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ORIGINAL ARTICLE

Indoor $PM_{2.5}$ Concentrations in the Office, Café, and Home

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ABSTRACT

Since individuals spend the majority of their times indoors, fine particles generated in indoor combustion processes and by resuspension are important for health effects assessment. The nature and magnitude of indoor particle exposures can change rapidly because of the rapid changes in activities and sources. Indoor $PM_{2.5}$ concentrations were measured in indoor office, café, and home where people spend majority of their time in there. A real time monitor was used to provide a high degree of resolution for investigating temporal patterns in particle concentrations. The average $PM_{2.5}$ concentration obtained from the direct reading compared with the mean $PM_{2.5}$ concentrations that are obtained by gravimetric measurements during the same continuous sampling. Mean $PM_{2.5}$ concentrations in the big office were more than twice as high as those measured in the small quiet office (19.8 and 7.3 respectively). In the home, cooking increased $PM_{2.5}$ concentration. The highest particle concentrations in home (average 28 µg m^{-3}) were related to a period around midnight when there were a larger number of occupants inside the living room. Mean $PM_{2.5}$ concentrations measured in the smoking area of the café were much higher than those measured in the non-smoking area (50.0 and 17.6 µg m^{-3} respectively). Outdoor air pollution can affect the indoor particulate concentration when the indoor source not exists. Smoking, cooking, and resuspension of indoor particulate matter are the most important sources for indoor particle concentrations.

Keywords: *Indoor air pollution, $PM_{2.5}$, Office, Café, Home*

INTRODUCTION

Epidemiological studies have found relationship between fine particle concentration in the air and several acute health effects, including mortality, hospital admissions, respiratory symptoms, and lung function [1, 2]. These studies mostly discussed about variation in outdoor air pollution measured by fixed site and its relation with health end points [3-5]. Major studies about personal exposure to particles have reported good relationships between indoor particulate air concentrations and personal exposure [6, 7]. Some other studies have found that personal exposure were higher than indoor $PM_{2.5}$ concentrations [8, 9]. Since individuals spend the majority of their times indoors, fine particles generated in indoor combustion processes (cooking, smoking, etc.) and by resuspension are important for health effects assessment. The nature and magnitude of indoor particle exposures can change rapidly because of the rapid changes in activities and sources, and because of differences in ventilation. Continuous real time monitoring of fine particle

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Table 1. Gravimetric correction factor for different sampling locations

Location	Correction factor	Sampling location	Real time mean [$PM_{2.5}$] (μg m^{-3})	Gravimetric mean [$PM_{2.5}$] (μg m^{-3})
Home	1.02	Home	18.1	18.4
Café	1.005	ETS	49.95	50.22
		Non-ETS	16.97	17.06
Office	1.07	Small	6.58	7.33
	1.70	Big	11.6	19.8

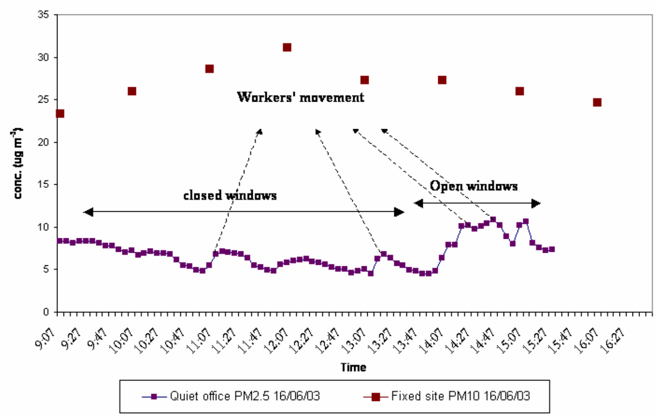

Fig 1. Real time $PM_{2.5}$ concentrations in the quiet office and fixed site PM_{10} concentrations

concentrations can improve exposure pattern of occupants.

This project is focused on evaluation of indoor particulate air pollution ($PM_{2.5}$) in indoor office, café, and home where people spend majority of their time in there (10).

