Research Report TM/01/05
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Measurement of personal exposure to PM_{10} in the Non-Workplace Environment using Passive Sampling Techniques

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This study investigated the use of a passive personal sampler originally developed for use in the workplace, to provide measures of long-term average exposure to particulates. This simple device which collects dust by electrostatic capture on to an electret (polypropylene) disc, is small, lightweight, unobtrusive, requires no power supply or pump and no operator attention during the collection period. The rate at which this sampler collects particles is related to their electrical mobility, which can vary according to their size and charge. Side-by-side measurements using the passive sampler and a pumped "conventional" PM_{10} samplers were made in various indoor and outdoor microenvironments.

In each of the microenvironments, there was evidence of a relationship between the exposure of the sampler and the mass collected by the sampler although the rate of collection of particles was significantly different, particularly between outdoor and indoor aerosols. In the outdoor environments, the masses collected were quite reasonable, the lowest mass collected being of the order of 150 µg. For indoor aerosols however, the collection rate was too low to be of practical value. Several approaches are suggested which could overcome these limitations including improved sampler and study designs. One important possibility is to combine use of the device with EM image analysis methods. Potentially this could provide a method to assess exposure to particle number and surface area.

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SUMMARY

This study investigated the use of a passive personal sampler originally developed for use in the workplace, to provide measures of long-term average exposure to particulates. This simple device, which collects dust by electrostatic capture on to an electret (polypropylene) disc, is small, lightweight, unobtrusive, requires no power supply or pump and no operator attention during the collection period. Potentially the device may be used either as a personal or a static sampler. However, the pilot study described here was restricted to the application of the sampler in the static mode.

The rate at which particles are collected by the device depends on the electrical mobility (and hence size and electric charge of the particles) although for aerosols which have aged (typically more than 30 min. after formation), it has been shown that collection rate is relatively insensitive to particle size.

The study aims were met by a sampling exercise in which side-by-side measurements using the passive sampler and a pumped "conventional" PM_{10} sampler were made in various microenvironments. The microenvironments chosen were those in which differences in the aerosol (in terms of both concentration and composition) might be expected. These microenvironments included domestic (urban and rural), office (smoking and non-smoking) and urban ambient in Sheffield and Edinburgh.

In its original geometry, the masses collected by the sampler in all microenvironments were too low to be of value. No clear relationship between the exposure of the sampler and the masses collected and could be established. The sampler was subsequently modified so as to incorporate a second charged electret (of opposite polarity), on the underside to the cover, parallel to the first electret with a separation distance of 6 mm.

In this configuration, the sensitivity of the device was greatly improved. In each of the microenvironments tested during the second study period there was evidence of a relationship between the exposure of the sampler and the mass collected by the sampler. In the outdoor environments, the masses collected were quite reasonable, even for a two week period, the lowest mass collected being of the order of 150 μg. For indoor aerosols however, the collection rate was still too low. Only in a heavily polluted smoking room were masses greater than 100 μg collected.

From the statistical analysis, a significant difference between the relationship of the masses collected and the exposure (defined as conc x t) was identified The observed rate of collection, relative to exposure, was greater for the outdoor aerosol than for the indoor. In the indoor microenvironments, there was also difference between the response in the domestic and smoking office microenvironments, when compared with that in the office environment. It is likely that these differences arise from differences in electrical mobility of the aerosol in these micro-environments and this does present some limitations to the potential use of the sampler.

Several approaches are suggested which could overcome these limitations. Potentially, the sensitivity of the device could be improved by modifications to the sampler design. A relatively simple change would be to double the diameter of the electret. This would increase the rate of collection of the device by a factor of four and although it would increase the overall dimensions of the device, it would still be of a size which was easily wearable.

However, a more interesting approach would be to change the analytical method to provide estimates of particle number or surface areas. Powerful image analysis techniques are now available, which offer the possibility of automatic or semi–automatic counting and measuring of particles collected on a substrate. The combination of this technique with a simple passive sampler would provide a very powerful tool since particle number (or particle surface area which may be derived from particle number and size) is now considered as potentially the key parameter that may provide the linkage between particulates and health effects. Uniquely, direct measurement of the exposure to particle number of groups of individuals using a simple easily worn badge type device would become possible.

