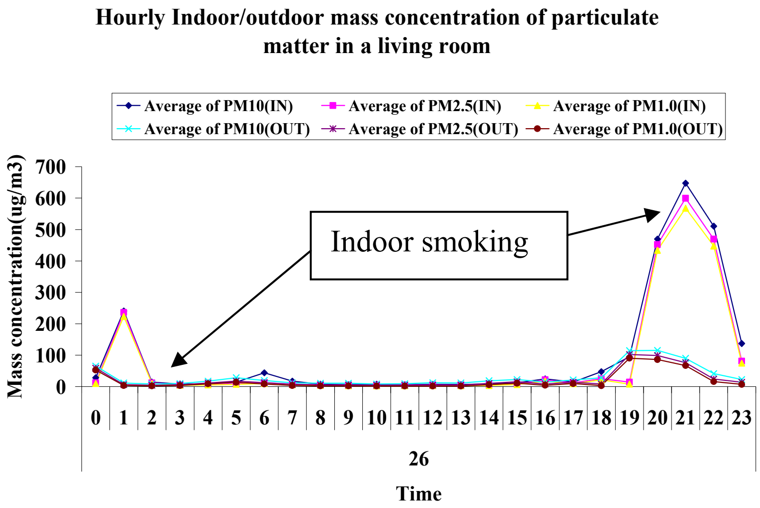

Figure 3. Hourly indoor /outdoor concentrations of PM in a living room

In kitchens a large variation was observed in hourly averages and concentrations were in the range 5 to 900 $\mu g/m^3$. This considerable ebb and flow was attributable to the type of cooking. For instance, frying was seen as the highest contributor to PM levels (Figure 4). During frying a concentration of more than 4000 $\mu g/m^3$ was repeatedly observed and it was more than double as compared to baking (Figure 4).

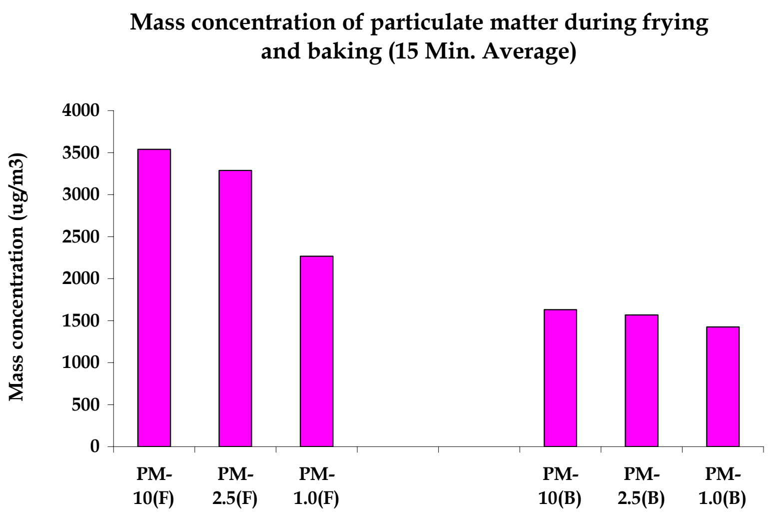

Figure 4. Effect of frying (F) and baking(B) on PM_{10}, $PM_{2.5}$ and PM_1

These findings were in agreement with other studies on indoor particulate pollution (He et al., 2004; Morawska et al., 2003). The ventilation rate in different rooms was in the range 0.30 to 7 air changes per hour (ACH). These ventilation rates were measured in naturally ventilated buildings with open and closed window conditions.

Conclusions

During the present study, the particle mass and number concentration was examined in different residential settings. This study showed that the concentration of particulate matter in indoor environments is largely effected by indoor activities of the inhabitants, type of the source and housing characteristics. The particle mass and number concentration varied from site to site. Cleaning, personal presence, vacuuming, smoking and cooking were found as major activities to elevate the indoor levels of particulate matter. Smoking in living rooms and cooking in kitchens with poor ventilation conditions resulted in excessive levels of indoor particulate matter. The concentrations of PM_{10}, $PM_{2.5}$ and PM_1 during smoking were 10 - 18 times higher than non-smoking residences. The concentration in kitchens showed a great variation during cooking. However, they provided an insight into the effect of different styles of cooking on particulate pollution. Styles of cooking had a significant effect on the concentration of particulate matter. The levels were more than double during frying in comparison to baking. Moreover, the present study demonstrated that in naturally ventilated buildings without any indoor activity, the indoor particulate level corresponds with outdoors. In the presence of human activity, these levels are substantially higher as compared to outdoors in a suburban environment and hence the estimation of indoor concentration based on outdoor levels could lead to erroneous results.

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4.3d Oxidative capacity of combustion-derived particulate matter from incense burning

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Background and objectives

Incense (e.g. Joss Sticks) have been burned for centuries and is an essential tradition to give respect to ancestors for deity worship in Buddhism and Taoism. The Joss stick is the most popular type of incense used during religious worship in Taiwan. When burning incense, the emitted smoke contains particulate matter, gas and organic compounds (Yang *et al*., 2007). Epidemiological studies have indicated that particulate matter with an aerodynamic diameter less than 10µm (PM_{10}) is a risk factor for respiratory and cardiovascular morbidity and mortality (Dominici *et al*., 2006). These health end-points are driven by PM physicochemistry (e.g. size, shape, crystal structure, chemical composition, surface area, charge and porosity). In Asian countries, incense burning is a critical indoor pollutant source; however, the physicochemical properties of incense PM and related health effects remain unclear.

Aims

The aims and objectives of this research are three-fold:

- Collect PM10 from the combustion of the typical Joss sticks currently used for deity worship
- Characterise the morphological and chemical profiles of the smoke emitted
- Determine the oxidative capacity of the combustion-derived PM.

Study description

Sample collection

In this study, three kinds of incense sticks, manufactured in Taiwan, were utilised (Figure 1a). Two different systems were employed for collecting incense combustion-derived particles. The first system involved a large volume air sampler, attached to a PM_{10} selective-inlet head (horizontal elutriator; C30 Classifier; Negretti, UK), with PM impacted directly onto polycarbonate filters (Millipore, UK) (BéruBé *et a*l., 1999). The second system involved the 'Airborne Sample Analysis Platform' (ASAP; Thermo, USA) that collected PM from 1 to 10 microns in diameter, onto polyurethane foam (PUF; Thermo, USA). These two different filter matrices were required in order to collect both the particle (polycarbonate substrate) and vapour phase (PUF substrate) products generated during incense combustion (Jones *et al.*, 2006).

Particle characterisation

The polycarbonate filters were cut into triangular sections and mounted onto plastic washers using Araldite, and then glued to scanning electron microscopy (SEM) stubs, using the same adhesive (Jones *et al*., 2001). The stubs were carbon coated to a thickness of 10nm (SC500 Biorad sputter coater; Biorad, UK). The morphology of incense PM was obtained by Field Emission SEM (Philips XL30; Philips Electron Optics, NL). Quantitative image analysis (Leica, UK) was used for obtaining the equivalent spherical diameter (ESD; BéruBé *et al*., 2003).

Oxidative capacity

Freeze-drying was used to concentrate PM extracted from the PUF substrates, using HPLC-grade water (Shao *et al*., 2006). The particulate Reactive Oxygen Species (ROS) was determined using the dichlorodihydrofluorescin (DCFH) assay (Koshy *et al*., 2007). Briefly, 2ml of NaOH (0.01N) was added to 0.5ml of 2',7'-dichlorodihyfluorescin diacetate (1mM; DCFH-DA) in methanol. After standing at room temperature for 30 minutes, 10ml of 25mM NaH_2PO_4, pH 7.4, was added. Reactions were carried out at 37degrees centigrade for 25 minutes. The fluorescence intensity was measured with a Fluorimeter (Cary Ecipse, Varian Instruments, CA, USA). In order to correlate the fluorescence of samples to equivalents of H_2O_2, a linear calibration curve of H_2O_2 was made.

Results

Incense PM characterisation

From the FE-SEM investigation, four major types of incense particles (soot, fly ash, mineral and organic) were generated during combustion of the three kinds of incense (Figure 1b). Soot was the predominant particle type and the fly ash the least dominant (Figure 2). Mineral and metal oxides were omnipresent in all samples. The soot fraction was less than 1µm in diameter and more than 50% of the total PM sample number (Figure 3). There was a peak between 0.9 to 2µm, which was suspected to be a contribution from the larger size mineral particle fraction.

Oxidative capacity

The DCFH assay was used to screen the oxidative capacity of the three types of incense sticks. From the results of oxidative capacity induced by incense PM, a significant dose-response was observed (Figure 4). The equivalent H_2O_2 concentration induced by incense type 1 was slightly higher than the other types in different particle concentrations. However, there was no statistical significance in Student T-test between these data. Comparisons of the incense PM and filter blanks demonstrated that the incense PM caused the increased oxidative stress (Student T-test, $p<0.05$).

Conclusions and discussion

This study has provided preliminary data on the physical characterisation and oxidative capacity of different kinds of incense products burnt regularly in Asia. The fine particles generated from incense combustion included soot, fly ash, mineral and organic matter. Quantitative images analysis revealed that the majority of particles were composed of soot, whereas the larger size fraction was mineral-based. Significant oxidative capacity was generated by three types of Joss sticks in a dose-response manner. The observations suggest that indoor incense burning may be a respiratory risk. Further work is on-going to characterise the chemical properties and bioreactivity (in vitro lung cell culture) to determine the causes of incense-driven ROS.

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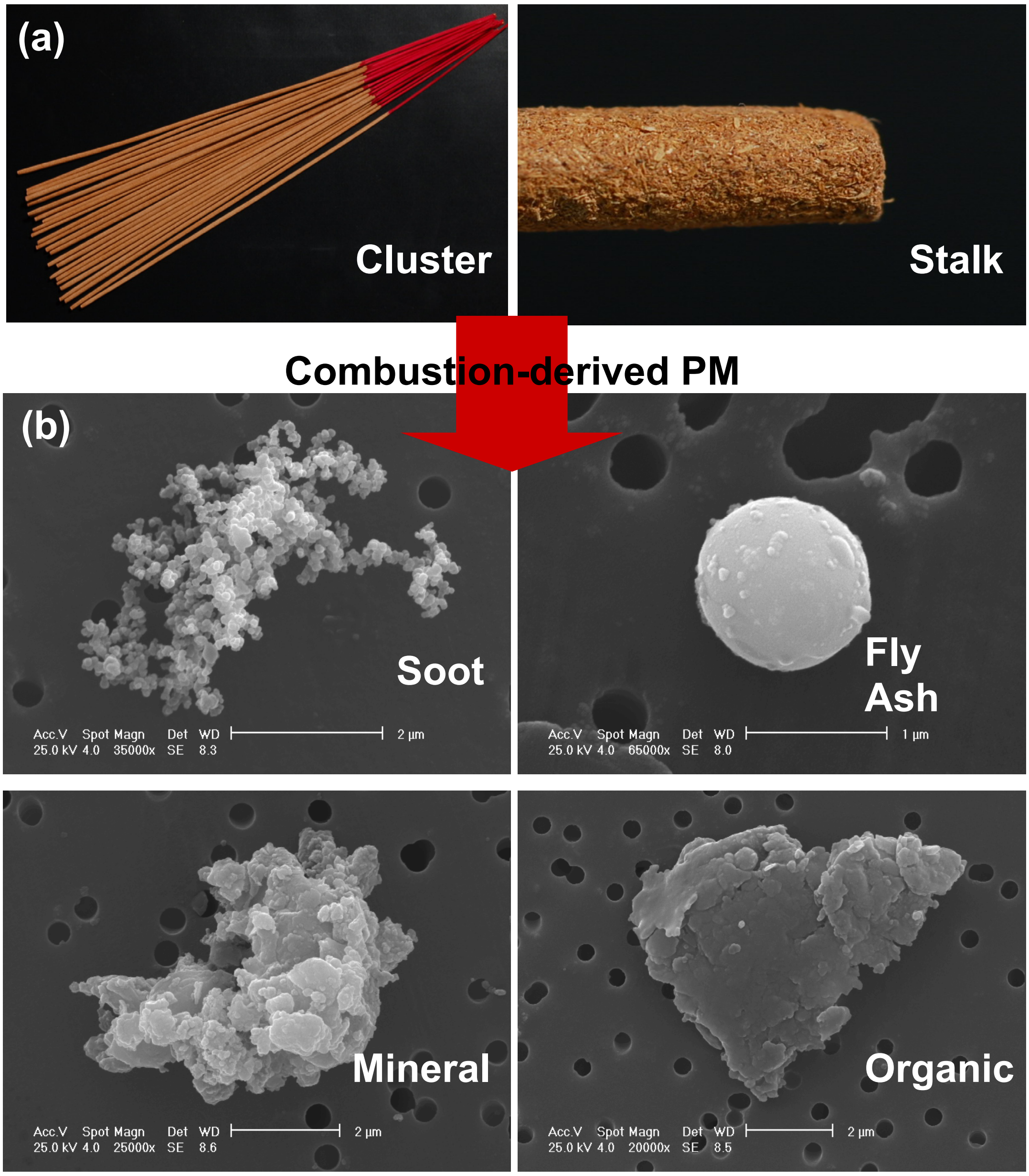

Figure 1. Cluster and stalk of joss stick (a) and four major types of incense PM (b) from three different types of incense, including soot, fly ash, mineral and organic.

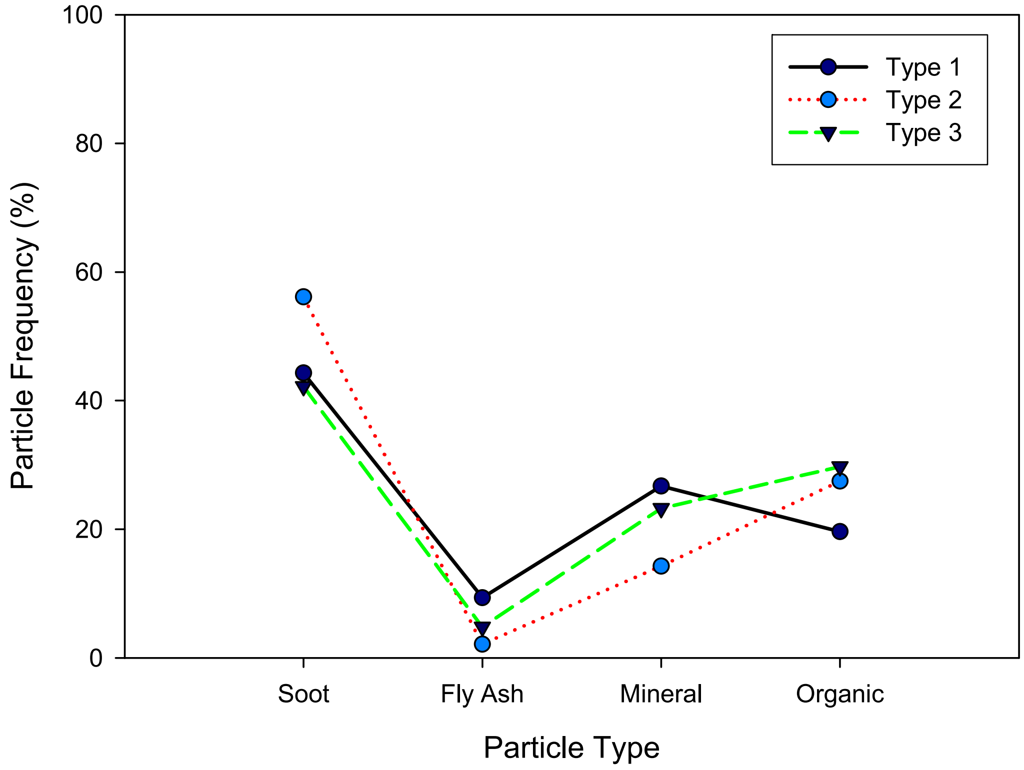

Figure 2. The particle frequency of the four particle types, soot, fly ash, mineral and organic generated by burning incense.

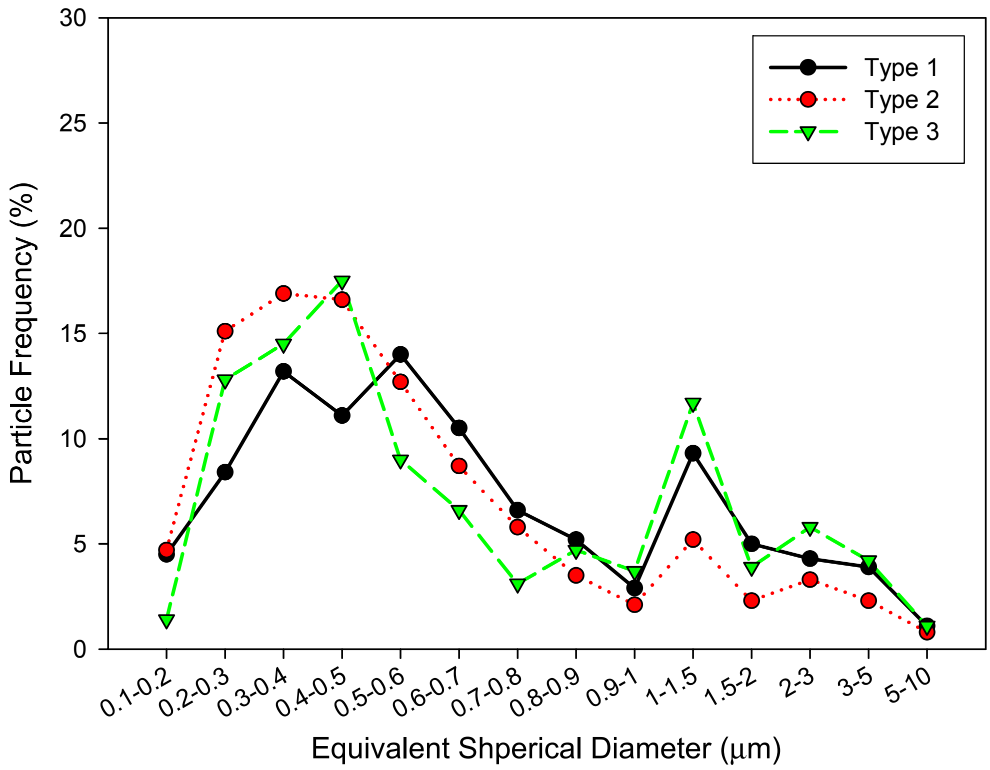

Figure 3. The size distribution of three types of incense PM, ranged from 0.1 to 10μm. Over 50% of incense PM was less than 1μm**.**

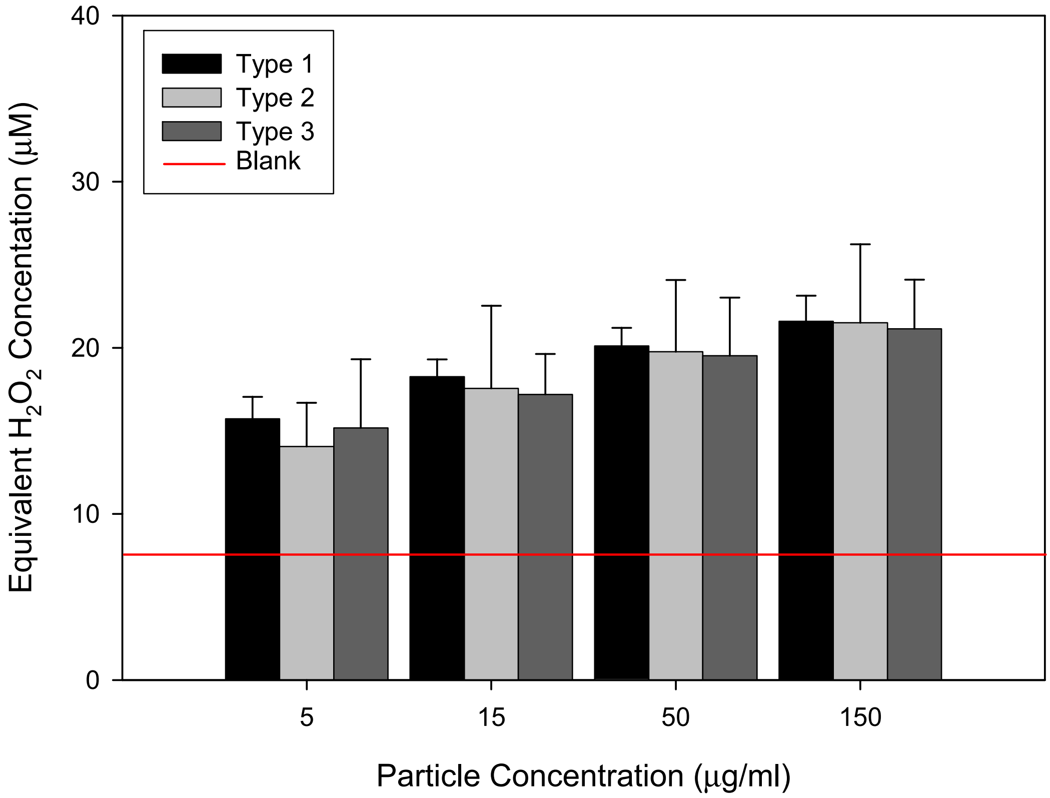

Figure 4. A comparison of equivalent H_2O_2 concentration induced by three kinds of incense PM in the particle concentration of 0 (blank), 5, 15, 50 and 150 µg/ml. A significant dose-response is seen.