MATERIALS AND METHODS

A real time monitor (MicroDust Pro, Casella, UK) was used to provide a high degree of resolution for investigating temporal patterns in particle concentrations. The MicroDust Pro measured particulate concentrations (range 0 to 2500 mg m^{-3}) using a near forward angle light scattering technique. Infrared light of 880 nm wavelength was projected through the sampling volume, where contact with particles caused the light to scatter and the amount of scatter was measured by a photo detector. In this instrument, a narrow angle of scatter (12-20°) was used to minimize the uncertainty associated with particle colour, shape and refraction index. The principle of near forward light scatter and the use of this technique imply that mass concentrations of particle were recorded.

This instrument was calibrated to a known reference dust standard. Different dust types causd a different response from this instrument due to variation in particle size, refractive indices and colour. In order to correct for this, it is necessary to calibrate the response of the instrument. This involves the collection of a gravimetric (filtered) sample of the dust after it has passed through the probe optics.

To measure the $PM_{2.5}$ concentrations, a size selective sampling cyclone was used in combination with a particle size adapter and a small Poly Urethane Foam (PFU) filter that was designed for $PM_{2.5}$ size fraction monitoring. A small personal sampling pump was used to provide a continuous airflow through the gravimetric adaptor and photo detector. For gravimetric calibration, particles were then collected on a 37 mm filter (Teflon filter, Gelman Science, PTEF, 2.0 µm, 37 mm, SKCinc, UK), which was assembled into the cassette, behind the air sample stream.

The weighed filter provides a mass of particles (in µg), and the volume of sampled air drawn through the instrument (in m^3) can be defined. The average $PM_{2.5}$ concentration obtained from the direct reading from the MicroDust Pro can then be compared with the mean $PM_{2.5}$ concentrations that are obtained by gravimetric measurements during the same continuous sampling.

The real time monitoring was carried out in two offices, one café, and one house. Offices were located on the second floor of a multi-storey building at the University of Bradford campus with 2 and 9 workers. This part of the study aimed to assess the effect of office occupancy. The non-ETS house was located on a busy road about 1 km from the city centre. This monitoring aimed to assess the factors influencing concentrations in the home with the highest levels of $PM_{2.5}$. The café was located in a shopping centre in the middle of the city that included smoking and non-smoking areas. This aimed to assess the effect of smoking activity. The EXCEL software was used to analyse measured data.

RESULTS

Results from simultaneous continuous monitoring data and gravimetric data are summarized in Table 1. The gravimetric correction factor varied from 1 to 1.07 in all locations except for the busy office, for which the value was much higher, at 1.70. In this study, the correction factor of 1.02 was applied for data of indoor

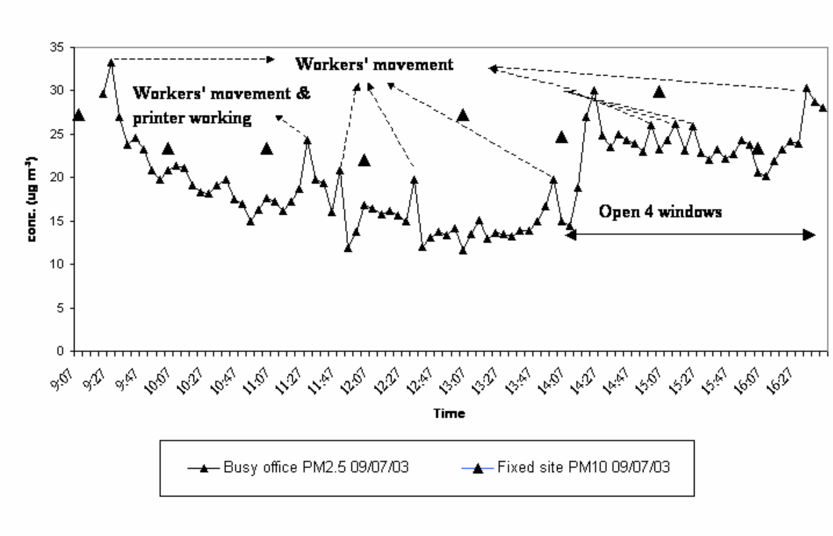

Fig 2. Real time $PM_{2.5}$ concentrations in the busy office and fixed site PM_{10} concentrations

home $PM_{2.5}$ concentrations. The correction factors of 1.005, 1.07 and 1.7 were also applied for particle concentrations that were measured in the café, small office, and big office respectively.