Limitations associated with the differing collection rates in different microenvironments could in principle be overcome by appropriate wearing or use strategies. For example, samplers could be placed in each of the (main) microenvironments in which an individual might be exposed and overall exposure assessed from estimates of the time spent in each. Or, a sampler could be used when the wearer was indoors and removed (and placed in a sealed container) when the wearer was out of doors. This sampler could be used to estimate indoor exposure with outdoor exposure being estimated from estimates of the time spent and of the ambient concentration. More complex strategies could be envisaged.

Additional work is now required to investigate these possible applications.

1. INTRODUCTION

1.1 BACKGROUND

The exposure of the general population in the UK to airborne particulates (PM_{10}), and the health effects which result, are matters of increasing concern. Information is required both on short term peak exposures, to investigate the relationship between these and acute health effects (e.g. mortality, hospital admissions), and on longer term average exposures, to examine chronic effects (e.g. asthma). Currently in the UK, estimates of personal exposure to particulates in the non-workplace environment are based largely on measurements of particle concentrations (PM_{10}) provided by the fixed Automated Urban Network (AUN) sites. However, it is now well recognised that individual exposures can vary greatly from the level reported by the AUN sites due to factors such as proximity to outdoor sources and differences between indoor concentrations, (in homes, offices and transport) and those outdoors. The task of estimating individual exposures is more complex in that even in cases where the indoor microenvironment concentrations are well characterised, the relationship between these and the personal exposure of individuals is not well understood (eg Seaton et al, 1999). While there has been some success in validating such indirect methods for gaseous pollutants, by comparing microenvironment and personal exposures directly, the approach has not yet been successfully used for particulates. One reason for this is the difficulty in requiring individuals to wear conventional personal sampling equipment for particles for extended periods.

This study investigated the use of a passive personal sampler (Brown and Wake, 1992), originally developed for use in the workplace, to provide measures of long term average exposure. This simple device is small, lightweight, unobtrusive, requires no power supply or pump and no operator attention during the collection period. The time necessary for this sampler to collect weighable quantities of material in the non-workplace environment (one to two weeks) makes it ideally suited for studies in which information about long term airborne concentrations needs to be collected, without confounding effects associated with short term variation. Potentially the device may be used either as a personal or a static sampler. However, the pilot study described here was restricted to the application of the sampler in the static mode.

1.2 AIMS AND OBJECTIVES

The principal aim of this study is to investigate the relationships between the mass collected by the passive sampler and the prevailing PM_{10} concentrations in three appropriate microenvironment types, these being urban ambient, domestic (kitchen) and domestic (living area). By examining the relationships obtained, the requirement or otherwise for different calibration functions will be established. A subsidiary aim was to quantify the variability associated with the passive sampler.

1.3 THE PASSIVE SAMPLER

The passive sampler described by Brown and Wake collects dust by electrostatic capture on to an electret (polypropylene) disc. The device is shown in Figure 1.1. Prior to use, the electret discs are charged using a corona device to a surface potential of approximately 1000 volts. On re-assembly and replacement of the cover plate (a metal conductor), an electric field is created between substrate and the cover. In use, particles enter into the space between the substrate and the cover and, encountering the electric field, move either towards the cover or the substrate. Collection rate is independent of the velocity with which the particles enter the field (provided that a critical velocity, shown to be approximately 0.02 $msec^{-1}$, is exceeded).

Particles, having a diameter of d_p move towards the substrate with a drift velocity U_d given by;

$$U_d = \frac{neE}{3\pi\eta d_p} \qquad (1)$$

Where n is the number of fundamental charges (e) carried by the particle, E the magnitude of the electric field, η the viscosity of the air and w the distance between the electret and the conductor. The ratio of the drift velocity to the electric field is known as the electrical mobility μ_e. The rate at which particles are collected by the device depends on the electrical mobility (and hence size and electric charge of the particles). The total mass collected by the sampler, M has been shown to be related to the aerosol concentration C in the vicinity of the sampler as follows (Brown et al, 1993, 1996);

$$M = \frac{CA\mu_e Vt}{w} \qquad (2)$$

where A is the area of the electret, w is the spacing between the electret and the cover plate, V is the surface voltage and t is the time of exposure.

It follows that in order to obtain absolute measurements of concentration, it is necessary either to independently measure the electrical mobility of the aerosols (usually very difficult) or to calibrate the sampler, by comparing it with conventional pumped samplers. This latter approach is the one that has most often been used (eg. Thorpe et al 1999).