4.3e Harmonisation of material labelling schemes in the EU

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Background and objectives

Emissions from construction products can constitute a significant source of indoor pollution. A wide range of volatile organic compounds (VOCs) and formaldehyde can be released, and concentrations can be particularly elevated in new buildings and following refurbishment. A number of national and industry focused labelling schemes for low emitting products exist in Europe and each has its own particular requirements for testing and criteria for product evaluation. This results in significant costs to industries wishing to provide low emitting products in different markets.

In response to this concern, and to further encourage the development and application of low emitting products, an EU expert group convened by the EC Joint Research Centre (JRC), Ispra, was established to seek consensus on the scope for harmonisation of existing schemes. This group published a report (ECA, 2005) that described the characteristics of existing schemes, identified the main similarities and differences between them and recommended further steps towards convergence:

- The need for common procedures of testing and analysis with the possibility of one emission test being sufficient to permit labeling in accordance with the different schemes; this could be achieved in advance of full harmonisation;
- Need for round robin tests to validate the common procedures;
- Need for appropriate quality control of testing.

Subsequently the initiative was taken forward by a conference in Berlin in 2007 and the formation of a working group with representatives of the Danish (DICL), and Finish (M1) labelling schemes and the German evaluation system (AgBB), as well as representatives of emission test laboratories in the UK, France and the JRC, Italy.

Study description

The working group is preparing a report on common requirements of a harmonised scheme. This is being informed by round robin testing of products according to the individual schemes and comparison of the results obtained. The group is also giving consideration to the on-going work within the European standards organization (CEN) to prepare a harmonised test method to determine the emission of dangerous substances from construction products in support of requirements for health safety and environment under the Construction Products Directive (CPD).

Table 1 summarises the main characteristics of each scheme. All involve the testing of emissions by placing materials in a chamber supplied with air at a known flow rate at a controlled temperature and humidity. The concentration of chemicals in the air of the chamber is measured and this can be used to calculate a rate of emission from the product because the air exchange, chamber volume and amount of material are known. The test procedure and the analytical methods used in the schemes are based on those described in international standards (ISO 16000, parts 3, 6, 9, 10 and 11). A sensory test is currently under development for possible inclusion in the AgBB scheme.

Table 1 Characteristics of labeling schemes

Requirements	M1	DICL	AgBB
Pre-assessment of product composition	No	voluntary	compulsory
Chamber	ISO 16000 series	ISO 16000 series	ISO 16000 series
Measuring points (days)	28	3, 10, and 28	3 and 28
Formaldehyde measured	Yes	Yes	No
TVOC measured	Yes	No	Yes
SVOC measured	No	No	Yes
Single VOCs measured	Some	Yes	Yes
Carcinogens evaluated according to	IARC class 1	IARC class 1	EU class 1 and 2
Irritants evaluated	Formaldehyde, ammonia	Formaldehyde and selected VOCs	All VOCs according to LCi values
Assessment of other VOCs	No	No	Yes
Sensory evaluation	Yes	Yes	No

TVOC = total volatile organic compounds

SVOC = semi-volatile organic compounds

LCi = lowest concentration of interest IARC = International Agency for Research on Cancer

Results

The first round robin involved testing of a rubber flooring material. Table 2 summarises the results of the evaluation according to the three schemes. The material was rejected by all schemes although for different reasons. The M1 and DICL schemes rejected the material because it was judged unacceptable by the sensory test and rejection according to the AgBB scheme was because of the emission of the class 2 carcinogen 1,3-dichloro-2-propanol. The M1 and DICL schemes do not have evaluation criteria specific to class 2 carcinogens. The test laboratories did detect the emission of 1,3-dichloro-2-propanol. The rate of emission was below the reporting limit for M1 of 0.005 mg/(m^2h) as toluene equivalents and was found by DICL with an emission rate of 18 µg/(m^2h) after 3 days and 11 µg/(m^2h) after 28 days.

Table 2 Results of evaluation of a rubber flooring

Requirements	M1	DICL	AgBB
Chamber size (l)	500	225	Emission cell (35ml)
Formaldehyde	Approved	Approved	-
TVOC after 28 days	Approved	-	Approved
SVOC after 28 days	-	-	Approved
Carcinogens	-	-	Rejected because of presence of 1,3-dichloro-2-propanol
Irritants	Approved	Approved	Approved
Assessment of other VOCs	-	-	Approved
Sensory evaluation	Rejected	Rejected	-

A further round robin exercise involving testing of a sealant material has also been undertaken and results are undergoing evaluation. Prior to selection of this material a number of flooring samples were investigated to select a material that would provide a good comparison at both 3 and 28 days of test and have appropriate homogeneity, but a suitable material was not found. The group have agreed that a harmonised set of criteria for evaluation should include;

- Health evaluation based on a common set of LCi values
- Carcinogens according to the EU list
- An upper limit for TVOC
- Sensory evaluation.

The next intended actions are the evaluation of the second round robin exercise and a review of the toxicological basis of establishing LCi (Lowest concentration of interest) values. A report will be prepared on the proposed requirements for a common harmonised scheme and the group will then seek to include a broader representation from the various stakeholders with the aim of finalising a harmonised scheme

Conclusions

The emission of organic chemicals from construction products can have an adverse effect on indoor air quality. Labelling schemes that identify low emitting products encourage the development of low emitting products and provide consumers, building designers and material specifiers with the information to select products with these characteristics. Harmonisation of these labelling schemes will provide clearer guidance to users and further promote low emitting materials, as well as reduce the administrative and testing burden for producers that wish to market in more than one country. The working group, supported by the European Commission, is developing a proposal for a harmonised scheme based on the experience of existing schemes and through generation of new test data. When completed, a report of the work will form the basis for a broader consultation with stakeholders to finalise a harmonised scheme.

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ISO 16000-6 Indoor air – Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS/FID.

ISO 16000-9 Indoor air – Part 9 : Determination of the emission of volatile organic compounds from building products and furnishings – emission test chamber method.

ISO 16000-10 Indoor air – Part 10 : Determination of the emission of volatile organic compounds from building products and furnishings – emission test cell method.

ISO 16000-11 Indoor air – Part 11 : Determination of the emission of volatile organic compounds from building products and furnishings – sampling, storage of samples and preparation of test specimens.

Acknowledgements

Members of the harmonisation working group; Stylianos Kephalopoulos (JRC Ispra, Italy), Liz Winther Funch (DTI, Denmark), Thomas Witterseh (DTI), Tina Tirkkonen (VTT, Finland), Jorna Sateri (FiSIAQ, Finland), Kristina Saarela (Finland), Wolfgang Horn (BAM, Germany), Christine Daumling (UBA, Germany), Ana Maria Scutaru (UBA), Francois Maupetit (CSTB, France).

5 Outdoor air exposure studies

5.1 Presentations

5.1a Particulates in the urban environment

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Airborne particulate matter contains a mixture of pollutants. Individual particles have a different chemical morphology and this data could provide information on the formation and reaction mechanism of these particles. It also helps to identify the source they originate from as well as their atmospheric history. Over the years, numerous studies have been conducted to characterise PM10 and little work has been carried out on PM2.5. However, there is an emerging interest in identifying the effects of very fine particles such as nano-particles.

The main objective of this research project was to carry out a comprehensive characterisation study of nano-particles collected from a city environment. Environmental monitoring samples from 6 local authority monitoring sites were collected over a period of 7 months using the tapered element oscillating microbalance technique (TEOM). The sample filters were then analysed for their morphology and elemental compositions using SEM/EDS and LA-ICP-MS. SEM/EDS analysis was able to detect several heavy metals in the particulate matter while the LA-ICP-MS showed that there were more heavy metals present in the filter samples especially the heavier metals. Some of these heavier elements could have been inhibited by organic or higher amounts of the more common metals found in the EDS such as Fe, Zn, Si and Al. Nano-particles originated from high temperature sources, biological, carbonaceous and road transport were also detected in the samples. It was also found that particles containing more metallic elements tended to have a more defined shape while carbonaceous materials typically had amorphous structures. Tests showed that particles with environmental dust compositions of Ca, Al and Si were abundant. It was observed that the biological particles had very fine sizes. An air dispersion modelling package was also used to model the particulate matter dispersion in the city area for the period of sampling. The results from the model showed that the highest point of emissions was around the Tinsley industrial area. Moderately high emissions were found in other industrial areas of the city. The contribution from the energy-from-waste plant located near the city centre was found to be insignificant compared to the other point sources.

5.2 Discussion

Temporal and spatial issues were raised during the discussion of outdoor air exposure studies. Professor Jim Swithenbank was asked about differences between metal species. It was noted that platinum was not detected in air monitoring systems around Sheffield, which was perhaps surprising considering the industrial activity in the area; he noted that in areas where silver is mined, trees downstream act as a net and silver is detected in their bark. In response to a question, Professor Swithenbank explained that particles greater than 100 nm are collected by Anderson sample filters whilst the TOEM collects smaller particles in the region of 10-15 nm. Dr Swithenbank warned that if the power is set too high on an electron microscope, then the particle can be vapourised.

5.3 Posters

5.3a Particle concentration measurements in a busy street canyon: initial observations from Swansea, Wales

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Background and objectives

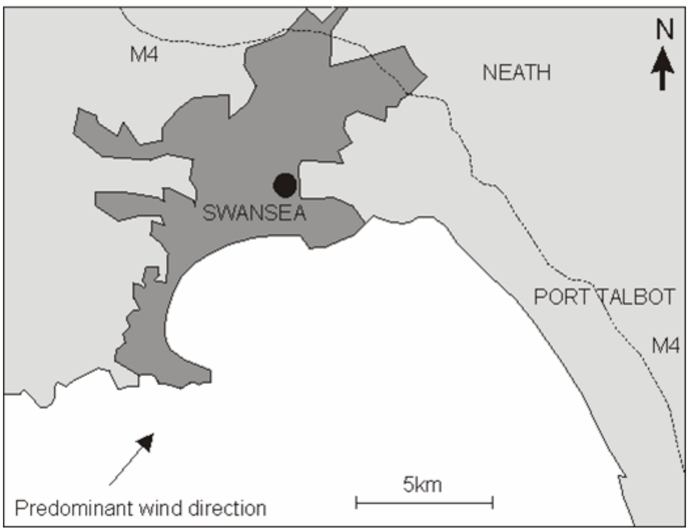
The levels of particle concentrations in urban locations are causing concern due to links with adverse health effects. For example, particle concentration increases have been associated with an increase in the symptoms of asthma sufferers (Penttinen *et al*., 2001) and increased hospital admissions (Zanobetti & Schwarz, 2005). In order to understand, and therefore predict, potential health outcomes, an understanding of particle number concentrations, and the physical and chemical properties of those particles is vital (BéruBé *et al*., 2008).

This study focuses upon particle number concentrations, and aims to quantify changes in these concentrations over time, daily and weekly, in three size fractions ranging from 7nm to 10µm in a busy street canyon.

Methods and site description

Neath Road, Swansea is a busy street canyon (~18,000 vehicles per day), and is a popular commuter route between Swansea and Neath (Figure 1).

Figure 1: Location map of sampling site (black dot) in south Wales (Price *et al*., 2009; in *review*)



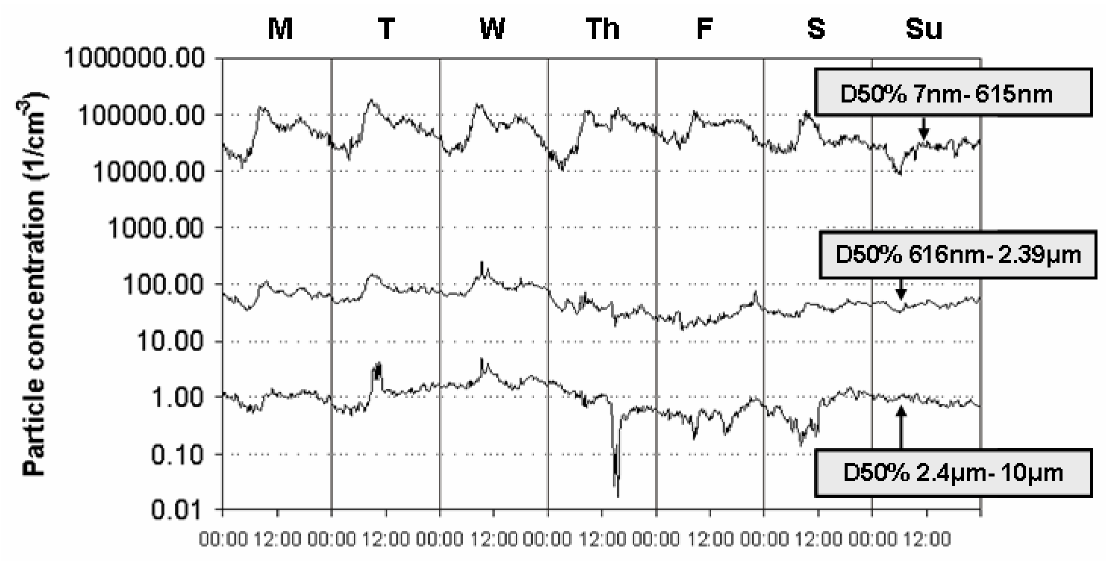
A Dekati™ Electrical Low Pressure Impactor (ELPI) is used to investigate particle number concentrations in this traffic "hotspot". The ELPI counts and collects particles into 12 size fractions (7nm - 10μm) based upon the particle's aerodynamic diameter (Keskinen et al., 1992). This study considers three size fractions (7nm - 615nm, 616nm - 2.39μm, 2.4μm - 10μm). Sampling takes place at a height of 5 metres above the road level.

Sampling in this location has taken place from September 2007- January 2009, with the examples of data outputs presented here representing a 10 week sampling period during winter 2007/ 2008.

Results and discussion

Particle concentrations vary diurnally and between different days (Figure 2).

Figure 2 Particle number concentrations for three size fractions (nano-fine, fine and coarse) at Neath Road, Swansea (Price *et al*., 2009; *in review*). Data points represent a 10 week average.



Mondays to Thursdays are similar in terms of both concentration profile and scale in the nano-fine size fraction. These days follow a pattern of a morning rush hour peak (8am; max: 180,000 particle cm^{-3}) and a secondary afternoon peak of smaller magnitude (4pm). This initially consistent profile then begins to break down, until Sunday when the nano-fine number concentration is much lower (max: 35,000 particles cm^{-3}), and the concentration profile is almost an inversion of the weekday profiles. This weekday-weekend change in particle number concentrations has been previously reported (e.g. Battarbee et al., 1997). The nano-fine particle concentrations are substantially composed of traffic exhaust particles (BéruBé et al., 2008). Therefore the profile identified (with morning and afternoon rush hour peaks) can be correlated to commuter times (e.g. Harrison & Jones, 2005). Similarly the weekend, and specifically Sunday particle number concentration reduction can also be explained in this way, that is due to reduced traffic numbers (cars, vans, articulated lorries etc) during the weekends (e.g. Voigtländer et al., 2006).

Particle number concentrations in the fine and coarse size fraction do not follow the weekday-weekend pattern of the nano-fine particles; however maintain the flattest (and therefore static) concentration profiles on Sundays. The observed number concentrations are much lower than the nano-fine size range with a peak of 240 particles cm^{-3} in the fine size fraction and 5 particles cm^{-3} in the coarse size fraction. Lower number concentrations in fine and coarse particles is well documented (e.g. Voigtländer et al., 2006). Similarities are occasionally seen through the week between fine and coarse particles in terms of number concentration profile (for example Wednesday 11am), however this is not a consistent relationship. This suggests that whilst fine and coarse particles may have the same sources (for example traffic derived soot agglomerates), each also has a contribution from sources not shared by both; for example, marine-derived halite crystals will contribute predominantly to the largest size fraction (Moreno et al., 2004).

Additionally, not only are different sizes of particles contributed to by different sources, but the way size fractions will react to meteorological effects will not be consistent. For example, changes in temperature have been found to affect nanoparticles differently to nano-fine particles (Olivares et al., 2007).

Conclusions

Particle number concentrations are found to vary both diurnally and from day to day at Neath Road in Swansea; a distribution explained by the delicate balance between particle inputs and particle removal mechanisms. This number concentration variability is inconsistent between different size fractions emphasising the different source/ removal mechanisms for particles of different sizes.

Further work regarding the importance of meteorological conditions and traffic (vehicle numbers and speeds) is required to understand more fully the changing particle concentrations within Neath Road traffic corridor.

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5.3b Characterisation of urban particulate matter

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Background and objectives

The aim of the PhD project is to contribute understanding both to the exact nature and origin of some of the carbonaceous fraction of particulate matter (PM).

Study description

Samples of PM_{10} (particles with a diameter smaller than 10 μm) are being collected from an urban background location in Edinburgh (St Leonards; OS Grid Reference: NT263731) using a Partisol 2025 gravimetric sampler. This locality provides PM that is more representative of suburban background air compared to a roadside site, which will be more directly influenced by traffic-related emissions. PM_{10} concentration (μg m^{-3}) and the level of black carbon (BC) have been determined for each daily filter sample. BC concentrations were derived by converting measured filter reflectance, using an assumed Black Smoke index, according to the analysis of Quincey (2007).

The second objective of the project is the comparison of different PM monitoring devices. The Partisol 2025 has been compared to a PM_{10} TEOM-FDMS (Tapered Element Oscillating Microbalance Filter Dynamic Measurement System) monitor from July 2008 to February 2009. These instruments are intended to measure the same quantity, so in principle they should give consistent results.