Real time monitoring in the office: The monitoring was carried out on 16th June and 9th July 2003. Both office doors opened to a small corridor, which was shared with 2 other rooms and no heating system was used during the sampling. The real time monitor was used for monitoring $PM_{2.5}$ concentrations during one working day in each office. The monitor was placed on a desk in the middle of the office.

To define the factors affecting $PM_{2.5}$ concentrations, conditions inside the office and occupants' behaviors were noted during the sampling period. The indoor profile of $PM_{2.5}$ concentrations over a weekday period in the quiet and busy offices, together with corresponding PM_{10} concentrations at the Bradford fixed site is illustrated in Fig. 1 and Fig. 2.

As can be seen in Fig. 1, the background (fixed site) PM_{10} levels were considerably higher than indoor $PM_{2.5}$ concentrations in the quiet office. There was an increase in $PM_{2.5}$ concentrations when the windows were opened. The $PM_{2.5}$ concentrations increased slightly when a worker was walking around inside the office.

Fig. 2 shows $PM_{2.5}$ concentrations in the busy office and corresponding PM_{10} concentrations measured at the Bradford fixed station. The indoor office $PM_{2.5}$ concentrations were slightly lower than the background (fixed site) PM_{10} levels. Opening the windows increased $PM_{2.5}$ concentrations inside the office, suggesting an increased penetration of outdoor particles into the office through open windows. The $PM_{2.5}$ concentrations increased considerably while people were walking around inside the office, or printing was in progress in the busy office.

Although there was a higher outdoor PM_{10} concentration while monitoring was in progress in the quiet office, the indoor $PM_{2.5}$ concentrations were higher in the busy office than the quiet office. Mean $PM_{2.5}$ concentrations in the big office were more than twice as high as those measured in the small quiet office (19.8 and 7.3 respectively).

Indoor home real time monitoring: Real time monitoring was carried out in the living room of a house with open windows located on a high traffic flow road, to identify the sources of indoor $PM_{2.5}$ concentrations. This house is located in an urban area on a busy road, about 1 km from Bradford city centre. It is a semi-detached house built between 1919 and 1944. There are separate gas heating stoves in each room, and gas and electricity were used for heating and cooking. Six non–smokers occupied the house and no heating appliance was working during the sampling.

Monitoring was carried out in the evening of 29th September 2003 (18:10-23:40) in the living room. The living room and kitchen were different rooms separated by a small corridor and 2 doors. The monitor was placed on a table about 1m above the floor in a corner of the room, about 70 cm from the walls.

One of the occupants was asked to report any human activity and air pollution related information during the sampling. Windows were closed during the sampling and no heating system was used. This implied that the indoor concentrations under these conditions were mainly influenced by activities that took place in the house in the evening. Short term cooking and occupants' movements were the only important activities that were reported during the sampling.

Fig. 3 shows the real time $PM_{2.5}$ concentrations in this home and background PM_{10} concentrations monitored at the Bradford fixed site. There was no occupant in the room during the first hour of monitoring, when the indoor $PM_{2.5}$ concentrations were much lower than background PM_{10} concentration. When cooking started in the kitchen and occupants came into the living room, the particle concentrations increased significantly. Although the $PM_{2.5}$ levels decreased slightly after cooking, the $PM_{2.5}$ concentration remained high until the end of monitoring period. The highest