Although these variable collection characteristics may appear to be a disadvantage, Brown et al (1994) showed that the mean electrical mobility, and hence collection rate, is approximately constant for particles which had been "neutralised" (i.e., reached equilibrium) irrespective of particle size (for particles in the size range 3-7 μm). In practice, aerosols which have aged (typically more than 30 minutes after formation) have equal numbers of positively and negatively charged particles, distributed according to the Boltzmann distribution. For highly charged particles, the electrical mobility is different but is also independent of particle size.

It follows that to properly evaluate the potential this device for use in the measurement of environmental aerosols, it is necessary to "calibrate" its performance against a range of range of aerosols and microenvironments likely to be encountered.

2. DESIGN AND METHODS

2.1 STUDY DESIGN

The study aims were met by a sampling exercise in which side-by-side measurements using the passive sampler and a pumped "conventional" PM_{10} sampler were made in various microenvironments. The microenvironments chosen were those in which differences in the aerosol (in terms of both concentration and composition) might be expected. The study was carried out in two parts. In the first part of the study, six microenvironments were investigated, as shown in Table 2.1.

In each location, five pairs of measurements were made with exposure times of approximately two weeks. In the urban sites and alternatively in each of the pairs of domestic sites, a second passive sampler was co-located with the first to provide information on within sampler variation.

Table 2.1 Microenvironment details, study period 1

Microenvironment	Location
urban ambient 1	Edinburgh, collocated with AUN site
urban ambient 2	Sheffield, collocated with AUN site
domestic (kitchen) 1	Edinburgh, house A
domestic (kitchen) 2	Sheffield, house B
domestic (living) 1	Edinburgh, house A
domestic (living) 2	Sheffield, house B

Changes to the study design were made after the first part of the study, due primarily to perceived limitations in the sensitivity of the instrument (discussed in more depth later). In the second study period four microenvironments were investigated, as shown in Table 2.2.

Table 2.2 Microenvironment details, study period 2

Microenvironment	Location
urban ambient	Edinburgh, collocated with AUN site
domestic (kitchen)	Edinburgh (semi-rural)
office	Sheffield
smoking room	Sheffield

In this part of the study, the exposure times were varied and comprised two, four and six week periods. The six-week period overlapped with the combined two and four-week periods.

2.2 SAMPLING METHODS

Before the start of the second study period, the samplers were modified to incorporate a second charged electret, on the underside of the cover, parallel to the first electret with a separation distance of 6 mm. The purpose of this was to increase the collection rate of the device, it having been identified that the collection rate of the unmodified device was too low.

In each of the urban ambient locations, the mass collected by the passive sampler was compared with that reported by the Tapered Element Oscillating Microbalance (TEOM) PM_{10} sampler at the AUN site. The hourly concentrations of PM_{10} data were downloaded from the Department of Trade and Industry (DTI) web-site at *(http://aeat.co.uk/netcen/aqarchive/auto.html)*. This information was collated to produce mean ambient concentrations at the sites of interest, averaged over the periods for which the passive samplers were in place.

In indoor environments this passive sampler was compared with a pumped sampler which comprised the IOM personal inhalable samplers (Mark and Vincent 1986), produced by SKC Ltd (Brighton, UK), which were modified by insertion of aerodynamically selecting porous foam plugs into their inlets. The foam plugs modified the entry characteristics such that their selection characteristics corresponded to those of the PM_{10} convention (Kenny et al 1997). The use of porous foams to develop sampling instruments having selection characteristics which match thoracic or PM_{10} characteristics has been widely reported (Vincent et al 1993, Aitken et al 1993, Aitken and Donaldson 1995). These devices are much simpler and less expensive to use than impaction based devices described elsewhere (Buckley et al 1991, Wallace 1996). Samplers were collected onto glass fibre filters. Very quiet, mains driven piston pumps were used with these samplers, low noise being an important requirement for sampling in domestic environments.

The mass of dust collected by the passive sampler was assessed gravimetrically using a six-figure Mettler balance within an environmentally-controlled room using a standardised weighing procedure incorporating the use of field blanks to correct for weight changes in unexposed substrates. All of the samples were weighed in the same laboratory. For the pumped sampler filter, appropriate weighing procedures incorporating the use of field blanks (MDHS 14/3, HSE 2000) were used in the analysis of the filters.