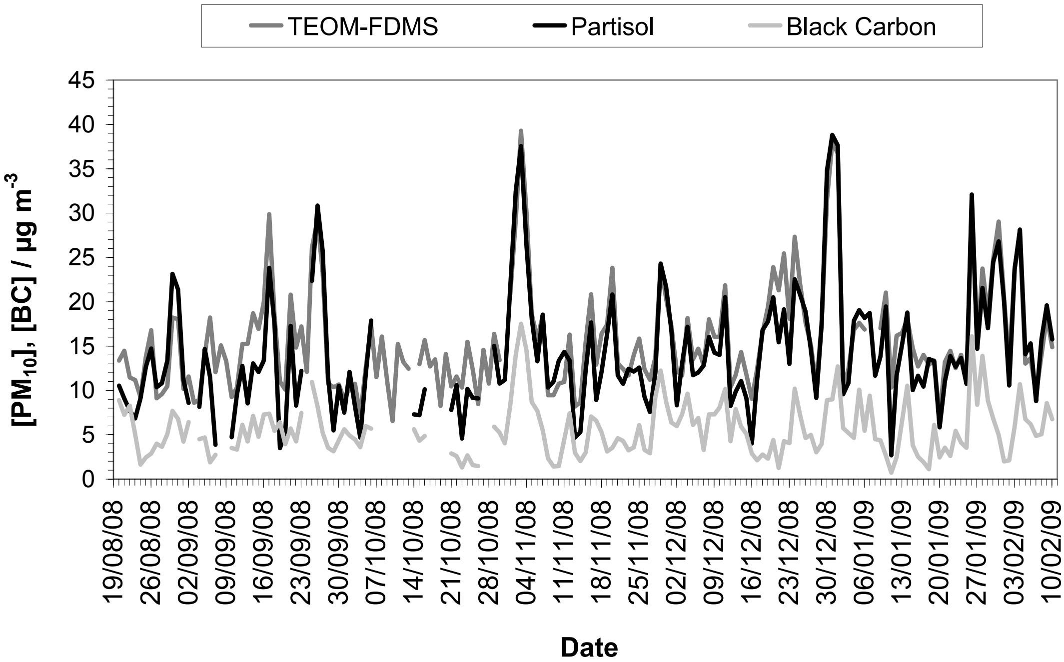
Semi-continuous data of PM_{10} concentration were collected from the monitoring devices for comparison. The hourly TEOM-FDMS PM_{10} measurements were averaged to daily values (midnight to midnight) provided there was at least 90 % data capture (22 1-hour measurements).

The third objective is to undertake multi-stage analyses of the water-soluble organic compounds using various techniques, in order to characterise, in a much more detailed manner, chemical aspects of this complex component of airborne PM. Standard reference materials (SRMs) of PM, obtained from the National Institute of Standards and Technology (NIST), have been analysed using the following techniques: water-soluble organic carbon (WSOC) analysis; ultraviolet-visible (UV-Vis) spectroscopy; and Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS). The NIST SRMs were dissolved in 18 MΩ water, and filtered through a 0.22 μm syringe filter, prior to analysis.

Results and discussion

Time series data of PM_{10} and BC concentration are shown in Figure 1. It can be seen that the general trends in daily PM_{10} concentration were followed by each of the instruments throughout the period of measurement, although data are missing. The peaks in PM_{10} on 5 November and 31 December, have been picked up by both instruments. However, there was a mean difference in PM_{10} concentration, between the TEOM-FDMS and Partisol, of 2 μg m^{-3} over the period of study.

Figure 1 Time series of daily mean PM10 and BC measurements.



Comparison of the Partisol gravimetric PM_{10} values against the TEOM-FDMS daily average PM_{10} data) shows a good linear correlation, with an R^2 value of 0.86. The major axis line has a slope > 1 and intercept < 1. This indicates a tendency for the TEOM-FDMS to give higher readings at low PM_{10} concentrations, and the Partisol to give slightly higher readings at higher concentrations. This systematic bias is linear so it could be corrected if necessary, subject to the uncertainty demonstrated by the scatter in the relationships.

BC is a sub-set of PM_{10} and is therefore expected to have a lower concentration. This is seen in the time series data (Figure1). However, there is no reason to expect a direct link between BC and PM_{10} although, in general, as PM_{10} concentration increases so does the level of BC (Figure 2).

The amount of water-soluble (WS) material in SRM 1649a was analysed. As the amount of PM was increased the amount of WS material measured increased linearly (R^2 = 0.99; Figure 3). This result shows that the technique worked as expected.

Figure 2 Comparison of daily mean PM10 concentrations between the Partisol and TEOM monitors, and daily mean BC and PM10 concentrations from the Partisol monitor.

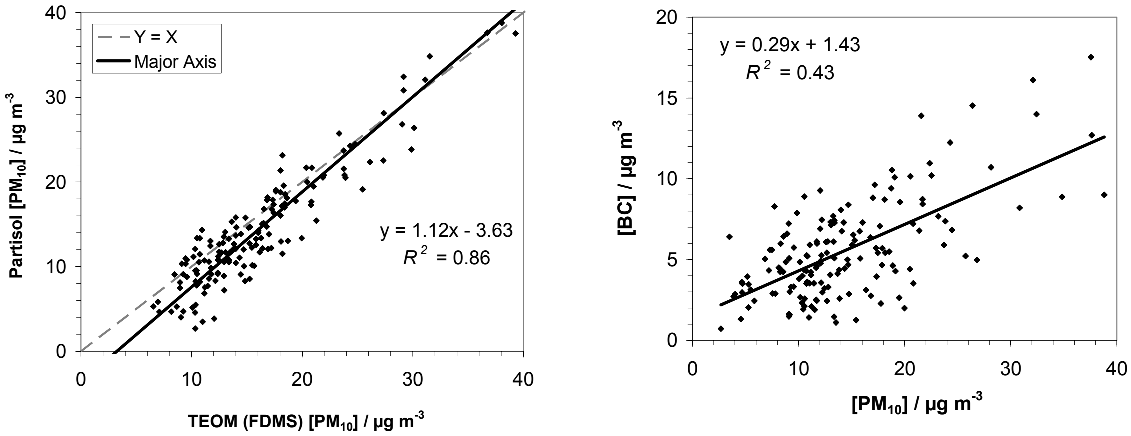
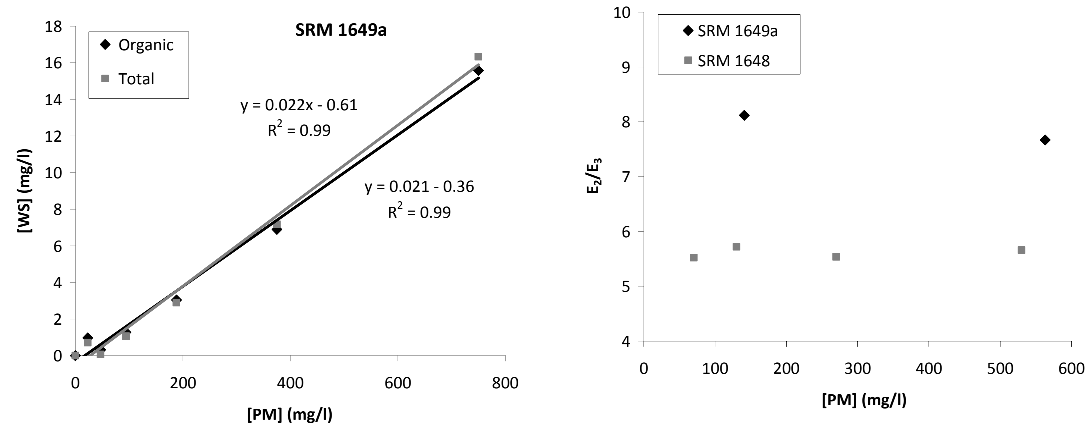


Figure 3 Amount of water soluble material, against PM concentration, in SRM 1649a, and UV-Vis E_2/E_3 for SRMs 1648 and 1649a



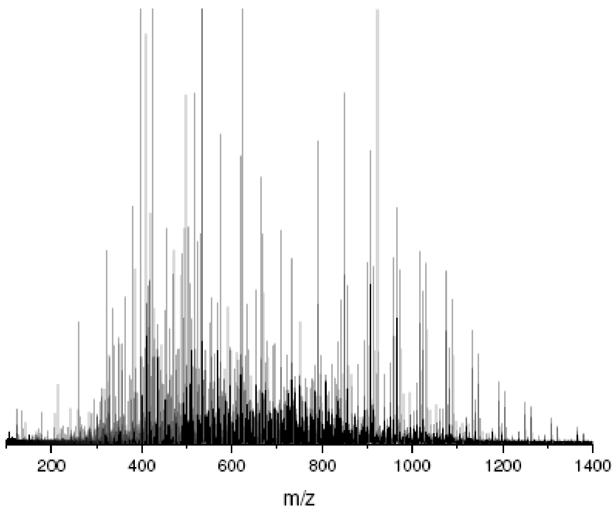
Samples were analysed before ("Total") and after ("Organic") acidification with phosphoric acid (Figure 3). The acidification causes the removal of inorganic carbon through the formation of CO_2. The amount of inorganic carbon present in SRM 1649a is show to be negligible, with approximately 2% of the total PM being WSOC. This is lower than values of 5 – 11% for WSOC reported by Duarte and Duarte (2005)

The UV-Vis spectra of WS PM tend to be featureless, with increasing absorptivity towards shorter wavelengths, and continuous absorption up to about 400 nm indicating the presence of conjugated double bond systems (Graber and Rudich, 2006). More qualitative information can be gained by studying the ratio of absorbances at 250 and 365 nm (i.e. the E_{250}/E_{365} or E_2/E_3 ratio), which has shown to be inversely correlated with molecular weight and aromaticity. For example, Duarte *et al.* (2005) reported a higher E_2/E_3 ratio in summer samples compared to autumn samples. This correlated with lower aromaticity in summer samples, as compared with autumn samples, and was confirmed by specific fluorescence intensity and ^{13}C-NMR.

The higher E_2/E_3 ratio for SRM 1649a (Figure 3) indicates a higher aromatic content and molecular weight in SRM 1648.

The positive ion electrospray ionisation FT-ICR mass spectrum of SRM 1649a is shown in Figure 4. Each peak represents a chemically distinct component and highlights the complexity of this sample of PM.

Figure 4 FT-ICR mass spectrum of NIST SRM 1649a, run in positive ion mode.



Conclusions

The Partisol and TEOM monitors are in good agreement, with BC following the general PM_{10} trend. ~2 % of NIST SRM 1649a is WSOC. NIST SRM 1648 has a higher average molecular weight and aromatic than SRM 1649a.

PM_{10} will continue to be collected at St Leonards, and the level of BC present will be monitored. Further chemical analysis will be undertaken on these PM_{10} samples.

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5.3c Dispersion of traffic related carbon monoxide in a street canyon in Nicosia

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Background and objectives

Urban areas are characterised by high levels of traffic-related air pollution concentrations. These are observed to be particularly high near ground level within street canyons, where tall buildings and different obstacles impede the pollutant distribution. A street canyon that is not well-ventilated can have an effect on human health and comfort. The dispersion process of pollutant concentrations depends on meteorological conditions such as wind speed and direction, on street geometry and building configuration and on vehicle emissions. Field measurements, laboratory experiments (wind tunnel and water flume) and mathematical models have been used to examine the interactions of mean wind and street geometry configurations on pollutant distribution within street canyons. (DePaul & Sheih, 1986; Vachon *et al,* 2002; Kastner-Klein *et al,* 2001; Crowther *et al,* 2002). Previous studies have revealed that under certain conditions in symmetrical canyons, e.g. for wind perpendicular to the street canyon a vertical vortex is formed within the canyon giving rise to maximum pollutant concentrations on the leeward side of the street (Vardoulakis *et a*l, 2003). In a numerical study of the case where the buildings are not symmetrical, Assimakopoulos et al (2003) report that a secondary vortex is created at the lower windward building corner of the street which leads to the accumulation of pollutants on the windward side of the street instead of on the leeward side. Further investigation needs to be done to understand the interaction of these street geometry effects on pollution dispersion.

Carbon Monoxide (CO) concentration distributions from vehicular emissions are investigated in a street canyon with an aspect ratio of 1.25 and one-way traffic in the centre of Nicosia in Cyprus. The objective of this study is to observe the distribution of pollutants along a street canyon on both sides of the street, as well as in the vertical direction, for wind blowing perpendicular to the street canyon, for a street with non uniform geometry under the case of low wind conditions. Furthermore, the performance of Operational Street Pollution Model (OSPM) will be examined for this case by a comparison to the field data. OSPM is highly validated for previous studies done with uniform building height and for quite high wind speeds (Berkowicz, 1998; Berkowicz *et al*, 2006).

Study description

Site and Methodology

A series of field experiments was performed in the central Nicosia in Cyprus in a non-uniform street canyon during the period December 2007-February 2008. The experiments were conducted in Rigenis street which is a one way street with quite high traffic running from East to West (traffic flow direction). The street is 160m long and 8m wide (W) (including the pavements) with variable building heights on either sides, as depicted in Figure 1. The building heights on the South side are H_S=11m on average and on the North side H_N=9m on average. The average building height (H) for both sides, 10 m, gives an aspect ratio H/W= 1.25. The South side of the street is the leeward side for southerly ambient winds.

The major emission source within the street canyon is traffic related and CO, a very good indicator for pollutant dispersion, was monitored since its chemical transformation is very slow. CO concentrations were recorded in several locations eight hours per day along the street at height 1.5m and 2.5m from the ground, as shown in Figure 2. Monitors were attached to pipe poles through cable connectors 0.1m away from the walls. The monitors provide mean CO concentrations averaged over 15 minutes.

Reference data on wind speed and direction, measured at 10m height, 3km away from the street canyon, were obtained from the National Meteorological Service of Cyprus. Local wind speeds were measured within the street canyon at height 1.5m from the ground on the South West side of the street. Traffic was measured for eight hours at the same location.

The field measurements were conducted under low wind conditions for wind perpendicular to the street canyon, and different traffic loads are summarised in two cases in Table 1: 1) high traffic, 2) low traffic.

Table 1 Overview of the field data

Cases	Reference mean wind speed (m/s)	Local mean wind speed (m/s)	Total number of vehicles in 8 hours	Temperature (C°)
1 .High Traffic	1.1	0.877	3655	16
2 .Low Traffic	1.2	0.955	2661	15.75

Model description

Field measurements are compared with calculations from an operational dispersion model for different traffic conditions. Operational Street Pollution Model (OSPM), developed by Hertel and Berkowicz (1989), is a parameterised model and pollutant concentrations are modelled with the combination of a plume model for direct contributions and a box model for the recirculation of pollutants in the street. The turbulence in the street is made up of the ambient turbulence based on the wind speed, and traffic - induced turbulence. Under low wind conditions the turbulence is dominated by the traffic - related component.

The model input is the heights of the buildings on both sides of the street, the width, length, and the orientation of the street, meteorological data (wind speed and direction above the roof level) and background CO concentrations obtained from the Department of Labour Inspection of Cyprus.

Results

An average of 15min of Carbon Monoxide concentration was obtained within the non-uniform building heights street canyon under low wind conditions and different traffic loads.

Field measurements of CO concentrations for high and low traffic

Figures 3 to 5 show the evolution of CO concentrations with time in the lateral (North-South), longitudinal (East-West) and vertical directions for the case where the wind is perpendicular to the canyon under high and low traffic conditions. As expected, CO concentrations along the street near ground level are higher for the case where the traffic is higher. CO concentrations in the lateral direction are greater on the windward side than on the leeward side for both traffic loads, with the difference ranging between 40 to 50 %.

In longitudinal direction CO concentrations are usually greater in the middle of the canyon on both sides of the street for high and low traffic as shown in Figure 4a and 4b. A notable exception is the concentration on the leeward side in low traffic conditions, Figure 4 (b). Furthermore, CO levels are higher on the windward side along the entire street.

Figure 5 shows the evolution of CO concentrations with time in the vertical direction on the leeward middle side of the street canyon for high and low traffic. CO concentrations decrease with height in both cases, ranging between 10 to 30 %. The difference among CO concentrations between the two heights is bigger for high traffic than for low traffic.

Comparison between field measurements and operational models

Hourly averaged CO concentrations were calculated with OSPM for the middle side of the canyon. Figures 6a and 6b show the hourly average CO concentrations with time when the wind is perpendicular to the street canyon for high and low traffic.

The model finds higher levels of concentrations on the windward side of the street, as do the field measurements. CO concentrations calculated by the model in low traffic conditions are correlated well with the CO concentrations measured in the field. However, the CO concentrations calculated by the model in high traffic conditions are not correlated well with the CO concentrations measured in the field.

Conclusions

Field measurements in the non-uniform building heights on the windward side of the street canyon in Nicosia in Cyprus and in low wind conditions find that CO concentrations were greater on the windward side of the canyon and the highest levels were observed in the middle of the street canyon. Furthermore, the concentrations levels decreased with height.

A comparison between field measurements and OSPM model calculations show that the model performance is not quite satisfactory under low wind conditions with the non-uniformity in building heights. These results are preliminary and more tests need to be done, to determine the performance of OSPM under low wind conditions for different street geometries.

Discussion

Pollution measurements taken near ground level on both sides of the street reveal a complex dependence on street geometry and layouts and on meteorological conditions. The observed levels of CO concentrations on the windward side confirm results of previous numerical study, that when leeward buildings are taller than the windward buildings, pollution dispersion characteristics are not the same as for a symmetrical street canyon where the concentrations are higher on the leeward side. This may be explained by the lower wind conditions and the weakness of the main vortex within the canyon that is expected under such conditions. Furthermore, this might indicate that a vortex is created at the lower level of the street, having opposite sense to the main vortex, and leading to the accumulation of pollutants on the windward building, as predicted by Assimakopoulos *et al (2003).*

The differences between the OSPM values to the measured values might be explained by the fact that the OSPM model does not accurately resolve traffic-related turbulence, the component which is especially crucial for the computed results under low wind conditions (Kukkonen *et al*, 2000). Furthermore, traffic emission estimates are always unreliable due to large variability amongst different vehicle models. The wind speed and direction were measured 3 km away from the street and may not accurately represent the roof level values in the street.

Further investigation will be done to examine the pollution dispersion in street canyons with more complex configurations in lower wind conditions. The experiments will be carried out in a water channel enabling a study of flow characteristics and patterns. Different geometrical characteristics will be examined under meteorological wind and traffic conditions, for example a) Leeward side will have varying heights and b) Windward side will have varying heights. Moreover the experiments will be compared with the Operational Street Pollution Model.

In previous studies of street canyons buildings are considered to have no gaps between them, which lead to higher accumulation of pollutants within the street. Rigenis street canyon presents a few gaps between the buildings as shown in Figure 2, and further investigation will be carried out to examine the affect of these gaps on the pollutant dispersion.