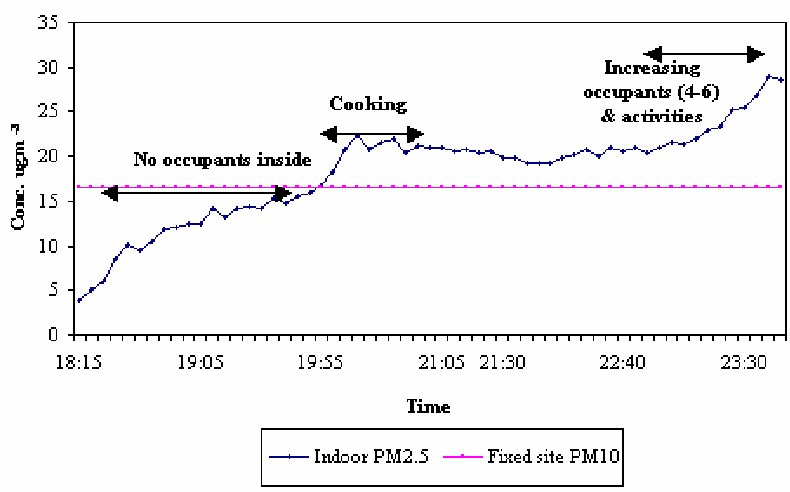

Fig 3. $PM_{2.5}$ concentrations indoor a home on a busy road and fixed site PM_{10} concentrations

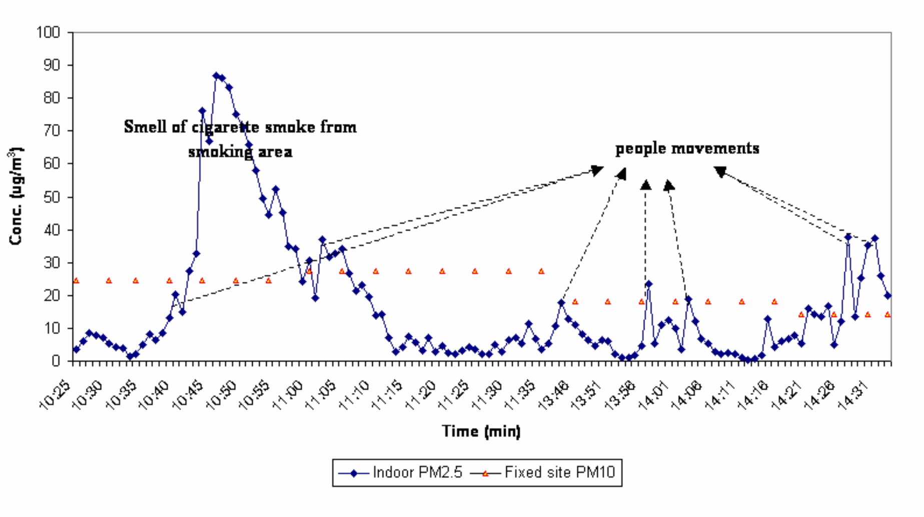

Fig 4. $PM_{2.5}$ concentrations in non-smoking area of a café and fixed site PM_{10} concentrations

particle concentrations were related to a period around midnight when there were a larger number (4-6 persons) of occupants inside the living room.

Real time monitoring in café: The multiple regression analysis of non-work personal exposure in other study showed a significant effect of time spent in the pub on personal exposure [10]. To assess the effect of environmental tobacco smoke (ETS) on $PM_{2.5}$ exposure, an attempt has been made to measure and compare temporal $PM_{2.5}$ concentrations in a smoking and non-smoking area of a café.

Real time monitoring was carried out in smoking and non-smoking areas of a busy café in Bradford city centre on 10th January 2004. This café was located in the ground floor of a shopping centre with no outside windows. The café was open to other parts of shop and there was an air conditioning system. Smoking and non-smoking area were located in a hall. 70% of the hall was a non-smoking area, and there was no separation between the two areas. There were 25-36 people in the non-smoking area and 8-15 people in the smoking area during the monitoring. The sampler head was placed on a table in the middle of both smoking and non-smoking areas alternately about 1m above the floor. Sampling was carried out for about 4 hours (2 hours in the non-smoking and 2 hours in the smoking area). There was no significant particulate matter source except cigarette smoke. Fig. 4 shows the $PM_{2.5}$ concentrations in non-smoking area and PM_{10} levels measured simultaneously by the Bradford fixed monitoring site. In the absence of particle sources, indoor $PM_{2.5}$ concentrations in the non-smoking area were lower than fixed site PM_{10} concentrations during the sampling period. For a short time, the indoor $PM_{2.5}$ concentrations increased dramatically. Penetration of cigarette smoke from the smoking area to non-smoking area was the only factor which could explain the increase in particle concentrations in this area. There were also some other peaks related to people movements around the monitor.