2.3 DATA ANALYSIS

Since the mass collected by the passive sampler is theoretically proportional to the incident aerosol concentration and the time spent in that concentration, the analysis was in terms of mass collected as a function of the product of measured concentration and exposure time. This product of the concentration and time may be thought of as the “exposure” of the samplers.

The data from the first and second sampling campaigns were analysed separately. For the first sampling campaign, the data were initially plotted as the mass collected by the passive sampler as a function of exposure. The data were then inspected and observations drawn.

For the second sampling campaign, the data were initially plotted as the mass collected by the passive sampler as a function of exposure.

The data were further analysed to quantify the relationships between the two measures and to determine whether the ratio between passive and pumped samples was constant or differed across the various microenvironments.

Three treatments of the data were performed, (i) no adjustment for changes in the weights of controls (ii) data adjusted for the change in weight of the control samples, and (iii) a correction to allow for the decrease in potential on the electret with time (this having been measured pre- and post exposure).

For each treatment, the ratio of mass from the passive sampler to the mass from the pumped samplers, (defined as concentration x time) was calculated for each of the four microenvironments in which the samplers were tested. The Kruskal-Wallis test (Altman 1991) was used to compare these ratios. Where significance was achieved, Mann-Whitney U tests were carried out in order to determine where the differences lay. Since multiple comparisons were carried out, the Bonferroni correction (Altman 1991) was applied, i.e. the level of significance was divided by the number of comparisons being made. The significance level was therefore 0.008 (0.05/6) instead of the commonly used 0.05.

Sampler variability was investigated by examining the precision of the sampler, using the approach described by CEN (1999). In this the absolute standard deviation is calculated as

$$s_a = \sqrt{\sum D_i^2 / 2n} \tag{3}$$

where D_i denotes the difference in the measured mass collected by two side-by-side samplers. The two-sided 95% confidence interval is then calculated as

$$CI_{95} = s_a \times t_{n,0.975} \tag{4}$$

In this study, this information in this form was only available for the results from the first study period. No direct side-by-side samples were taken during the second study period although some information was available from the six week sample which was taken alongside the two and four week samples.

3. RESULTS AND ANALYSIS

Figures 3.1 and 3.2 shows the data from the first study period plotted as the mass collected by the passive sampler as a function of exposure. Figure 3.1 shows the data from the external (ambient) micro-environments and Figure 3.2, from the indoor microenvironments. These are all unadjusted data (treatment1).

Inspection of the data in these two figures indicates evidence of differences in the relationship between passive and pumped samplers in the indoor and outdoor environments. On inspection of the data in these two figures, the overall impression is of low sensitivity of the passive samplers (typical collected masses are less than 30 μg) and of high variability (particularly so with the external microenvironments). There is little evidence of any clear relationship between the mass collected by the samplers and their exposure.

This result led to the modification of the sampler described earlier (by addition of the second electret) in the second study period.

The data from the second part of the study are shown in Figures 3.3 and 3.4. Again, the unadjusted data are shown (treatment 1)

In Figure 3.3, the data from the external microenvironment in study period 2 are plotted with those from study period 1 (shown earlier in Figure 3.2). Initial inspection of this figure indicates that the sensitivity of the passive sampler has been greatly increased in the second period relative to the first. Although the exposures in each of the two study periods are similar, the mass collected by the passive sampler was much greater during the second period (ranging from, approximately, 150 to 300 μg) than the first (20 to 90 μg). There is also much more evidence of a relationship between exposure and the mass collected in the second study period than there was in the first.

Figure 3.4 shows the all of the data from the second study period. Again the collected mass is plotted as a function of exposure. First indications from this figure are that there appear to be a difference in the relationship between collected mass and exposure for the indoor and outdoor microenvironment but the relationship for all of the indoor environments looks similar.

Plots of the same type were produced for the datasets for the other two treatments. However, these were very similar to Figure 3.4 and are not reproduced here.

Additional analysis of the data was carried out (as described above) by taking the ratios of the mass collected by the passive sampler, to the exposure of the sampler (derived from concentration x time). These are presented in Table 3.1 for each of the data treatments.

From this table, it is immediately apparent that the ratios from sampling in microenvironment 2 (outdoor) are an order of magnitude higher than those in the other environments. This difference is confirmed by the Kruskal-Wallis test which indicated that there were significant differences between ratios from the different microenvironments for all data treatments ($P < 0.001$ in all cases).