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Figure 1 Rigenis Street canyon

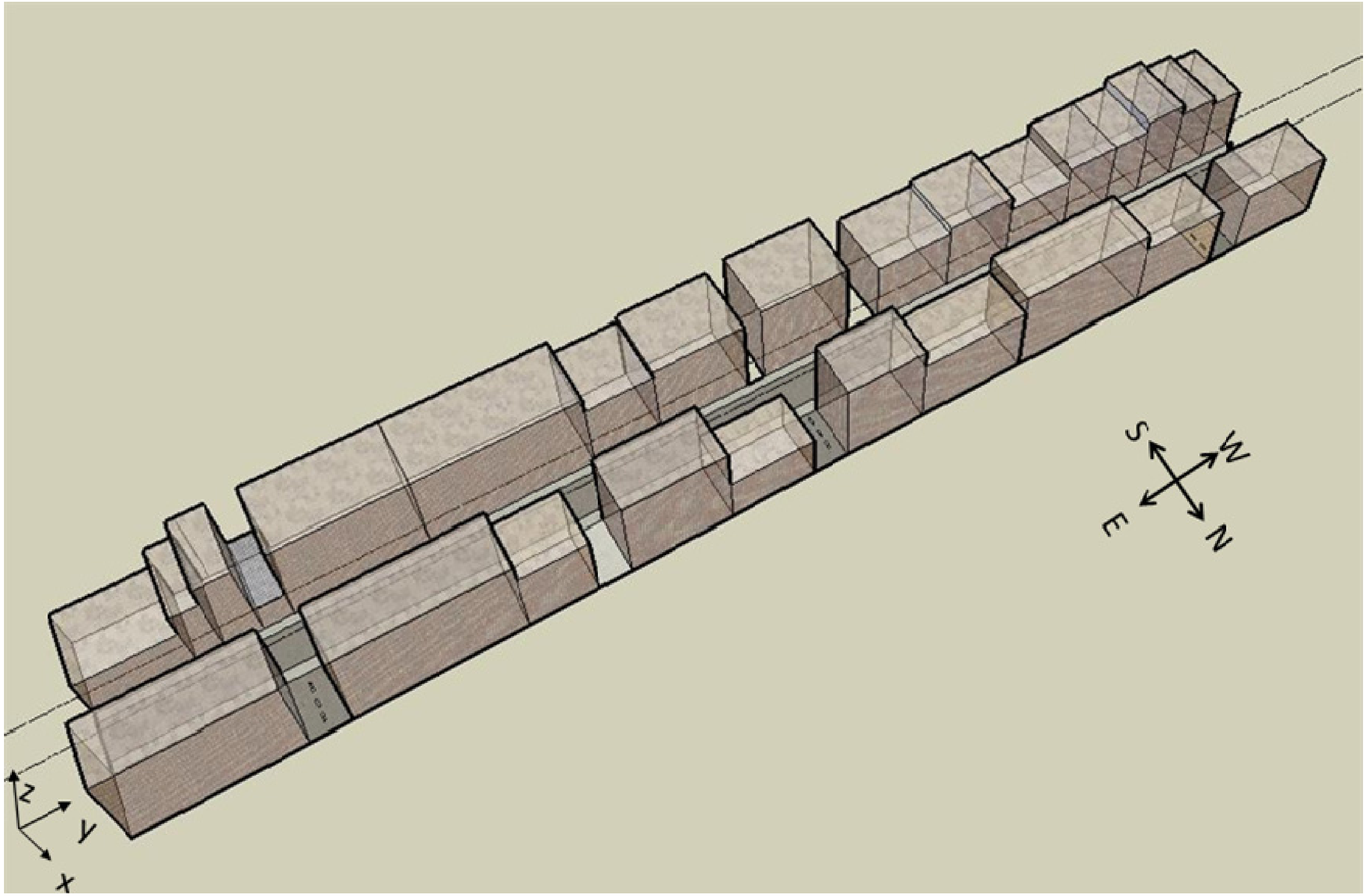


Figure 2 Schematic diagram of Rigenis Street and monitors positions

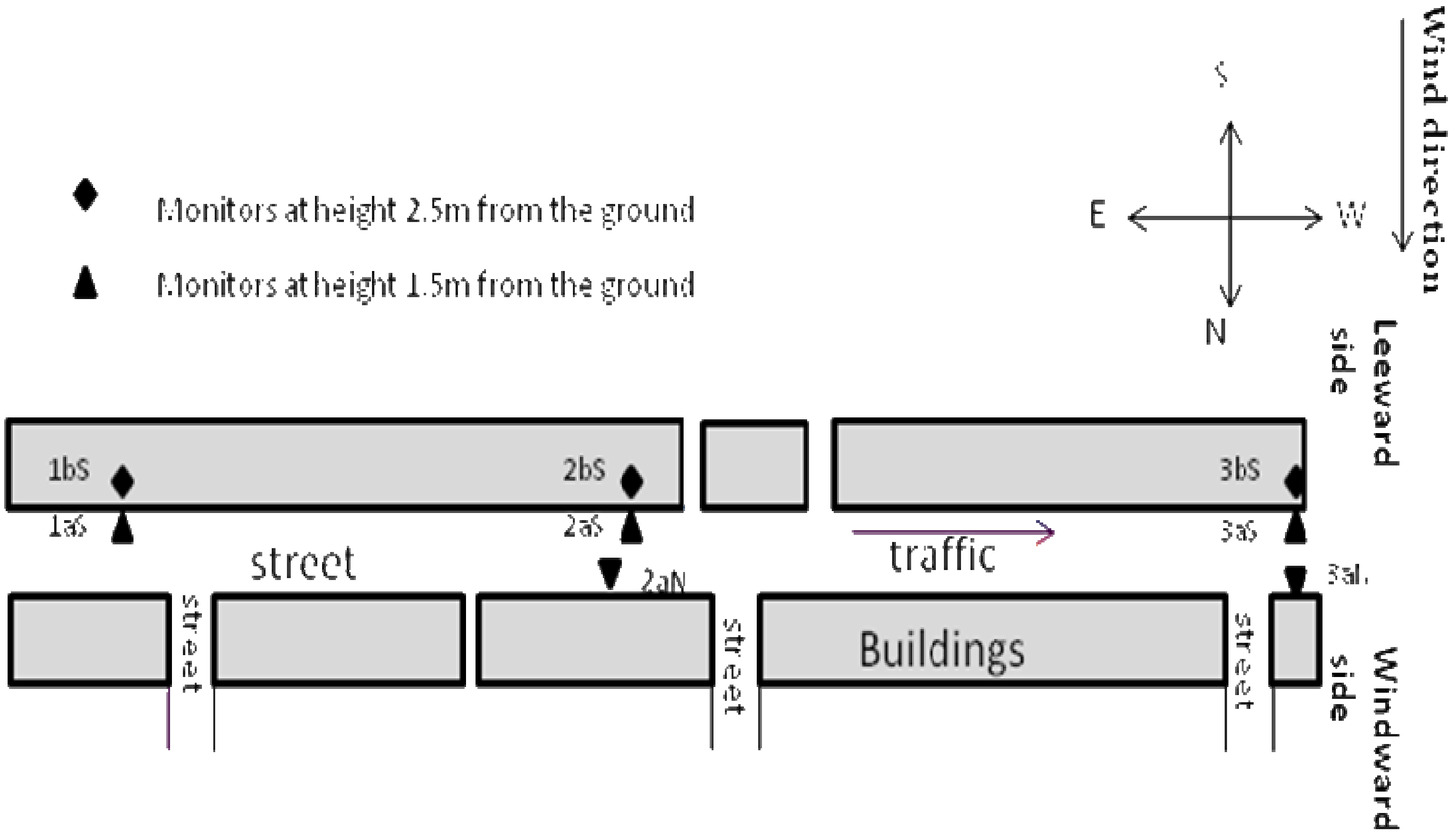


Figure 3 CO concentrations in the lateral direction for wind blowing perpendicular to the street canyon for two traffic loads

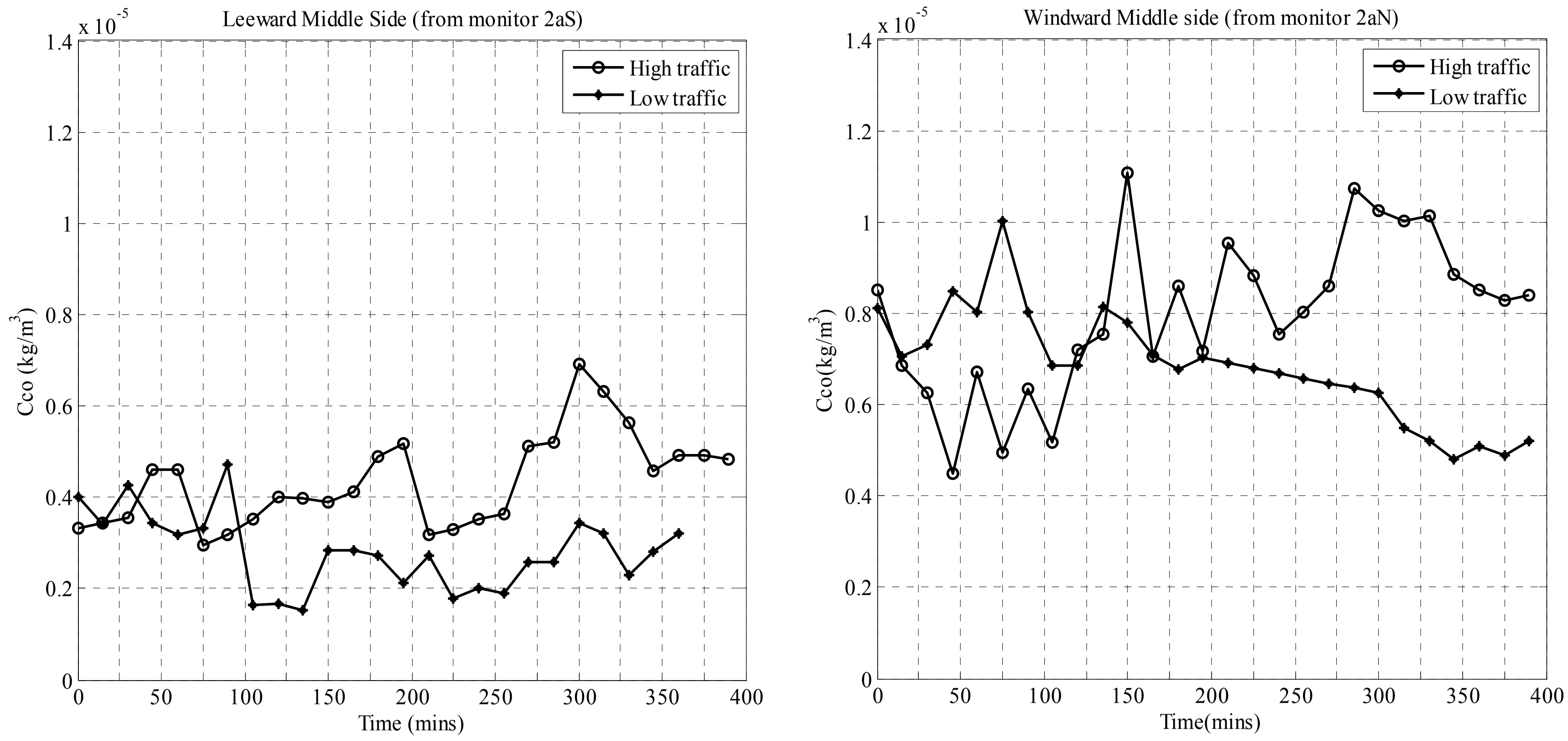
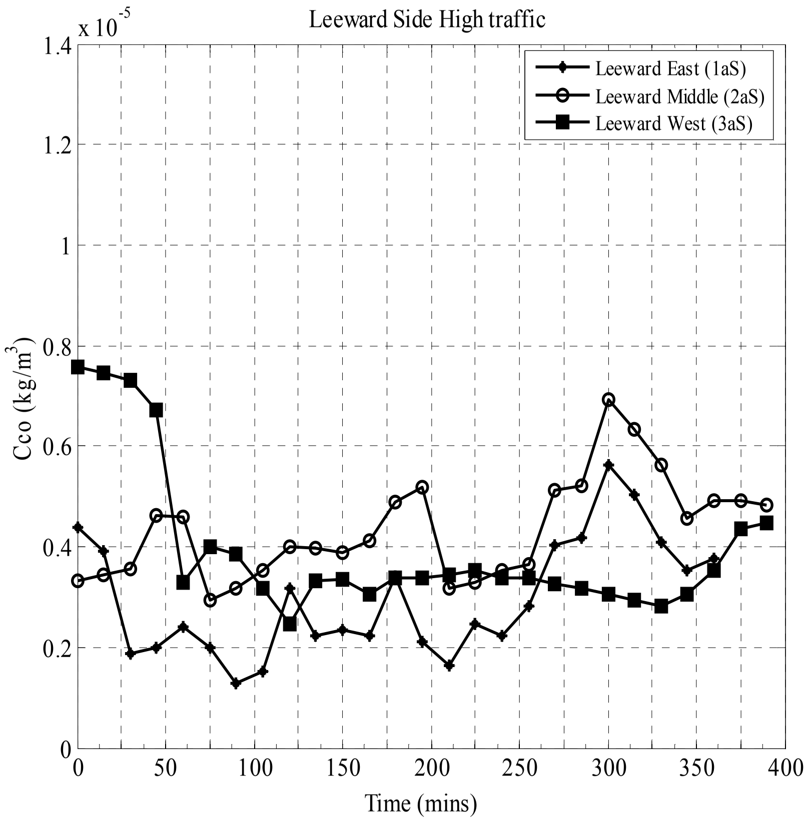
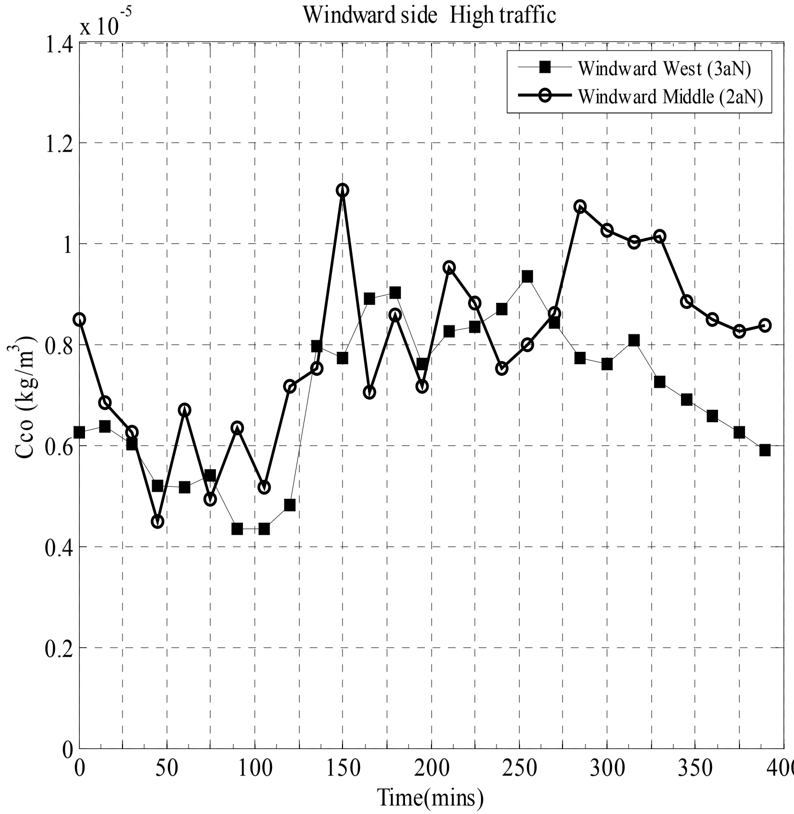


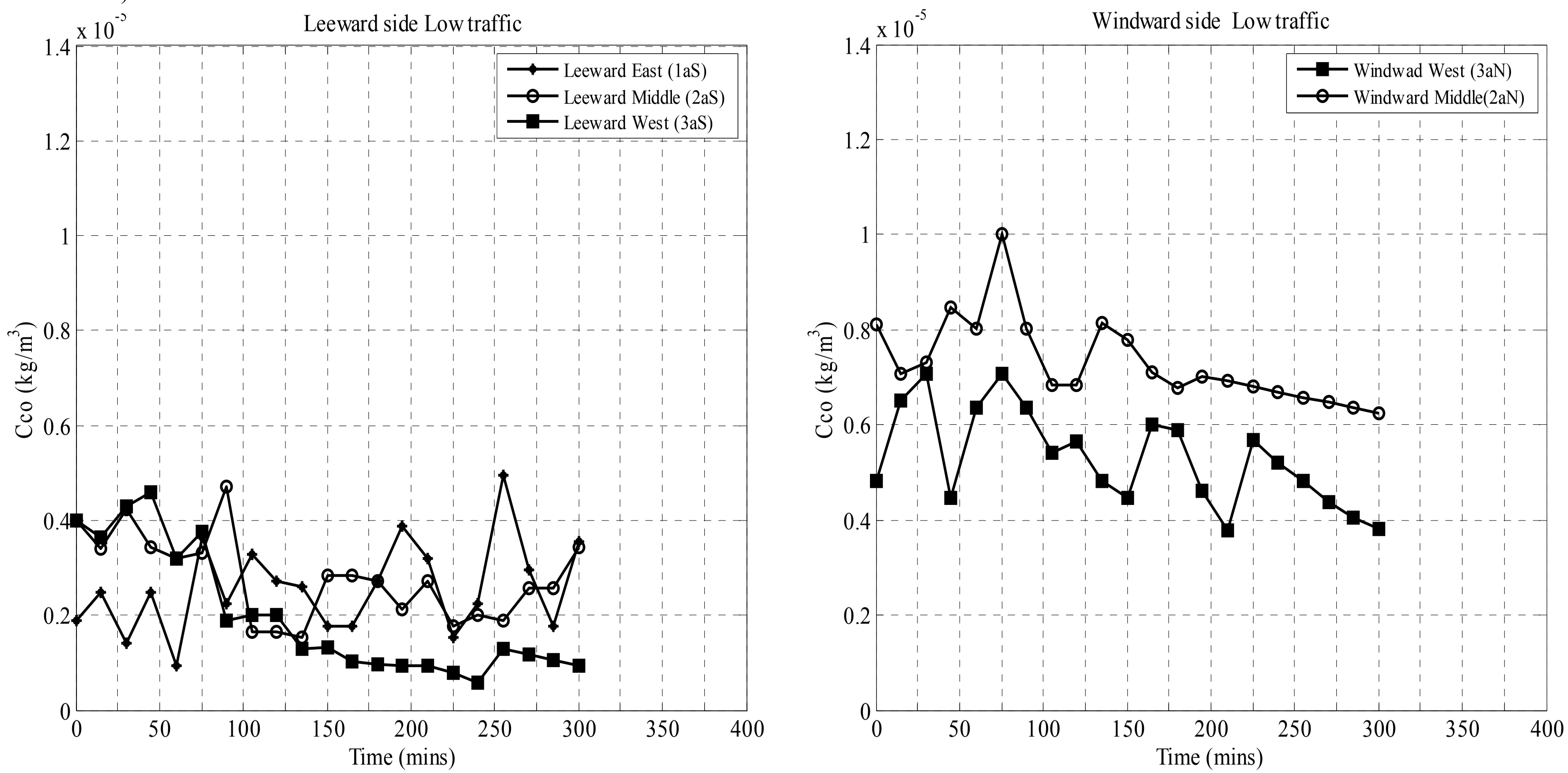
Figure 4 CO concentrations in longitudinal direction for wind blowing perpendicular to the street canyon: a) High traffic, b) Low traffic

a)





b)



Leeward side Low traffic
x 10^-5
Cco (kg/m^3)
Time (mins)
Leeward East (1aS)
Leeward Middle (2aS)
Leeward West (3aS)
Windward side Low traffic
Windwad West (3aN)
Windward Middle(2aN)

Figure 5 CO concentrations in the vertical direction for wind blowing perpendicular to the street canyon in high and low traffic