Table 3.1 Ratios of mass from the passive sampler to exposure

Treatment		Microenvironment				P value
		1 IOM domes	2 IOM envir	3 HSL smoke	4 HSL office	
1 no adjustment	Median	0.003	0.020	0.001	0.010	< 0.001
	Minimum	0.001	0.016	0.001	0.006	
	Maximum	0.004	0.029	0.001	0.013	
2 adjusted for controls	Median	0.001	0.020	0.001	0.008	< 0.001
	Minimum	0.001	0.014	0.001	0.004	
	Maximum	0.003	0.027	0.001	0.010	
3 adjusted for voltage	Median	0.002	0.030	0.002	0.008	< 0.001
	Minimum	<0.001	0.024	0.001	0.004	
	Maximum	0.003	0.036	0.002	0.012	

The results of the Mann-Whitney U tests indicated that there were no significant differences between ratios from microenvironments 1 and 3, or between microenvironments 3 and 4.

In the side-by-side comparisons (in the first study period), the absolute differences between the two sampling heads ranged from 0 to 28 μg with a mean of 9.3 μg. The two-sided 95% confidence interval was calculated as 18 μg. This provides an estimate of the uncertainty associated with the device. Unfortunately, no equivalent information was available for modified sampler in the second study period.

4. DISCUSSION

Passive samplers potentially have many features which would make them attractive to use to provide estimates of personal exposure. Generally, they are small, unobtrusive, inexpensive, require no power supply or pumping system and no operator attention. Providing the sensitivity was adequate, they could be used to assess the long term average concentrations of particles in the ambient and environmental atmosphere. In principle, a sampler of this type could either be used as a static sampler for measurement of microenvironment concentrations or directly as a personal sampler to measure personal exposure. As a static sampler, the instrument would be suitable for studies concerned with characterising long-term average concentrations in different microenvironments, differences within microenvironments and further studies to look at the relationship between microenvironment and personal exposure for different groups of individuals, different domestic environments etc. As a personal sampler, the device would offer unique benefits in that for the first time it would open the possibility of carrying out direct measurement of the exposure of large groups of individuals using a simple easily worn badge type device without the necessity of extensive microenvironment monitoring.

In this study, the potential application of a device of this type has been evaluated.

In the original geometry described, the masses collected in the six microenvironments were too low to be of value. No clear relationship between the exposure of the sampler and the masses collected was established. There were some indications that the response the indoor and outdoor aerosols differed but any effect was swamped by the variability in the data.

In the modified geometry, the sampler was sensitive enough to provide a measure of exposure. In each of the microenvironments tested during the second study period there was evidence of a relationship between the exposure of the sampler and the mass collected by the sampler. In the outdoor environments, the masses collected were quite reasonable, even for a two week period, the lowest mass collected being of the order of 150 μg. This would seem to indicate that the device does have some potential application there. Whether any estimate obtained using the device in this environment would be any better than an estimate based on time spent in the environment and the average AUN concentration has not been demonstrated but it would seem at least to be a possibility. For indoor aerosols however, the collection rate is too low. Only in the heavily polluted smoking room were masses greater than 100 μg collected. It would seem that the collection rate is too low to be practical at this stage in these environments.

From the statistical analysis, there was a significant difference between the response of the sampler against indoor and outdoor aerosols, as evidenced by the differing ratios obtained. The observed rate of collection, relative to exposure, was greater for the outdoor aerosol than for the indoor. In the indoor microenvironments, there was also difference between the response in the domestic and smoking room microenvironments, when compared with that in the office environment.

It is probable that these differences arise from differences in electrical mobility of the aerosol in these micro-environments. A common feature between the domestic and smoking micro-environments is that in each case aged environmental tobacco smoke would be the dominant aerosol present and this could account for the similarity of the response in each case.

This work has indicated that the sampler in its current configuration may be used to provide estimates of concentration in the outdoor environment. This could have potential application

in studies to consider long term spatial distribution of particulate. Clearly though, there are limitations for the wider application of this device due to a continued lack of sensitivity, at least in some microenvironments and differences in sensitivity (collection rate) in different microenvironments. These limitations present both challenges and opportunities.