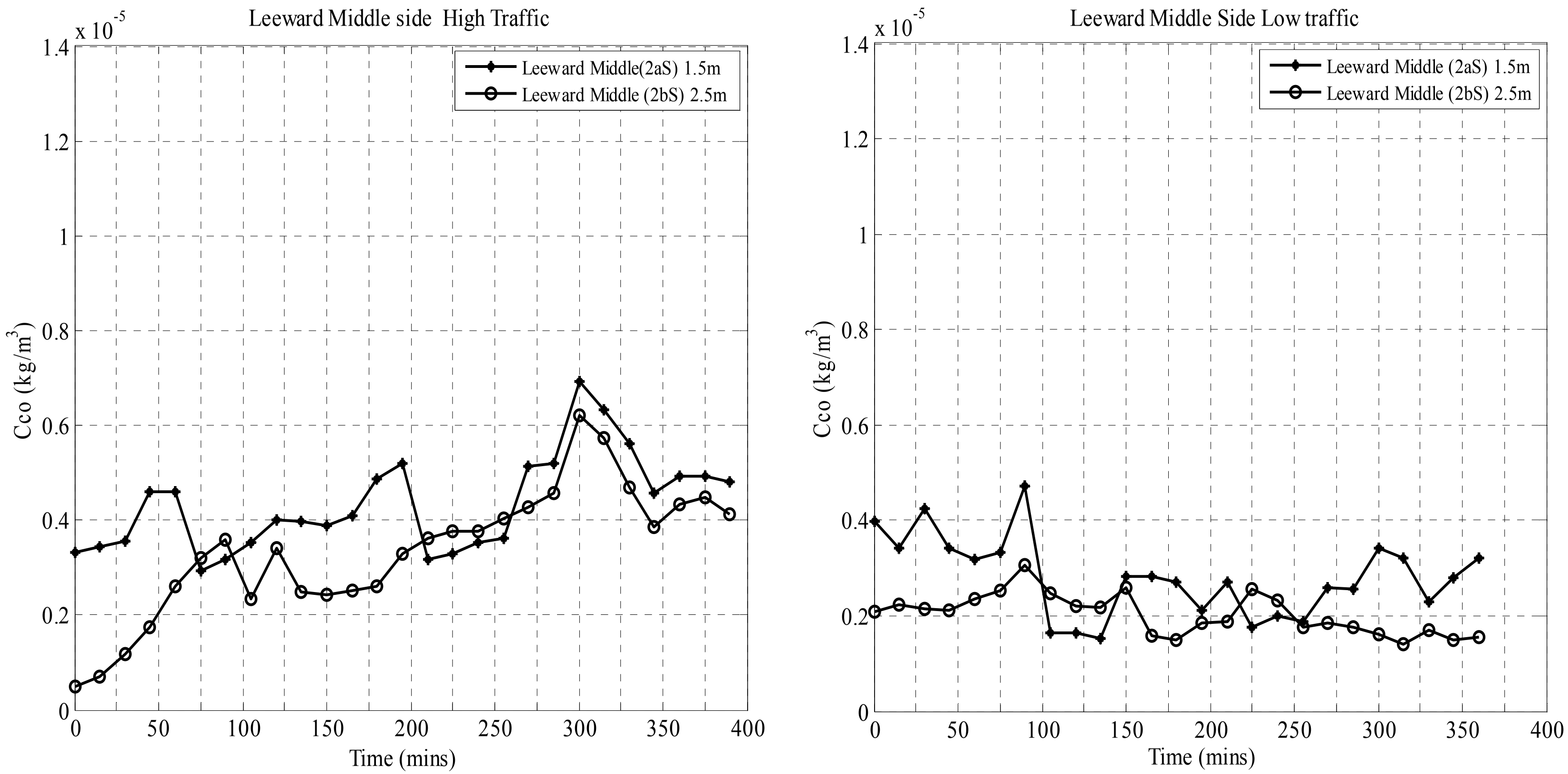
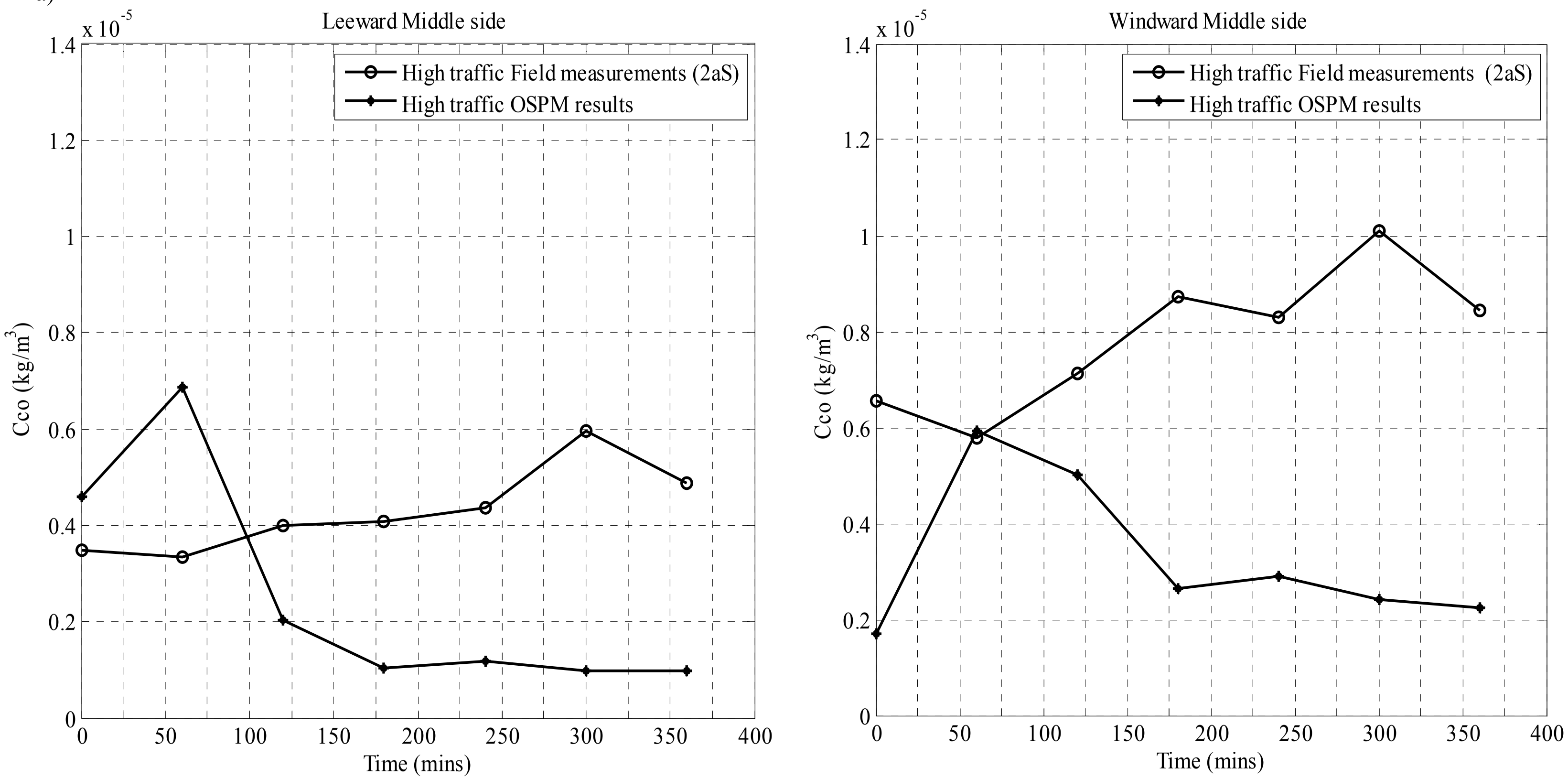
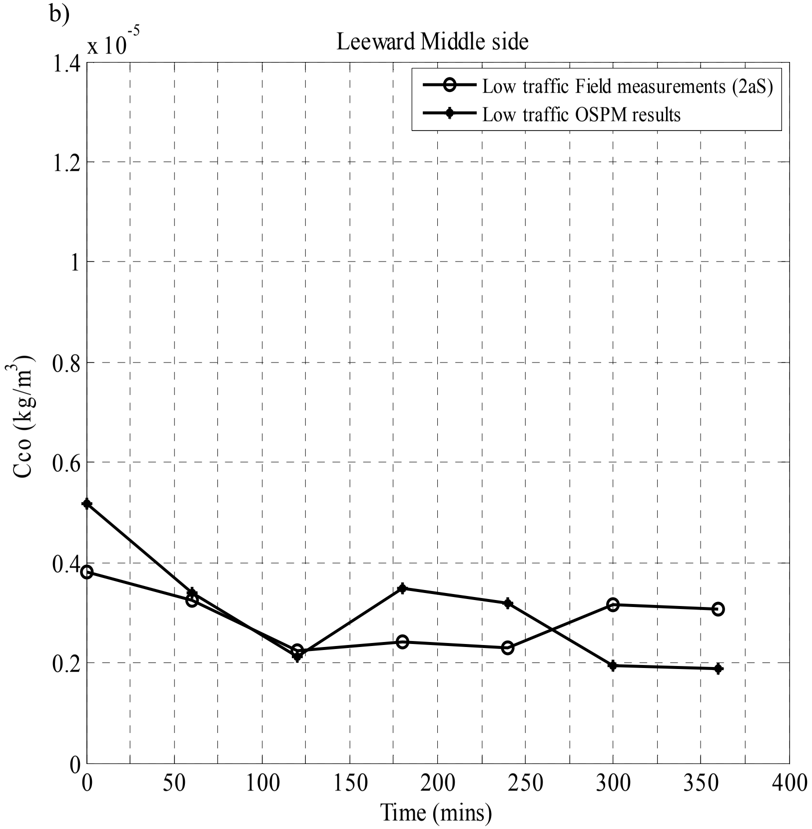


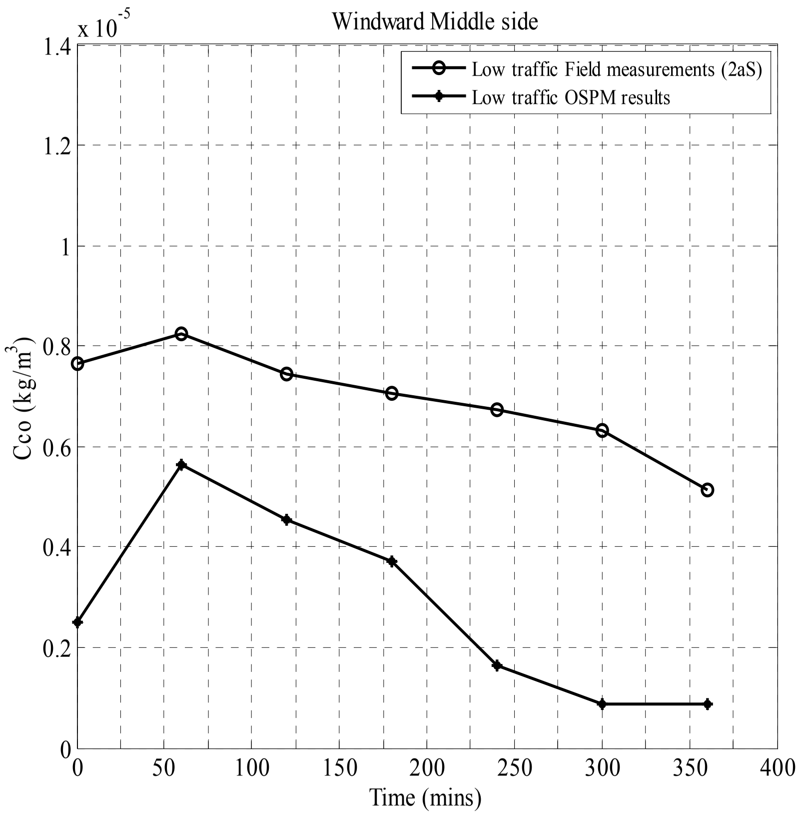
Figure 6 Correlation of CO concentrations from Field measurements and OSPM results: a) High traffic b) Low traffic

a)



b)


Leeward Middle side
x 10^-5
Cco (kg/m^3)
Time (mins)
Low traffic Field measurements (2aS)
Low traffic OSPM results
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
50
100
150
200
250
300
350
400


Windward Middle side
x 10^-5
Cco (kg/m^3)
Time (mins)
Low traffic Field measurements (2aS)
Low traffic OSPM results
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
50
100
150
200
250
300
350
400

6 Toxicology and human health studies

6.1 Presentations

6.1a Oxidative activity – a promising new marker of PM toxicity

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Despite relatively small observed associations between ambient levels of particulate matter (PM) and adverse health effects, widespread exposure leads to large population attributable risks even in developed countries where ambient levels are comparatively low (Kunzli et al, 2000). Much of the available evidence supports a causal relationship between exposure to particles and cardiovascular disease, and no threshold has been identified below which exposure is no longer harmful (Brooke et al, 2004; DH, 2006). In the UK exposure to anthropogenic PM is estimated to reduce life expectancy by up 8 months, with an estimated cost of £8.5 - 20 billion per annum (Defra, 2007).

Appreciation of the adverse health effects of PM from epidemiologic and controlled exposure studies has led to the establishment of mass-based air quality standards for particles according to particle size. It is however widely accepted that PM mass represents only a surrogate of the biologically active dose of particles, and is therefore far from an ideal metric (Kelly, 2003). PM is a complex mixture, and there is considerable interest in the specific components responsible for the observed health effects (Borm et al, 2007). Clearly a better understanding of the properties or components of PM that are most linked with health effects will allow for the development of more targeted and efficient control strategies (Defra, 2007a).

The mechanisms underlying PM related health effects are still incompletely understood. One popular hypothesis under investigation is that many of the adverse effects may derive from PM induced formation of reactive oxygen species (ROS) at the surface of and within, target cells. There is a growing literature on specific health effects in association with cellular oxidative stress, including the ability of PM to induce pro-inflammatory effects in the nose, lung and cardiovascular system. High levels of ROS cause a change in the redox status of the cell and its surrounding environment, thereby triggering a cascade of events associated with inflammation and, at higher concentrations, apoptosis (Xiao et al., 2003; Schafer et al., 2003). Consequently, tests designed to quantify the potential of particles to exert oxidative stress have been developed, and are being used in a comparative manner to evaluate those particle properties, most influential in eliciting toxicity.

This approach is under investigation in my laboratory at King's College London. We have established an *in vitro* screening system, which involves the incubation of PM samples within a synthetic respiratory tract lining fluid (Zielinski et al., 1999; Mudway et al., 2004). The respiratory tract lining fluid (RTLF), represents the first physical interface encountered by inhaled materials and contains high concentrations of the antioxidants ascorbate (vitamin C), urate and reduced glutathione (GSH). Examining the extent to which PM depletes antioxidants from this model with time (37◦C, pH7.4) thus provides not only a quantitative output of activity, but also reflects reactions likely to occur *in vivo* at the air-lung interface. Following extraction of PM from a variety of filter matrices, particle suspensions are added to the synthetic RTLF, containing the equimolar concentrations of the antioxidants urate, ascorbate and GSH (200 μM), at PM concentrations ranging from 10–50 μg/ml. The capacity of the particles to deplete ascorbate and GSH from this model is then monitored over a 4 h period. In contrast to other oxidant pollutants such as ozone or nitrogen dioxide, urate is not a target for any PM component (Kelly, 2003).

Further characterisation of the oxidative activity of PM can be achieved by performing co-incubations with metal ion chelators and antioxidant enzymes such as superoxide dismutase and catalase the hydroxyl radical scavenger dimethyl sulfoxide. Given that any measure of particle oxidative capacity needs to be robust over time, it is important to ensure intra-assay standardisation between experiments. To achieve this, we routinely run a number of particle-free and particle controls (Zielinski, 1999). Blank filters or foams are also routinely extracted and run through the assay system.

My presentation will provide an overview of progress with this approach by presenting data from a number of European and UK studies.

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6.1b Database and meta-analyses of prevalence and cohort studies of air pollution and asthma

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Background and objectives

Epidemiological evidence for health effects of long-term exposure to air pollution has been reviewed many times by various groups. The intention of these reviews was mainly to evaluate the health hazard potential of air pollution and the reviews addressed this in qualitative terms. This approach is no longer adequate. Firstly, the use of evidence for policy development has increasingly used quantitative risk assessments for which quantitative estimates of health effects are required. Secondly, it has become appreciated that any evaluation of observational evidence about environmental health hazards requires a rigorous and systematic protocol driven approach in order to ensure that it is comprehensive, transparent and unbiased. With this in mind, the Department of Health established what was to become the Air Pollution Epidemiology Database (APED) at St George's, University of London, with the purpose to support COMEAP in reviewing the very extensive evidence on the temporal relationships between air pollution and health outcomes.

This project aims to extend the application of this concept to epidemiological evidence relating spatial variations in air pollution to asthma and other respiratory symptoms. These normally take the form of prevalence studies in which health outcomes are ascertained at one point in time or over relatively short periods of time, or incidence studies in which the occurrence of health outcomes is ascertained in cohorts followed over time. Because ambient air pollution is almost always measured at the population level, such studies need to involve a number of areas varying in air pollution concentrations. These might be between different cities, or within a city where it is possible to compare populations or individuals characterized by different exposure to line (roads) or point (e.g. industrial) sources. Spatial studies are prone to confounding by factors such as indoor environment, personal behaviour or socio-economic characteristics.

The aim of this project is to develop, establish and maintain a database of studies containing data relating to the association between chronic exposure to outdoor air pollution and the incidence and /or prevalence of asthma and other respiratory symptoms. Building on St. George's experience with time-series studies we are creating a database of prevalence studies of asthma and air pollution which can provide an up-to-date, rapid and flexible response to policy questions.

In this abstract we provide a description of the progress with the project so far and present some examples of outputs prepared for the COMEAP asthma report.

Project description

The project comprises the following stages:

1. Systematic ascertainment of relevant studies from the peer reviewed literature.
2. Development of an Access database and extraction of data.

3. Presentation of results in graphical and tabular forms.
4. Exploration of the possibility and appropriateness of standardizing and quantifying effect estimates for various pollutant and respiratory outcomes.
5. Preparation of reports.

A search string was developed and tested using the bibliographies of those prevalence studies already known. It was necessary to start with a search string that retrieved a large number of studies.

Medline, Embase and Web of Science were searched to identify relevant studies on prevalence and incidence. Studies were first sifted for relevance by title and then, by abstract content. Only original studies reporting results at community level and published in English were considered.

A data extraction protocol was developed to be able to summarize the wide heterogeneity of the studies design. The full text of the relevant studies was read and their bibliographic and descriptive details recorded using a data extraction form (Level 1 Form). If the study was eligible for further analysis, a second data extraction form (Level 2 Form) was used to record estimates reported in the results and related information needed for their standardization and characterization.

An Access database was constructed for the recording, structuring, presentation and analysis of the data, including meta-analysis through direct links with the statistical program Stata.

The Access database contains two parts;

i. The 'Level 1' part, in which descriptive details of the study (i.e. authors, country, study design, sex and age of participants, outcome parameter, outcome topics, type of exposure comparisons) are entered. It reflects the structure of the Level 1Extraction Form;
ii. The 'Level 2' part, in which quantitative details of the study's estimates and related information are entered. It reflects the structure of the Level 2 Extraction Form.

Additional commands, such as standardisation of pollutant increment were coded into the database to facilitate data analyses.

Results

More than six thousands studies were retrieved and sifted for relevance. Around 300 relevant studies on the association between chronic exposure to air pollution and asthma and/or related symptoms have been identified. Their designs proved to be extremely varied in population sampling, outcomes, exposure characterizations and comparisons, adjustment of confounders, and statistical analyses.

For the purpose of the Asthma report we are concentrating on studies of

1. Birth cohorts,
2. Other cohorts
3. Multicenter prevalence studies.

Twelve birth cohort studies, seventeen other cohort studies and twenty multicenter prevalence studies have been identified as eligible for the Level 2entry.

Discussion/Conclusion

The development of this project has shown that it is feasible to construct a database of chronic exposure studies which complements the existing database of short-term exposure studies despite fundamental differences between the two types of literature. Although the heterogeneity in outcomes and exposure characterizations among the long-term studies may limit the opportunities to combine estimates for quantitative meta-analyses, the graphical presentation of standardized estimates will facilitate the evaluation of evidence.

6.1c A study of the concentration-response relationship for the effects of ozone on health

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Background and objectives

A number of epidemiological studies have linked exposure to ambient outdoor ozone concentrations with increases in the numbers of all cause and cause specific deaths and emergency admissions to hospital with respiratory diseases. There is less evidence for an association between daily ozone levels and cardiovascular hospital admissions (COMEAP, 2006].

The existence of a threshold (an ozone concentration above which health effects are only observed) and its value is fundamental to health impact assessment calculations. Epidemiological studies provide mixed evidence for the existence of a threshold for the association between ozone and daily mortality and hopsital admissions. A recent time series analysis of the large NMMAPS database (Bell *et al*., 2006) concluded that the health effects of short term exposure to ozone were observable at concentrations far below US and international standards adding to the concern over the evidence for a threshold. The European equivalent, the APHEA (Air Pollution and Health: a European Approach) study included ozone in its analysis of daily mortality in 23 cities and reported evidence for a linear concentration response function for all cause mortality during summer months (Gryparis *et al*., 2006). Few studies have examined the evidence for a threshold systematically, assessing various health outcomes, diseases, copollutants and variations by season and over time. Also, it is possible that within-city exposure variation around fixed monitors may mask true threshold values since some of the population might be above and some below the threshold for health. Little work has been undertaken in this important area of research that may have a significant impact on identification of appropriate threshold values. A further complication arises in that the effect estimates may vary over time as the air pollution mix changes and abatement strategies take effect as found for particles (Dominici *et al*., 2007).