Potentially, the sensitivity of the device could be improved by modifications to the sampler design. A relatively simple change would be to double the diameter of the electret. From Equation 2, this would increase the rate of collection of the device by a factor of four and although it would increase the overall dimensions of the device, it would still be of a size which was easily wearable. Reducing the spacing between the electret and the cover plate would also increase sensitivity. Both of these modifications would also increase the critical velocity (the minimum air velocity around the sampler to ensure even distribution of aerosol across the surface) and this would have to bet taken into account.

However, a more interesting approach would be to change the analytical method to provide estimates of particle number or surface areas. Image analysis techniques such as that described by BéruBé (1999) offer the possibility of automatic or semi – automatic counting and measuring of particles collected on a substrate. The combination of this technique with a simple passive sampler would provide a very powerful tool since particle number (or particle surface area which may be derived from particle number and size) is now considered as potentially the key parameter which may provide the linkage between particulates and health effects. A device of this type would help to overcome what is a major problem in establishing any relationships between exposure and health outcomes in the absence of suitable methodology for measuring exposure. Potential applications of a device of this type would include; studies concerned with characterising average concentrations in different microenvironments, differences within microenvironments and further studies to look at the relationship between microenvironment and personal exposure for different groups of individuals, different domestic environments etc. Uniquely however, direct measurement of the exposure to particle number of groups of individuals using a simple easily worn badge type device would become possible.

Limitations associated with the differing sampling rate could in principle be overcome by appropriate wearing or use strategies. For example, samplers could be placed in each of the (main) microenvironments in which an individual might be exposed and overall exposure assessed from estimates of the time spent in each. Or, the sampler could be used when the wearer was indoors and removed (and placed in a sealed container) when the wearer was out of doors. This sampler could be used to estimate indoor exposure with outdoor exposure being estimated from estimates of the time spent and of the ambient concentration. More complex strategies could be envisaged. All such strategies would of course have to be validated prior to their implementation.

Additional work is now required to investigate these possible applications.