This two year project, starting in April 2009, aims to investigate the nature of the relationships between short term exposure to ozone and death and admission to hospital. In particular, the study aims to examine the shape of the concentration-response function to assess the evidence for the existence of a threshold. This aim will be met using two distinct approaches:

1) Ecological time series study of daily counts of deaths in 5 urban and 5 rural centres and respiratory admissions in two urban centres

2) Case crossover time series analysis of mortality in England using daily modelled ozone concentrations at a fine spatial scale.

Study description

Part 1 – Time series analysis A dataset compiled for the MRC-funded project "Heat waves in the UK: impacts and public health responses" (Ben Armstrong) will be used to provide daily numbers of deaths together with pollution and meteorological data for the period 1993-2006. Data for the 5 largest conurbations in England and Wales (London, West Midlands, Manchester, Tyneside and Liverpool) will be selected for analysis. A further 5 rural areas will be chosen and similar health and pollution data compiled and added to the dataset. Respiratory admissions data for London and West Midlands will also be obtained from existing datasets held at St. George's.

The statistical analysis will follow a two stage hierarchical approach. Time series models will be fitted to the health outcomes for each city to allow for specific control for seasonal effects, meteorology and other potential confounders of the ozone/health relationship. Non-parametric smooth functions of ozone will be included in the models to allow a non-linear concentration response function between ozone and the health outcome. These individual relationships will be described and assessed for evidence of a threshold. In the second stage the concentration response functions will be combined to arrive at an overall estimate of the potentially non-linear associations between ozone and mortality. Sensitivity analyses will be conducted to investigate potential confounding or effect modification by season, weather and outdoor pollutants together with evidence for temporal changes in threshold values over time.

Part 2 – Case crossover analysis of spatially disaggregated data. Post-coded mortality data from the Office for National Statistics in England & Wales enable the mapping of health events on a fine spatial scale and over time. These data will be linked with modelled daily ozone concentrations at a 5X5 km grid resolution. This analysis supplements the ecological analysis in part 1 in that it uses spatially disaggregated data to 5 km square grids. This will allow assessment of a possible problem with spatially aggregrated measurements, which can blur the true concentration response relationships since within-city variation around the fixed monitors mean that some of the population might be above and some below the threshold for health effects.

This component of the research comprises an extension of pilot work currently underway in the collaboration between the LSHTM and Edinburgh University funded by the NERC. In the pilot work, the exposure estimation model is being refined, spatially-referenced mortality data assembled, and the combined data set used to examine independent and combined associations of ozone and heat with mortality. The proposed work will extend this by (i) extending the duration of exposure data [limited by large computer time demands of the model]; (ii) focussing analysis on the possible existence of a threshold for an ozone effect.

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6.1d Association between air pollution and hospitalisations for respiratory disease in Leeds

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Background and objectives

The health effects of air pollution have been subject to several studies in recent years. Earlier studies focussed on increase in mortality and hospital admission during air pollution episodes. Attention has now shifted to weather-driven, day-to-day variations in air pollution over long periods of time as determinants of day-to-day variations in mortality, hospital admissions, and other public health indicators. The quantification of the relationship between air pollution and daily mortality can be useful for developing policy interventions.

This study aimed to explore the association between ambient air pollution concentrations in Leeds and respiratory hospital admissions. This was in order to add to the limited number of studies in the UK that have explored this association before, thereby increasing the knowledge of how these associations vary spatially. The main aim was to determine whether daily variations in PM_{10}, NO_2, CO and O_3 levels over a period of five years were associated with daily variations in cause-specific respiratory hospital admissions. The study also investigated the relative risk associated with an increase across the inter-quartile range of each pollutant, for all-cause respiratory disease. The relative risks were investigated for the above on different age groups and at different times of year.

Study description

Air quality, meteorological and health outcome data

The ambient concentrations of PM_{10}, NO_2, SO_2, CO and O_3 in Leeds were used as a surrogate for pollutant exposure. The hourly air pollution data for Leeds for five years (2001-2005) was collected from the Urban Centre AURN monitoring site.

The health outcome time-series were all respiratory hospital admissions, and the data came from Leeds Primary Care Trust. Following the praxis of previous studies (e.g. Goldberg *et al.,* 2000), hospital admissions data were broken down by the International Classification of Diseases (ICD) Codes; the ICD 10 Codes for respiratory diseases are J00 – J99 (WHO, 2007). Total respiratory admissions were then disaggregated by age group (0-59, 60-69, 70-74, 75-79, over 80). Daily data on temperature and relative humidity/dew point temperature were necessary to control for the potential confounding effects of weather (Katsouyanni *et al.,* 1996). Since one of the predominant factors in determining concentrations of pollutants is wind speed (and through wind speed, pollutant dispersion), data on wind speed was also included. Meteorological and hospital admission data were collected for 2001-2005.

Base Model

The analysis was in the form of a time-series study, which serves to assess the association of short-term variation in pollution and health outcomes within the same geographical area.

Meteorological data and data on respiratory admissions were used with the pollution data in a time-series analysis. A Base Model was developed using Poisson regression model that allows for over-dispersion (Schwartz *et al*, 1996).

By controlling for the confounding effects of long-term trends, seasonality and meteorological influence, the association between an increase in pollutant concentration and changes in the daily rate of hospital admissions were ascertained. The primary issue was to control properly for potential confounding, and the principal concern was confounding by factors that vary on similar timescales as pollution or hospital admissions. The different sources of potential confounding can be broadly classified as either measured or unmeasured; measured confounders include weather variables such as temperature and relative humidity, and unmeasured confounders are those factors that produce seasonal and long-term trends in admissions (Peng *et al.,* 2006).

To account for long-term trends (for example, year-to-year fluctuation), and for systemic difference in the health outcome in relation to the day-of-the-week (DOW), terms for year, season, month and DOW were all entered alternately into the model as 'class' variables. Time trends, accounted for by linear and quadratic terms for day-of-study, were also considered. By developing the Base Model in this way, X^2 statistics were available for each model component; these allowed comparison of the fit and contribution of all parts of the model (Spix and Wichman, 1996). Only those class variables that made significant contributions to the model ($p<0.05$) were kept in the model.

The model-building process so far removed temporal trends and seasonal effects. To complete the base model, weather terms were then entered into model; these carry information about the effects of short-term variations in weather on mortality or morbidity (Schwartz *et al*, 1996). There were three temperature variables tested (mean, minimum and maximum), and also variables for relative humidity and mean wind speed. Following Goldberg *et al.* (2000), a series of statistical models for each of the above variables were produced, which included the temporal filters for seasonality and time trend; the meteorological variables were entered into the models separately, for lags 0 through 5 days. The set of meteorological variables that accounted for the most variation in the model residuals was used in the final model (the temperature variable was one of the mean, minimum or maximum, not all three). To select the variables which accounted for the most variation in the model residuals, X^2 statistics were examined for each of the variables, at each lag. Each of the meteorological variables was included in the base model, irrespective of its significance in the model (Petroeschevsky *et al.,* 2001).

The process so far resulted in complete base models, including up to a total of 20 independent variables (including all possible sinusoidal terms). It was necessary to build separate models for each age group, because daily counts of admissions in various diagnostic groups and age-groups exhibit different seasonal and long-term trends; separate models are needed to ensure the most appropriate control for those trends (Touloumi *et al.,* 2004). This resulted in a prolonged model-building process.

Single Pollutant Models

After building the base models, the subsequent step was to add the pollutants and their respective lags individually to the model in a Poisson regression. Following Petroeschevsky *et al.,* (2001) lags of 1 day, 2 days and 3 days, and also the 3- and 5-day average lags (over lags 0 to 2, and lags 0 to 4 respectively) were examined. To produce overall estimates comparable to other published results, linear terms were used for all pollutants (Touloumi *et al.,* 2004). To run the final model, the GENMOD procedure was used within SAS.

Multiple Pollutants Model

Multi-pollutant models were used where more than one pollutant showed a significant positive relationship with an outcome variable (Schwartz *et al*., 1996). To avoid potential problems associated with collinearity between the pollutants in question, a dummy variable which represented the top 20% of the potential confounder was used, where the high levels of the co-pollutant were given the value of 1 (Petroeschevsky *et al.,* 2001). Final results were calculated as the percentage change in admissions associated with one interquartile range (IQR) increase in each pollutant. An IQR increase can be thought of as the difference between a moderately good day and a moderately bad day, and this makes the increases from different pollutants more comparable (Barnett *et al.,* 2006).

Results

Single Pollutant Models

Single pollutant models gave the percentage increase in the number of admissions associated with each pollutant (more specifically, an increase in each pollutant equal to that pollutants' inter-quartile range) by age group for zero lag, one day lag and two days lag. Results for all the lags were investigated and the significant associations were identified. The change in admissions associated with the pollutants (the effect estimate) are in the range of -2.53% (CO lag 0, aged 70-74: insignificant at $p<0.05$) to 4.64% (PM_{10} lag 2, aged 75-79: significant at $p<0.05$).

Particles (PM_{10})

Significant, positive associations were found for admissions in the over 80 group and the 75 – 79 group. An increase across the interquartile range (of 14.16 $\mu g/m^3$) resulted in a 1.71% increase in admissions for the over 80s (same-day, or lag 0), and a 4.64% increase in admissions for the 75 – 79 group (lag of two days, or lag 2). For the three younger age groups, the associations were mostly positive, but none were statistically significant. The biggest associations tended to be with either zero lag, or with a two-day lag.

NO_2

Associations between admissions and mean NO_2 were positive for all but the 70 – 74 group at a one day lag. Effect estimates ranged from 1.812 (two day lag, in the 75 – 79 group) to -0.180 (two day lag, in the 70 – 74 group), and generally effect-estimates were comparable with other pollutants. However, there were only significant associations in one age group, the 0 – 59 age group, for which an increase across the IQR of 18.016 $\mu g\ m^{-3}$ results in a 1.45% increase in admissions (with zero lag).

Multiple Pollutants Models

These results present a mixed picture of the effects of air pollution on elderly groups. There are positive associations between PM_{10} (both lag 0 and lag 2) with admissions for all the age groups except for the 0 – 59 group with PM_{10} (lag 2). In the case of PM_{10} (lag 0) these associations were with 8-hour O_3 (lag 2) and 8-hour CO (lag 1). Only significant association in this case was for the over 80 age group with 1.71% increase in hospital admissions for IQR of 14.166 $\mu g\ m^{-3}$. In the case of PM_{10} (lag 2) the significant association was with SO_2 (lag 0) for the age group 75-79 (4.34% increase in hospital admissions for IQR of 14.166 $\mu g\ m^{-3}$). However, it is only the two more elderly groups that display significant associations (over 80s and the 75 – 79 group, for PM_{10} lag 0 and PM_{10} lag 2 respectively). This is the only evidence that there is any trend towards increasing effect-estimates with increasing age in those over 60; indeed, the estimate of change in admissions was greater in the 60 – 69 group than the over 80 group for both PM_{10} lag 0 and lag 2. One notable point is that the associations are much smaller with the 0 – 59 group compared to the other groups. The age-relationship between NO_2 and admissions is in contrast with that for PM_{10}. Although it is again the case that no particular trend across the age groups can be discerned, it is the two younger groups that have the larger effect estimates, whilst the smallest associations are those for the over 80 group and the 70 – 74 group; the only significant association is with the 0 – 59 group.

O_3 (with PM_{10} (lag 1) and max 8-hour CO (lag 1) in particular seems to display evidence of an age-specific association; the only significant association is with the over 80 group (2.84% increase in hospital admissions for IQR of 28 µg m^{-3}), and the only other positive association is with the 75 – 79 group. The magnitude of the effect-estimate also decreases between these groups. CO displays some evidence of a similar effect [with PM_{10} (lag 1) and max 8-hour O_3 (lag 2)]: the two most elderly groups have positive associations, and just as with O_3, only the over 80 group has a significant association (2.42% increase in hospital admissions for IQR of 0.5 µg m^{-3}). In addition, the magnitude of the effect-estimate decreases from the over 80 group to the 75 – 79 group. However, whilst the associations for the 70 – 74 group and the 60 – 69 group are negative, the association for the 0 – 59 group is positive, albeit insignificant. At 0.52%, it is a small increase in admissions, but nonetheless presents a scenario where increases in daily CO effect the very elderly and the younger population (i.e. those over 80 and under 60 years old), but not those in between.

Conclusions

The results serve to highlight the heterogeneity in the associations found between different age groups. They indicate that PM_{10} and O_3 are positively associated with respiratory admissions, but only in the elderly. Although other associations were apparent, they were not sufficiently consistent to justify reaching the conclusion that there is a clear association in Leeds. The results for PM_{10} and O_3 support previous work which suggests that the elderly are a vulnerable sub-population; the results further support previous suggestions that the NAQS are not set sufficiently low enough to prevent adverse health impacts in vulnerable people.

Discussion

The discussion of these results makes positive progress towards understanding the mechanisms behind vulnerability to air pollution, and in particular, towards understanding why the elderly seem to be more vulnerable than young adults to the effects of some pollutants but not others. It is considered that this relates to the extent to which each pollutant affects exogenous or endogenous physical characteristics.

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6.1e Central nervous system effects of carbon monoxide

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Introduction

Carbon monoxide is a product of incomplete combustion and as such is associated with human activity wherever energy is generated by the burning of carbonaceous fuel. This is unfortunate since the gas competes with oxygen for the haem moiety on several important molecules. The most important of these is haemoglobin and carbon monoxide is more than 200 time more effective as a competitive ligand for deoxyhaemoglobin than oxygen forming carboxyhhaemoglobin, a molecule that does not transport oxygen in the blood. In addition, the presence of caboxyhaemoblobin shifts the haemoglobin oxygen dissociation curve to the left and this results in less oxygen being released to tissues so accentuating hypoxia. Carbon monoxide is about 60 time more effective than oxygen in competitive binding to myoglobin and this reduces oxygen transport in muscle, an effect which is most important in the myocardium. Carbon monoxide binds to and inactivates a number of other molecules including cytochrome P450 enzymes, neuroglobin and cytochrome A3 enzymes. The significance of these interactions is unclear. Cytochrome P450 inactivation would inhibit the metabolism of other, concurrent, toxins. The significance of neuroglobin inactivation may become clearer when more is known about the function of this chemical. Cytochrome A3 inactivation is potentially lethal but carbon monoxide is less effective as a ligand than oxygen for this molecule. Endogenous carbon monoxide is an activator of guanylyl cyclase and interacts with nitric oxide metabolism. Exogenous carbon monoxide has the potential to disrupt this relationship but the precise nature of this effect is as yet unclear.

As carbon monoxide poisoning progresses and blood oxygen carrying capacity falls, cardiac output increases and cerebral and cardiac vasodilatation occurs. This maintains cerebral and cardiac oxygenation in animal models (1) and the same effects are observed in man (2,3) but when reduction of blood oxygen carrying capacity exceeds this circulatory compensation there is a sudden fall in cardiac output. This point occurs at a carboxyhaemoglobin level of 50-60% in animal models of poisoning. When this happens, both the heart and brain are subjected to profound hypoxia caused by low oxyhaemoglobin levels in the blood and hypoperfusion. Decompensation would logically occur at lower levels of carboxyhaemoglobin during exercise and is associated with the onset of coma.

The symptoms of acute carbon monoxide exposure are those of hypoxia and resemble closely the effects of exposure to altitude, lowered inhaled oxygen levels and cyanide poisoning. During acute exposure, symptoms closely relate to the blood carboxyhaemoglobin level although any relationship with severity of disease is lost during the post-exposure phase. Prior to the onset of coma the symptoms of acute exposure to carbon monoxide are, progressively, headache and nausea, ataxia, lethargy and deterioration of cerebral function. In acute exposure studies this series of symptoms starts at a carboxyhaemoglobin of 15-20% at rest although it is logical to think that onset may be at lower levels with exercise. There is no convincing evidence for any behavioural CNS effect at lower carbon monoxide levels (4). Using predictive models, at equilibration, this equates to a carbon monoxide exposure of between 70-120 ppm or a four hour exposure to 100 ppm under conditions of light work. Symptoms of headache, dizziness and tiredness in association with carbon monoxide exposure have been termed “chronic carbon monoxide exposure” but they are actually indicators of acute sub-lethal carbon monoxide poisoning. Interestingly, headache and nausea are symptoms seen with raised intracranial pressure and they may be related to increased cerebral blood volume rather that any direct hypoxic effect.

Central nervous system effects persisting after poisoning seem to be due to either cerebral damage sustained during the acute event or a relapsing condition producing a mild to severe dementing condition which may be associated with cerebral oedema and fatality. A similar condition is observed after acute hypoxic insults, such as cardiac arrest, and evidence from animal models suggests that it is due to a cerebral reperfusion injury.

The literature on direct carbon monoxide central nervous system effects is large and intriguing. Its uncritical application to clinical manifestations in people exposed to carbon monoxide, however, is not entirely justified. Affective disorders are common after poisoning and, intriguingly, commoner in victims of severe as opposed to mild poisoning (5,6) A study of victims of carbon monoxide poisoning indicated that a number of individuals experienced a long term condition typified by multiple non-specific symptoms and depression with most victims feeling that their attending physician did not know how to help them or were of the opinion that exposure to carbon monoxide would have no long term effects (7). The condition is commoner in women and has many of the attributes of a somatoform disorder. Somatoform disorders are defined as conditions where symptom complaint has no identifiable corresponding physical cause (8). They may have a basis in physical disease or injury but frequently occur in isolation and examples are chronic fatigue syndrome and irritable bowel syndrome. They may be associated with traumatic event as in chronic whiplash injury, post concussion syndrome and are thought to be potentiated by medicolegal action and the possibility of compensation as is repetitive strain disorder. There may be measurable neurobehavioural effects including depression, lowered attention and short term memory impairment (9). Sufferers have high levels of anxiety about their health, but, most importantly have a perception that their symptoms relate to a physical process and there is a strong tendency to attribute a cause to their problems. Carbon monoxide poisoning is a life threatening event and as such can give rise to post-traumatic stress which should be considered a direct consequence of the accident and dealt with appropriately. Equally, however, a person may develop the perception that exposure to carbon monoxide is related to their symptoms in the absence of any definitive proof of significant exposure or physical effects persisting after exposure. In other words, a perception of carbon monoxide exposure or the experience of being poisoned may give rise to CNS effects unrelated to carbon monoxide toxicity itself.

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6.1f An investigation of the effects of long term exposure to air pollution on cardiorespiratory morbidity in a large population cohort

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Background and objectives

Exposure to outdoor air pollution has been associated with death and hopitalisations from both cardiovascular and respiratory diseases. Epidemiological evidence for these associations has come from both long term and short term exposure studies. The former have focused upon death as the health outcome and these have been extensively reviewed and reanalysed (COMEAP, 2007). These temporal-spatial studies exemplified by the analysis of the American Cancer Society data correlate death rates with air pollution measures taking into account individual risk factors (Pope *et al.*2002). They tend to report larger estimates for the effects of air pollution than those derived from short term exposure studies. This may reflect the fact that longitudinal studies account for health effects derived from both long and short term exposures to air pollution. Whilst the most important health endpoint is death there remains the possibility that there is a substantial burden on both individuals and health care services from chronic and short term disease arising from long term exposure to air pollution. These impacts are not clearly understood and require large, validated longitudinal records of patient medical histories to investigate the evidence for associations and also to identify the population groups most sensitive to air pollution.

This project aims to estimate the effects of long term exposure to air pollution on cardiovascular and respiratory morbidity and to characterise susceptible individuals in terms of pre-existing disease, symptoms, treatment, lifestyle etc. The health end points will be the incidence of obstructive lung disease and ischaemic heart disease morbidity indicated by 1) the first diagnosis recorded in the General Practice primary care record and 2) the first hospital admission.

Study description

The General Practice Research Database (GPRD) in the UK is a computerised database of anonymised longitudinal medical records from primary care. It is managed by the GPRD group within the Medicines and Healthcare Products Regulatory Agency (MHRA), the UK's medicines and devices regulator. The database contains demographic information (gender, age, sex and practice location and a community level marker of deprivation), clinical information (diagnoses, symptoms, procedures and medical history), treatment, prescriptions and immunisation details as well as lifestyle information such as BMI, weight, smoking and alcohol consumption for registered patients. The database covers 432 practices across the UK covering 4.6% of the population. From 2001 these data are linked to hospital episodes statistics detailing specialty, urgency and nature of the referral (and also to mortality data), the linkage being achieved via NHS number.

As part of their contract with Defra, the Atomic Energy Authority produce modelled annual air pollution concentrations on a fine spatial scale. These estimates are derived from emission estimates provided by the UK National Atmospheric Emission Inventory. The UK total emission estimates for each activity are then distributed across 1x1 km squares covering the whole of the UK. Annual mean concentrations at background locations are calculated by summing the estimated concentrations for pollutant-specific components, for example:

- Distant sources (characterised by rural background concentrations, interpolated from rural measurements)
- Point sources (calculated using an air dispersion model)
- Local area sources (calculated using a kernel based air dispersion model).

The area source model is calibrated using data from the national automatic monitoring networks for the relevant year. Additional components are taken into account for different pollutants. Additional calculations and processing occurs for NO2 and ozone. Details of the modelling methodology are published (Kent *et al.*, 2007). As part of this project, these data will be used to provide annual pollution estimates for a range of pollutants for each postcode centroid in England. Modelled annual mean pollution estimates are available for PM_{10} (1994-2006), $PM_{2.5}$ (2002-2006), NO_2 1994-2006, CO 2001-2006, SO_2 1994-2006 and O_3 1994-2005. These estimates will be linked to the patient records in GPRD using the full postcode. This linkage will be undertaken by a trusted third party to ensure patient anonymity.

This study, starting in April 2009 for three years, will use a retrospective cohort design. Patients enter the cohort on registration with a GP practice and only subjects without pre-existing cardiorespiratory disease resident in England will be elegible. Cox proportional-hazards regression will be used to estimate hazard ratios associated with exposure to a range of pollutants. This analysis will be stratified by year to ensure both cases and controls are exposed to contemporaneous air pollution.

Acknowledgements

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6.1g Distinguishing the independent health effects of exposure to ambient nitrogen dioxide from those of particulate matter and other factors

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Background and objectives

Nitrogen dioxide (NO_2) has been linked to adverse effects on a range of health outcomes in epidemiological studies (evidence as reviewed by US EPA, 2008; WHO, 2006). Although these statistical relationships with NO_2 certainly exist, doubt remains as to whether the associations represent a toxic effect of nitrogen dioxide, per se, or whether they reflect a surrogate effect. Epidemiological evidence has suggested that the reported associations between concentrations of NO_2 and health outcomes might be confounded by concentrations of particulate matter (PM). In addition, it has been shown that, in some geographic locations, the adverse effects of particulate pollution can be enhanced when concentrations of NO_2 are elevated, thus suggesting the possibility of effect modification (Katsouyanni et al, 2001). These findings have been attributed to the correlations between concentrations of NO_2 and PM which have made it difficult to disentangle any possible independent adverse effect of NO_2 from PM and other pollutants in the combustion-related pollution mixture emitted by similar sources, especially vehicular traffic.

In order to understand the underlying factors which give rise to the heterogeneity and inconsistencies in the epidemiological evidence on NO_2, a systematic review of the evidence from ecological time-series and panel studies has been proposed. The overall aim of the work is to identify adverse effects of NO_2 that are independent from those of PM and other factors, and, if so, to calculate appropriate concentration-response functions for use in health impact assessments. The core objectives of the project are to:

- To assess the strength of the epidemiological evidence from studies using two- or multi-pollutant statistical models which simultaneously incorporated concentrations of PM to estimate the effects of short-term exposure to NO_2 on health.
- To create a database of quantitative effect estimates linking short-term exposure to NO_2 with health outcomes and data on a range of possible confounders and effect modifiers.
- To conduct exploratory statistical analyses to identify the sources of heterogeneity and effect modification in the effect estimates linking short-term exposure to NO_2 with outcomes of health.

Study description

The plan for this systematic review contains, broadly, three main elements: systematic searching, screening and collation of the literature; database development; and, descriptive and statistical analyses.

- Systematic searching, screening and collation of the literature
  Standard bibliographic methods are being used to identify all peer-reviewed, ecological time-series and panel studies which investigated associations between short-term

variations in outdoor concentrations of NO_2 and health outcomes, primarily those studies which incorporated concentrations of PM simultaneously in two-/multi-pollutant statistical models.

Three major categories of health outcomes from time-series studies are being considered:

- Mortality: "all (non-accidental) causes" and specific causes (e.g. respiratory and cardiovascular diagnoses)
- Hospital admissions: for specific causes
- Emergency hospital visits: for specific causes

For panel studies, respiratory symptoms, lung function and a cardiovascular disease-related outcome are being considered.

All studies are being selected according to pre-defined criteria. References from the Air Pollution Epidemiology Database (APED) will be used to cross-check references attained using the project's search strings.

- *Database development*
  A Microsoft Access relational database of quantitative estimates of NO_2 and data on possible confounders and effect modifiers is being created. This began by taking an extract of data from APED. This extract will be expanded by adding new data assembled from a range of sources. Examples of the new data include:

  - details of all effect estimates pertaining to nitrogen dioxide and particles: all relevant multi-pollutant model, seasonal model and lagged model results;
  - those on possible confounders and effect modifiers, e.g. pollution levels in each study and meteorological data;
  - those describing the health status of the populations examined.

- *Descriptive and statistical analyses*
  Descriptive analyses will be carried out before the statistical analyses. This will include, for example, forest plots of estimates ordered by possible confounders and effect modifiers, e.g. geographical region, temperature. Statistical analyses will include: meta-analyses, meta-regression and examination of publication bias.

In addition to the work outlined above, a brief review of epidemiological studies on long-term exposure to NO2 and of toxicological studies bearing on the research problem will be conducted. No statistical analyses of quantitative data from these studies are planned.

Preliminary results

Work conducted to date has focused on an interrogation of the quantitative data for NO_2 from time-series studies held in APED.

APED currently contains references and quantitative estimates from time-series studies, for all common ambient pollutants, published up to the year 2006 (2007 for studies conducted in Asia):

185 peer-reviewed papers for a total of 11 categories of health outcomes linked to short-term exposure to NO_2. Of the 185 studies available, 70 have examined the possible associations between NO_2 and health using two- or multi-pollutant statistical models. Five health outcomes (mortality; hospital admissions; emergency room visits; GP consultations; GP house calls) have been investigated in these 70 studies, with mortality and hospital admissions being the most common ones examined. The available estimates (total = 336) from these 70 studies have been derived mainly from analyses using 1-hour and 24-hour measures of exposure to NO_2, although a few have been derived using an 8-hour measure. In addition, the 336 estimates have been produced largely from studies conducted in Europe, the United States of America (USA) and Canada. No estimates of NO_2 are available from the South East Asia WHO Region[2]. Less than 25% of the estimates (i.e. 81 of 336 estimates) from two-/multi-pollutant analyses are based on studies using a multi-city design.

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[2] Countries in the WHO South-East Asia Region: Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Indonesia, Maldives, Myanmar, Nepal, Sri Lanka, Thailand, Timor-Leste.

6.1h Noise, air pollution and cardiovascular disease

***Lars Järup*, Imperial College London**

Combined exposures to noise and air pollution occur commonly, in particular in relation to transport, road traffic being the most obvious source of exposure. In spite of this obvious co-exposure there is a lack of interaction between the scientific community dealing with health impacts due to exposure to noise and that dealing with air pollution. This lack means that the health impact of the combined exposures have so far largely been ignored in epidemiological studies in both fields. This paper focuses on cardiovascular disease and associated risk factors (hypertension in particular).

Environmental exposure to noise and air pollution have been associated with cardiovascular disease in several studies during the last decades, in particular in relation to road traffic. Air pollution studies have commonly used distance to road as a proxy for exposure, but not controlled for noise as a confounder (which it clearly is). The possibility of noise acting as a confounder has only recently been observed by air pollution researchers. Similarly, noise studies have not controlled for air pollution, and have only recently acknowledged the potential effects of co-exposure to air pollutants.

Whereas the mechanisms behind the cardiovascular effects of air pollution have been recognised only recently, mechanisms for noise associated cardiovascular effects have been well established in laboratory studies. Already in 1980, WHO noted that vasoconstriction and significantly increased levels of blood pressure or vasodilatation of blood vessels had been reported in persons exposed acutely to high levels of noise. More recent research has shown that noise may have a large temporary and permanent impact on physiological functions in humans. Cardiovascular and hormonal responses may appear, including increases in heart rate and peripheral vascular resistance, changes in blood pressure, blood viscosity, blood lipids, and shifts in electrolytes (Mg/Ca) and stress hormone levels.

The putative biological mechanisms linking air pollution to heart disease involve direct effects of pollutants on the cardiovascular system, blood, and lung receptors, and/or indirect effects mediated through pulmonary oxidative stress and inflammatory responses.

Conclusions

Several air pollutants are well established risk factors for cardiovascular disease and there is increasing evidence that noise may be a risk factor for cardiovascular morbidity. As air pollution and noise exposure commonly occur together, investigations on impacts of noise on cardiovascular health should consider air pollution exposure as a potential confounding variable. Similarly, air pollution studies need to not only assess the impact of specific air pollutants but also consider the confounding or modifying effects of noise on cardiovascular disease risk.

6.2 Discussion[3], [4]

It was considered very important to adopt a multidisciplinary approach when considering PM toxicity, as ably illustrated by Professor Kelly in his plenary lecture, and this is critical for other groups working in the area. Professor Kelly explained that it is now increasingly recognised that there is a strong link between oxidative stress and epidemiological results. Although he is convinced that this is the main relationship, there is as yet no robust evidence to back this conclusion. There is a requirement for more toxicologically-linked epidemiology studies, and also more multidisciplinary studies. When questioned as to how the London study distinguished between the role of particle matter concentrations and oxidative capacity (as similar composition would be expected across the city), Professor Kelly identified additional work that had been conducted (see poster presentation) and elaborated that there were big differences across the city with relevant factors suggested to include fresh traffic, tyre and break wear, and the different nature of vehicles.

Professor Kelly clarified that mass was not correlated with oxidative stress and that there was another factor (currently unknown) involved in the process. Particle concentration may be linked to oxidative stress, but there is not necessarily a link between particle concentration, number and oxidative stress; bigger particles have higher transition metal concentrations, so particle number alone is not a sufficient measure. (Many assume that particles less that $PM_{2.5}$ are more important, but this may not be the case).

In response to a question about the high test concentrations used compared to those of exposed individuals, Professor Kelly explained that that the *in vitro* model does not show replenishment of anti-oxidant levels and the experimental exposures were higher in order to obtain the desired response within 4 hours.

With regard to the capacity of epithelial lung lining fluid to deal with particles, it was suggested that whilst healthy people should have no concerns (1:60 challenge (approximately 2.5 ppb) results in bronchiole inflammation but lower concentrations do not), if health is compromised (e.g. asthma or COPD) then there is likely to be more of an effect.

The difficulties of diagnosing very young children (0 – 2 years) with asthma and the differences in diagnosis between countries were noted. When asked how such differences were dealt with in her study, *Dr Graziella Favarato* stated that the study used only the available data but that more recent studies consider longer periods (e.g. 0-10 years, Norway/Sweden) as well as different triggers and data other than from birth cohorts, which would improve cross-sectional analysis.

Dr Anil Namdeo was questioned about the appropriateness of the size of his study population and the characterisation of the study groups, especially the inclusion of a 0-59 age group rather than a more logical split into 0-16 (children with asthma), 16-44 (adults with asthma), and 44+ (COPD only). It was suggested that different groupings would have allowed for a distinction of COPD

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[3] Professor Ross Anderson presented the HPA Annual Air Pollution Research Lecture (Air pollution and health: Putting together the evidence) for which no abstract is available.

[4] An additional poster presentation was given by Dr Cathryn Tonne (Characterizing temporal and spatial variability in oxidative potential of particulate matter) for which no abstract is available.

sufferers. In response, Dr Namdeo explained that the focus of his study was the older (>59 years) population.

In Dr John Ross's study blood was taken from non-smoking middle aged people in winter and summer (with different heating types in home) and significant differences in cyclic GMP levels were found between different heating types and between winter and summer. It was assumed that this could be due to chronic low level exposure to CO (or perhaps NO) but only low levels were measured in homes. In response to a question on these differences, Dr Ross explained that compensation mechanisms of cyclic GMP were not seen, and that COHb and MetHb have previously been shown to demonstrate a seasonal variance. MetHb levels in hospital admissions are also shown to be increased from normal levels. This may be due to increased oxidative stress and therefore endogenous processes need to be considered. The change in cyclic GMP may be due more to effects of particles and resultant inflammatory conditions than CO itself.

In response to a question as to whether the study suggests that chronic low level exposure will cause psychological rather than physiological symptoms, Dr Ross stated that GPs appreciate that after a survival situation there is an increased stress level which contributes to psychological symptoms, but that the patient's perceived symptoms may not be as severe as they think. If a GP cannot see physiological effects in CO poisoning survivors, then they should start to think in terms of Medically Unexplained Physiological Syndrome (MUPS). Anxiety following a CO poisoning incident generally increases (as the patient starts to believe that the house is no longer safe) which may in turn lead to psychological symptoms.

Stephanie Trotter brought the audience's attention to the fact that there is no free test that consumers can obtain to check CO emissions from an appliance and she considered such a service would improve gas safety. While the Gas Emergency Service has a duty to 'make safe' with respect to CO as well as gas, the response can involve cutting off the one appliance (or the whole house or flat) and she was concerned that other possible sources in the dwelling or in an adjacent property may not be checked. She also considers there to be a lack of suitably qualified and equipped persons to conduct appropriate tests and provide assurance to householders. She referred to the algorithm recently put out by the Department of Health and the responsibility on Environmental Health Officers to investigate homes where there is a suspicion of CO exposure but considers that they should have more training and equipment for this task. She also referred to recommendations of the Health and Safety Commission in 2000 about equipment for testing appliances for CO that should be used by the Gas Emergency Service. She believes there is a continuing need to raise awareness of the dangers of CO and for more research.

Professor Richard Atkinson (effects of ozone on health) was questioned as to whether the work considers seasonal variations (e.g. ozone is negatively correlated in winter) and whether the seasonal differences are less marked if measurements are controlled for particles. In response Professor Atkinson pointed out that the work presented related to a new study and that these issues were to be addressed in future work.

Miss Inga Mills was questioned about the relevance to her study of previous literature on NO_2 in indoor air. She explained that the study plan did not include indoor air studies but instead considered a) long term NO_2 exposure effects and b) NO_2 chamber studies. She acknowledged the limits of the work (as it uses secondary data and no primary research), and emphasised that the study is unlikely to identify new fundamental findings, as primary data would be needed to do this. Instead it was suggested that the current research will help to understand the variability in effect estimates and the role of possible confounding factors (e.g. PM_{10} levels). The study plan was praised and it was commented from the floor that the issue of NO_2/NO_x effects on health are very important as the guidelines on NO_2 are unclear or uncertain.

In the discussion following *Professor Richard Atkinson*'s study (investigation of the effects of long term exposure to air pollution and cardio-respiratory morbidity in a large population cohort) concerns were raised about the amount of information necessary for such studies and the effort needed to get ethical approval - and the impact this may have on the capacity to do the research; it was suggested that there is a need to do a risk assessment on the impact of research ethics committees. It was suggested that ethical decisions and approval procedures (especially in epidemiological studies) cause delay and can result in lost data and associated problems while the actual risks of compromising data are very small.

Considering that previous studies have suggested that the characteristics, not just the absolute level, of noise are important, *Dr Lars Jarup* was asked whether it was possible to measure effects of change in noise as part of noise and air pollution studies. He acknowledged that there are acute effects when single noise peaks occur, but it is not known what happens when continuous peaks occur. Whilst noise modelling is possible, Dr Jarup acknowledged that there was scope for more research in this area.

Dr Jarup's presentation showed a relationship (from meta analysis) between cardiovascular morbidity and noise levels within a population, but this was shown not to be linear, suggesting that it may not be a simple relationship. More data would be needed to confirm this and it would require a pan-European cohort. Queries were raised as to whether there was a correlation between noise and ultra-fine particles, with the comment that if there is a good correlation between particles and noise it would not be possible to work out which one is more important regarding health impacts. Further to this, it was suggested that both noise and nanoparticle dispersion may be influenced by air movements.

6.3 Poster

6.3a The critical time windows for the effect of black smoke on birth weight: the Newcastle Particulate Matter and Perinatal Events Research (PAMPER) study

Rakesh Ghosh, Svetlana V Glinianaia, Judith Rankin, Mark S Pearce, Tanja Pless-Mulloli on behalf of the PAMPER study research team

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Background and objectives

There is growing evidence from different locations across the world that exposure to ambient air pollution during pregnancy is associated with adverse birth outcomes, including reduction in birth weight (Glinianaia et al., 2004; Lacasana et al., 2005; Maisonet et al., 2004; Sram et al., 2005). Most studies used exposure to air pollution averaged over the whole pregnancy or trimesters of pregnancy. To our knowledge, few studies have investigated critical time windows of exposure to air pollution in association with birth weight using monthly periods during pregnancy (Dejmek et al, 2000; Hansen et al, 2007, Lee et al, 2003), and there are no published studies to date on the effect of air pollution on birth weight examining shorter windows of exposure. The aim of this study covering 32 years was to investigate the critical time windows for the effect of black smoke (BS) on birth weight using weekly exposure estimates of black smoke air pollution during pregnancy.

Study description

These analyses were part of the historical UK Particulate Matter and Perinatal Events Research (PAMPER) cohort study investigating the association between maternal exposure to BS and adverse perinatal outcomes in singleton births (N=109,086) in Newcastle upon Tyne from 1961 to 1992. The PAMPER birth record database contained information on date of birth, birth weight, gestational age, infant sex, maternal age, parity and neighbourhood socio-economic status (Glinianaia *et al*, 2008). Weekly maternal black smoke exposure estimates for each individual pregnancy were derived from a two-stage modelling process incorporating monitored black smoke data with temperature and pollution source information (Fanshawe *et al*, 2008). First, a seasonally varying temporal trend in black smoke exposures was estimated using a dynamic linear model. Secondly, the remaining spatio-temporal variation was accounted for using temporal and/or spatial covariates (number of chimneys within 500m of monitor, distance of monitor to nearest industry, type of land use and implementation of the Clean Air Act). The residual spatio-temporal correlation remaining after this process was negligible.

In these analyses we investigated the effect of BS on birth weight using weekly exposure windows. Linear regression was used to model the effect of black smoke exposure on continuous birth weight and fractional polynomials were used to model non-linear relationships. All weekly exposure-response models were adjusted for gestational age, neighbourhood socio-economic status (Townsend deprivation score), maternal age, parity and year of birth. The weekly exposure windows were examined separately for males and females.

Results

Male infants were found to be vulnerable from week five to week 37 of gestation. The association was highest and the relationship was non-linear from the fifth to the 12th week of gestation (Fig 1a). From week 13 to 37 the relationship was linear and the associations were relatively smaller (Fig 1b). The association was highest in the fifth week during which birth weight in male infants was estimated to reduce from 3638g (95% CI: 3623, 3654) to 3527g (95% CI: 3511, 3544) with an increase in exposure from the 1st ($6\mu g/m^3$) to the 75th ($92\mu g/m^3$) percentile. From week 13 onwards birth weight reduced by about 10g for every $100\mu g/m^3$ increase in exposure.