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7. FIGURES

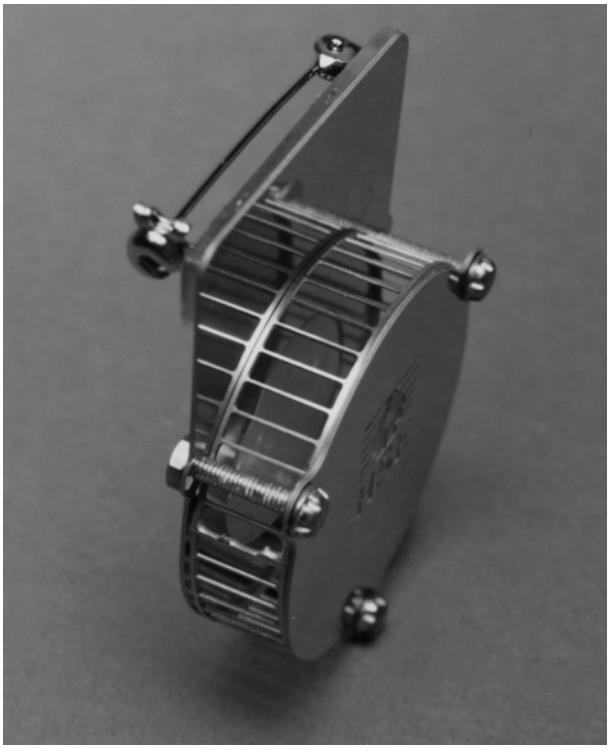

Figure 1.1 The passive sampler

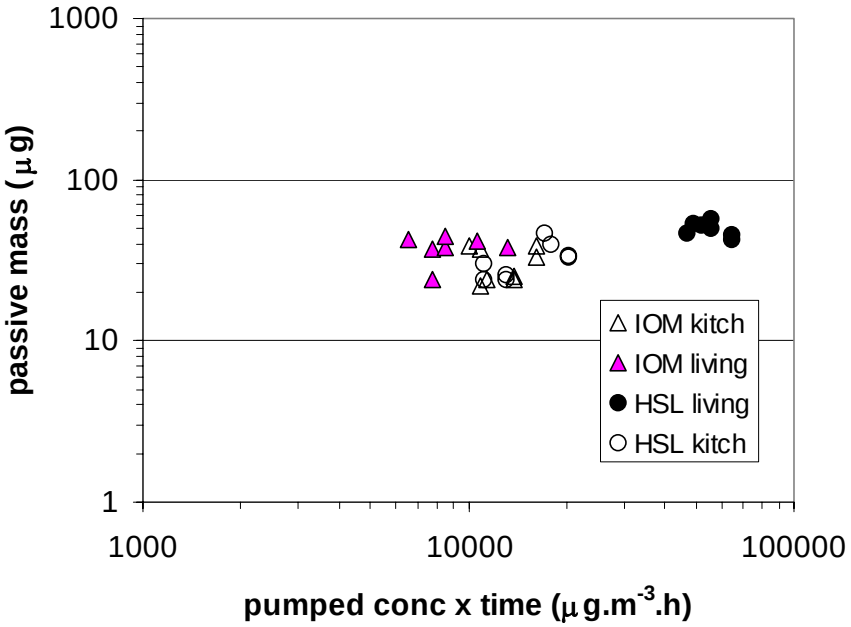

Figure 3.1 Indoor microenvironments, study period 1

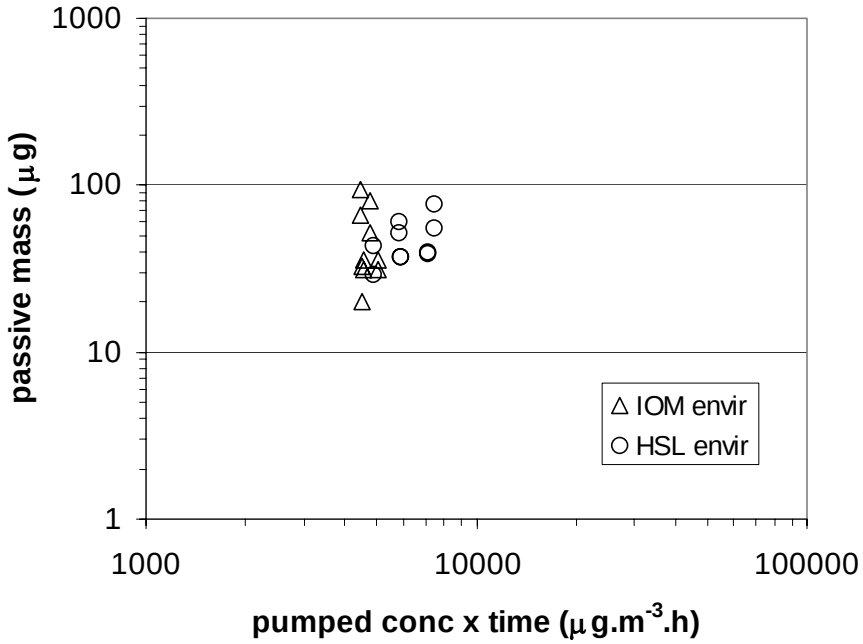

Figure 3.2 Outdoor microenvironments, study period 1

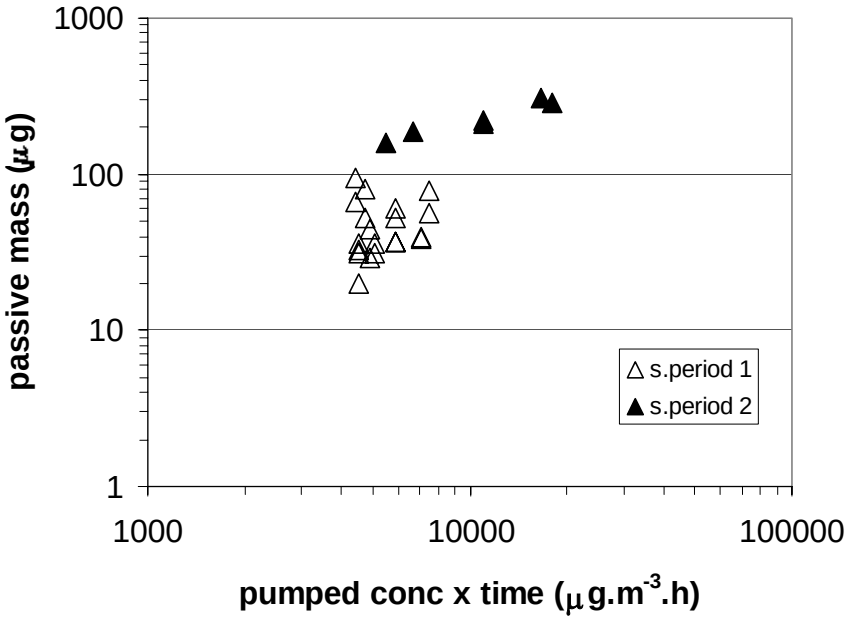

Figure 3.3 Outdoor microenvironments, study periods 1 and 2

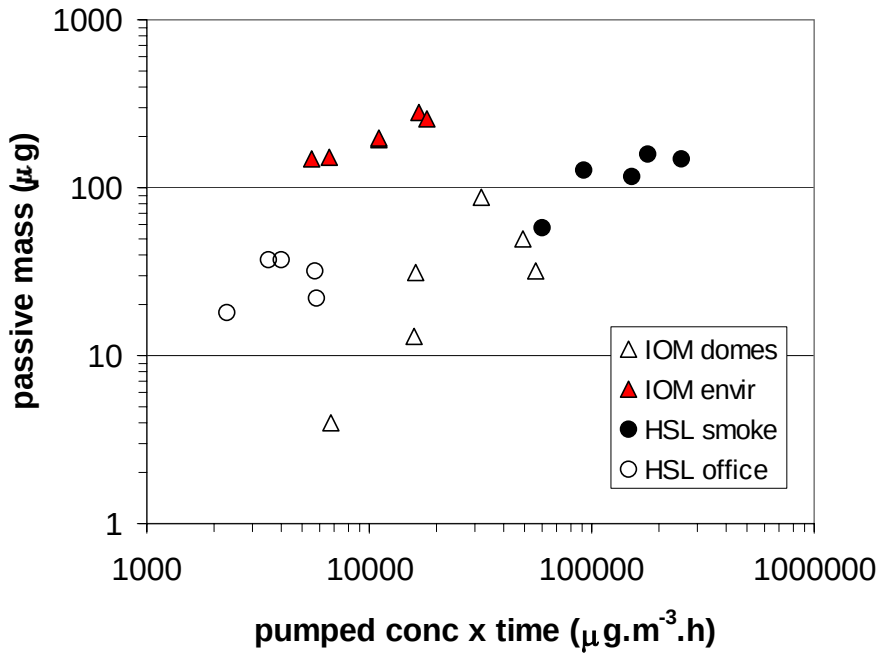

Figure 3.4 All microenvironments, study period 2

Institute of Occupational Medicine

WORLD HEALTH ORGANISATION
COLLABORATING CENTRE
FOR OCCUPATIONAL HEALTH

Applying science for a better working environment

The Institute of Occupational Medicine

The IOM is a major independent centre of scientific excellence in the fields of occupational and environmental health, hygiene and safety. We aim to provide quality research, consultancy and training to help to ensure that people's health is not damaged by conditions at work or in the environment. Our principal research disciplines are exposure assessment, epidemiology, toxicology, ergonomics and behavioural and social sciences, with a strong focus on multi-disciplinary approaches to problem solving.

Our beginnings

Our first major research programme began in the 1950s, on respiratory health problems in the coal mining industry. Major themes were quantification of airborne dust concentrations in different jobs, characterisation of types and constituents of the dusts, measurement of health effects, relationships between exposure and disease, and proposals for prevention. This research became an international benchmark for epidemiological studies of occupational health, and was the primary influence on dust standards in mines in the UK, US and other countries.

Current themes

Our current work spans many other industries including asbestos, MMMF, pesticides, chemicals, energy, telecoms, metals, textiles, construction, agriculture as well as the environment. While diseases of the respiratory tract remain a major interest, our scope now extends to many other health outcomes such as mortality, cardiovascular effects, cancer, back pain, upper-limb disorders, hearing loss, skin diseases, thermal stress and psychological stress. Related work includes the development and application of measurement and control systems, mathematical models and survey methods.

Who we work for

Our work in these areas is conducted for a wide range of organisations in the UK, the EU, and the US, including Government departments, international agencies, industry associations, local authorities, charitable organisations, and industrial and commercial companies. The IOM is a World Heath Organisation (WHO) collaborating centre and is an approved institute of the Universities of Edinburgh and Aberdeen, enjoying collaborative research links with NIOSH, IARC, and many other institutes throughout the world.

Publication

We believe that our research findings should be publicly available and subject to the scrutiny of the international scientific community. We publish our findings in the peer reviewed scientific literature and through our own series of Research Reports.

Contact

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