In female infants the critical time window of exposure was narrower than in males: from week nine to week 33 (Fig 2). Between week nine and twelve the estimated reduction was <10g for every $100\mu g/m^3$ increase in exposure, after which it slightly increased. On week 23 the birth weight reduction was highest, about 15.8g (95% CI: 9.2, 22.4) for every $100\mu g/m^3$ increase in exposure. Unlike in males, there was no significant association after week 33.

Conclusion and Discussion

This is the first study that has used weekly exposures to BS to investigate the critical time windows of exposure during pregnancy for the effect of BS on birth weight. Using detailed individual exposure estimates we did not confirm earlier reports of the effect of particulate air pollution on birth weight to be limited to a particular month or trimester of pregnancy. These analyses showed a continuous association between increasing exposure to BS and reduction in birth weight throughout pregnancy. Furthermore, the vulnerable period for male infants was longer than for females, and the reduction in birth weight in males was higher than that in females for similar weeks of early gestation. However, the results from the weekly models need to be viewed with caution as the weekly exposures are correlated.

The results of these analyses, using weekly exposure windows, suggest that there is a significant association between maternal exposure to BS and birth weight, differential by infant sex. Although the exposure windows are different, these findings, however, are consistent with the suggestion from our systematic review that the association between air pollution and low birth weight may be different for male and female infants (Ghosh *et al*, 2007).

Acknowledgements

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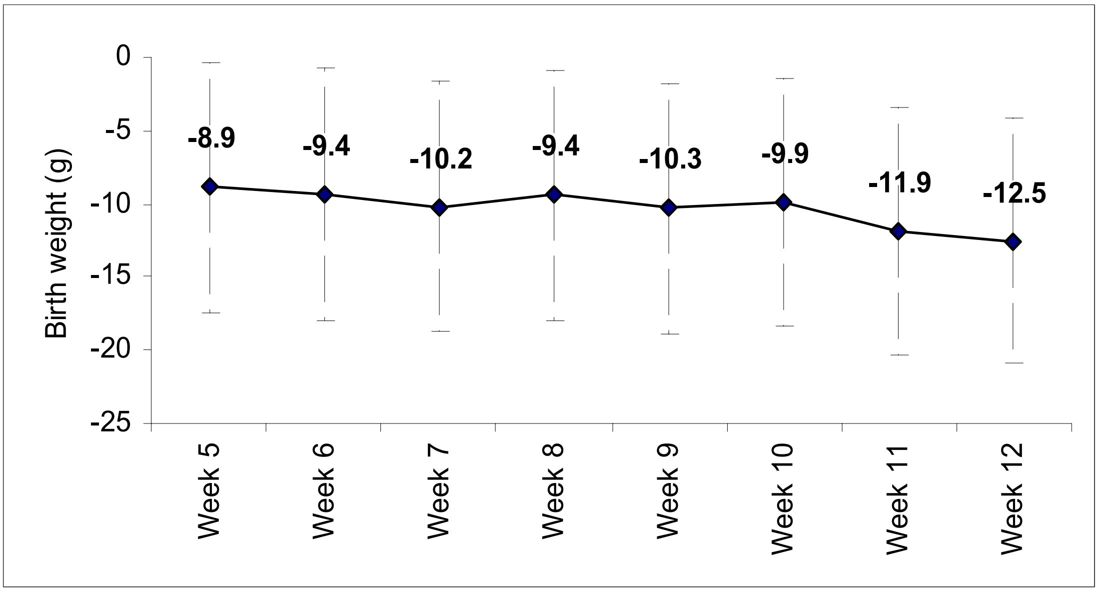
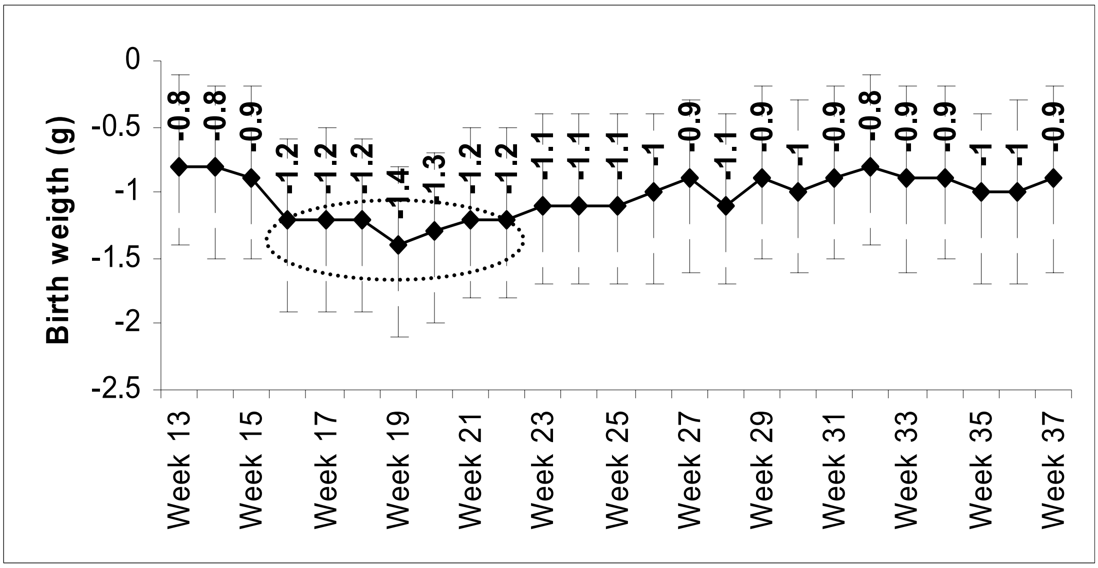
Figure 1 Critical exposure windows for males

a) Reduction in birth weight for each log* unit increase in black smoke exposure from week 5 to12



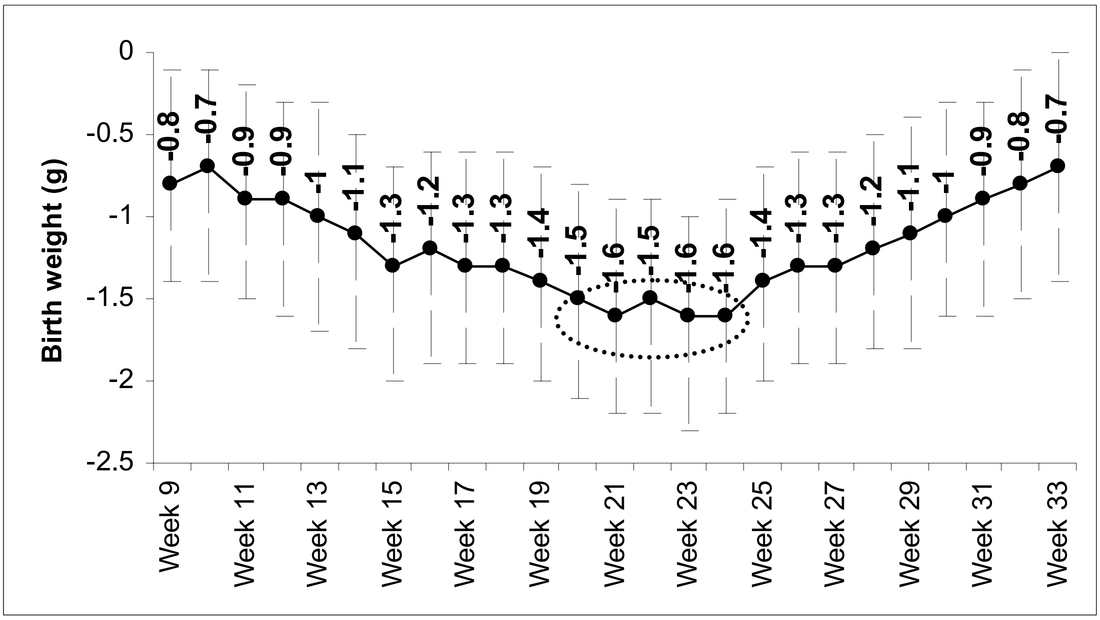
* The log model is the best fitting fractional polynomial model

b) Reduction in birth weight for every 10µg/m³* unit increase in black smoke exposure from week 13 to 37



* The linear model is the best fitting model

Figure 2 Critical exposure windows for females: reduction in birth weight for every 10μg/m³* unit increase in black smoke exposure from week 9 to 33



* The linear model is the best fitting model

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7 General discussion and close of meeting

Further to a question about whether we yet have sufficient data on exposure to particles, Wolfgang Kreyling expressed surprise at the fact that we still have mainly PM_{10} data and that fine particles are rather neglected. Derrick Crump commented that while larger amounts of data are available on PM_{10}, $PM_{2.5}$ is becoming more widely monitored and studied. Roy Harrison added that it is a matter of waiting for such data to come through as it has only recently been made a legal requirement to measure $PM_{2.5}$. Wolfgang Kreyling emphasised that while currently all [most] particle data is considered in terms of mass, surface areas is another metric that should be considered and taken more widely taken into account. Richard Atkinson said that $PM_{2.5}$ and PM_{10} monitoring data are being collected in London and will be published soon.

Duncan Laxen noted that the meta-analysis study presented at the workshop excluded studies in foreign languages and wondered whether the researchers were therefore missing something. Ross Anderson was uncertain about this, but thought the question becomes where do you stop when collecting and compiling data. Richard Atkinson added that time-series studies in non-English publications have normally been submitted in English as well (causing potential duplication of results) and it is actually not very easy to find non-English publications. Bob Maynard expressed the opinion that once the meta analysis database of publications gets to a certain size, additional publications are unlikely to make any difference to the outcome. A challenge to this point of view was the danger of missing an important development that could change the outcome.

In answer to Jim Swithenbank's question whether outdoor concentrations are sufficiently correlated with personal exposure, Derrick Crump answered that addressing that would likely take up a whole session in itself, but clearly there were concerns that outdoors was not a good measure of personal exposure, particularly for pollutants with strong indoor sources.

Bob Maynard was interested in the NO_2 and particles debate, especially the polarised "NO_2 is a primary acting pollutant" versus "particle effects are responsible for the apparent toxicity of NO_2" argument. In general, for traffic pollution people consider particles to be more important, whilst indoor air pollution studies consider NO_2 to be more important (i.e. primary acting). Paul Harrison added that little is known about NO indoors or the NO_x mixture, and that this is another important area for research. Jon Ayres expressed the view that NO_2 is a marker of something else, as chamber studies have shown that high exposures to NO_2 are needed to produce a biological response (i.e. overt NO_2 toxicity requires a high NO_2 concentration). His group is currently completing a study looking at the results of NO_2 challenge on patients with cardiovascular disease.

Ross Anderson stated that there is a problem with the application of outdoor guidelines to the indoor environment, as the pattern of exposure is very different. He also asked what we know about recovery (e.g. nocturnal indoor exposure, then airway recovers over the day before next night-time exposure), which also raises concern over the applicability of outdoor guidelines for diurnal indoor exposure. Using the example of cigarette smokers, Frank Kelly explained that the airway is very responsive to challenge, resulting in increased glutathione concentrations and detoxification pathways and suggested that regular exposure might lead to a higher level of protection. Daffyd Walters added that the cellular response may take longer to recover (e.g. whooping cough toxin can linger for months until infected lung cells are renewed).

Bob Maynard probed further the differences between indoor and outdoor air quality (including different pollutant mixtures and exposure patterns) and the derivation of appropriate guidelines: if setting guidelines for outdoor air quality, then studies conducted outside should be used (and visa versa for indoor air). He suggested that this may need to be included in a philosophical discussion for the next WHO guidelines. Michal Krzyzanowski explained that current WHO guidelines do consider exposure patterns but there are notable limitations with available data. For example most of the literature on nitrogen dioxide is more than 15 years old and the chamber studies reported are not very appropriate for understanding effects of long term exposure. Therefore new data is required to inform current discussions.

Bob Maynard highlighted a number of key areas of interest from the meeting:

- Particles - new information on mechanisms of exposure
- toxicological endpoints
- health impact assessment
- exposure assessment
- NO_2 – primary or index of traffic effects
- interaction of pollutants
- asthma
- indoor environment and the importance of monitoring/ climate change and tighter homes
- nanotechnologies
- need to consider including noise within studies of effects of air pollution on health.

Chamber studies were noted to be absent from this year's workshop, but are thought to be very useful as part of a necessary 'range of evidence' approach. With regard to the indoor environments and climate change more studies are required, we need to avoid problems that have been encountered elsewhere such as in Scandinavia.

Ross Anderson suggested that 'clever' studies not just new studies are needed. This includes the requirement for meta-analysis of data, debunking the myth that "reviewing is the last refuge of the intellectually destitute". John Ross felt that there is a lot more going on in air pollution and health effects than we presently know about. Lars Jarup suggested that more needs to be done on noise and cardiovascular disease, and that studies on the impact of noise need to consider interactions (different mechanisms of noise action) and prevention (reduce traffic). Heather Walton enquired whether noise should be added into the air quality strategy and questioned whether the health coefficients for air pollution are correct if not adjusted for noise.

Michal Krzyzanowski added that there were as yet no clear answers to questions about the health impacts and mechanisms of particles, no understanding of the distribution of particle generation sources (PM10), and that there is a need to consider climate change and air pollution.

Close of meeting

Thanks were given to the Department of Health, IEH, and all the speakers, Chairs and participants for contributing to a very successful meeting.

Annex I List of delegates

Name	Affiliation
Ross Anderson	St George's Hospital Medical School
Morris Anglin	Newcastle University
Andrew Apsley	University of Aberdeen
Mohd Shukri Bin Mohd Aris	King's College London
Ben Armstrong	London School of Hygiene
Mike Ashmore	University of York
Richard Atkinson	St George's Hospital Medical School
Jon Ayres	University of Birmingham
Clare Bayley	Defra
Angie Bone	Department of Health
Alison Buckley	Health Protection Agency
Hsiao-Chi Chuang	Cardiff University
John C Clark	University of Edinburgh
Derrick Crump	Institute of Environment & Health, Cranfield University
Paul Cullinan	National Heart and Lung Institute
Juana Maria Delgado-Saborit	University of Birmingham
Andy Dengel	Building Research Establishment Ltd
Karen Exley	Health Protection Agency
Graziella Favarato	St George's Hospital Medical School
Agatha Ferrão	Department of Health
Sarah Floud	Imperial College London
Svetlana Glinianaia	Newcastle University
Nina Glover	University College London
Andrew Grieve	King's College London
Mark Hammonds	University of Edinburgh
Otto Hänninen	National Institute for Health and Welfare (THL)
Paul Harrison	Visiting Fellow, Cranfield Health, Cranfield University
Roy Harrison	University of Birmingham
Stephen Holgate	University of Southampton
John Hoyte	Aerotoxic Association
Lars Jarup	Imperial College London
Hazel Jones	Imperial College London
Styliani Karra	University College London
Michaela Kendall	University of Birmingham
Frank Kelly	King's College London

Tim King	COMEAP Lay Member
Wolfgang Kreyling	Helmholtz Zentrum Munich
Michal Krzyzanowski	WHO European Centre for Environment and Health
Duncan Laxen	Air Quality Consultants Ltd
Joe Lunec	Head of Cranfield Health, Cranfield University
Ian Matthews	Cardiff University
Jackie Maud	Environment Agency
Bob Maynard	Health Protection Agency
Brian Miller	Institute of Occupational Medicine
Inga Mills	Health Protection Agency
Isabella Myers	Health Protection Agency
Anil Namdeo	Newcastle University
Zaheer Ahmad Nasir	University of Essex
Louise Newport	Department of Health
Elizabeth Norris	King’s College London
Sean O’Byrne	Defra
Paul Overton	CO-Gas
Jack Pease	Air Quality Bulletin
Heather Price	Cardiff University
Sophie Rocks	Cranfield University
John Ross	University of Aberdeen
Michael Routledge	University of Leeds
Sean Semple	University of Aberdeen
Gary Smith	Casella Monitor Ltd
Vicki Stone	Edinburgh Napier University
Jim Swithenbank	University of Sheffield
Caren Tan	University of Sheffield
Stephanie Trotter	CO-Gas
Cathryn Tonne	King’s College London
Frank de Vocht	University of Manchester
Dafydd Walters	St George’s Hospital Medical School
Heather Walton	Health Protection Agency
Giles Watson	Health Protection Agency
Ursula Wells	Department of Health

Annex II Workshop programme

TWELFTH ANNUAL UK REVIEW MEETING ON OUTDOOR AND INDOOR AIR POLLUTION RESEARCH: MEETING PROGRAMME

At CMDC, Cranfield University

20-21 April 2009

Monday 20th April

09.30-10.30 Registration & Coffee

10.30-10.45 **Welcome and Introduction –** Paul Harrison, Derrick Crump, & Bob Maynard

10.45-11.15 **Oxidative activity, a promising new marker of PM toxicity – Frank Kelly**

11.15-12.00 **Research Presentations**

1. A study of the concentration-response relationship for the effects of ozone on health – Richard Atkinson

2. Health implications of polycyclic aromatic hydrocarbons in indoor environments – Juana Maria Delgado Saborit

12.00-12.30 **Invited Keynote Presentation 'Toxicokinetics of inhaled nanoparticles' – Wolfgang Kreyling**

12.30-13.00 **Discussion Session**

13.00-14.00 Lunch

14.00-14.45 **HPA Annual Air Pollution Research Lecture 'Air pollution and health: Putting together the evidence' – Ross Anderson** Chair: Bob Maynard

14.45-15.30 **Research Presentations**

1. Particulates in the urban environment – Jim Swithenbank

2. Ozone, heat, and mortality in England and Wales: epidemiology and modelling – Ben Armstrong

15.30-16.00 Tea

16.00-16.40 Research Presentations

1. Association between air pollution and hospitalisations for respiratory disease in Leeds – Anil Namdeo

2. Database and meta-analyses of prevalence and cohort studies of air pollution and asthma – Graziella Favarato

16.40-17.10 Short Poster Presentations (1)

17.10-17.30 Discussion Session

17.30-18.00 Issues in indoor air quality: insights for policy development in Europe from the EnVIE Project– Otto Hänninen

Poster viewing

20.00 Meeting dinner (Mitchell Hall)

Tuesday 21st April

09.15-09.45 Development of WHO guidelines on indoor air quality – Michal Krzyzanowski

09.45-10.25 Short Poster Presentations (2)

10.25-10.45 Research Presentation

1. Indoor air quality and ventilation in energy efficient homes: implications for health and well being – Derrick Crump

10.45-11.15 Central nervous system effects of carbon monoxide (Sponsored by the CORGI Trust) – John Ross

11.15-11.45 Coffee

11.45-12.45 Research Presentations

1. Measuring indoor air pollution in homes in Malawi: a methodological paper – Sean Semple

2. An investigation of the effects of long term exposure to air pollution and cardiorespiratory morbidity in a large population cohort – Richard Atkinson

3. Distinguishing the independent health effects of exposure to ambient nitrogen dioxide from those of particulate matter and other factors – Inga Mills

12.45-13.00 Discussion Session

13.00-13.45 Lunch

13.45-14.15 Transport of carbon nanotubes across pulmonary epithelium using an isolated perfused rat lung preparation – Ian Matthews

14.15-15.00 Research Presentations

1. Nanotoxicology of PM: particle interactions with lung surfactant polymers – Michaela Kendall

2. Modelling personal exposures to PM_{10} in an urban population – Mike Ashmore

15.00-15.30 Noise, air pollution and cardiovascular disease – Lars Jarup

15.30-15.45 Final Discussion Session – Chair: Bob Maynard

15.45-16.00 Future Steps & Close