Fig. 5 shows the real time $PM_{2.5}$ concentrations in the smoking area of the café and the corresponding PM_{10} concentrations at the Bradford fixed station. Smoking cigarettes was the only source of particles in the smoking area. The indoor $PM_{2.5}$ concentrations were

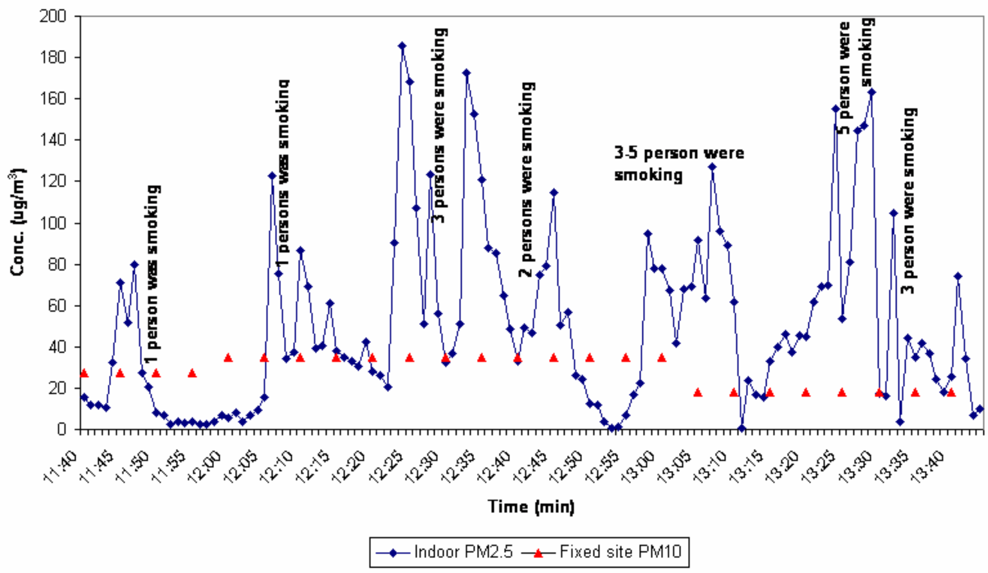

Fig 5. $PM_{2.5}$ concentrations in smoking area of a café and fixed site PM_{10} concentrations

higher than fixed site PM_{10} concentrations for the majority of the sampling period and smoking cigarettes was the only factor identified to explain the increasing particle concentrations. Smoking cigarettes was associated with rapid increases and decreases in $PM_{2.5}$ concentrations. Mean $PM_{2.5}$ concentrations measured in the smoking area were much higher than those measured in the non-smoking area (50.0 and 17.6 µg m^{-3} respectively).

Discussion

This study showed that opening the windows increased $PM_{2.5}$ concentrations inside the office, suggesting an increased penetration of outdoor particles into the office through open windows. Some other studies concluded that in non-source public places, outdoor particulate air pollution was the only factor of indoor particle concentrations [11]. In this study, although there was a higher outdoor PM_{10} concentration while monitoring was in progress in the quiet office, the indoor $PM_{2.5}$ concentrations were higher in the busy office than the quiet office, suggesting an influence of worker numbers and their activities on resuspension of particles and increasing $PM_{2.5}$ concentrations. In the home also, when cooking started in the kitchen and occupants came into the living room, the particle concentrations increased significantly, suggesting an effect of cooking and penetration of particles into the living room. Some other similar studies concluded that human activities, indoor sources, number of occupants and resuspension of particles can play an important role in affecting indoor particle concentrations [12-14].

Real time monitoring in a smoking and non-smoking area in a café also showed that smoking was an important contributor to higher indoor $PM_{2.5}$ concentrations. The mean $PM_{2.5}$ concentration (33 µg m^{-3}) was higher in the smoking area in comparison to non-smoking area. A significant association was found between the number of cigarette smoked and $PM_{2.5}$ concentrations in the smoking area. Wallace and co-workers conducted a real time monitoring in 294 homes of asthmatic children in the U.S. and concluded that smoking was a major indoor source, which elevated indoor $PM_{2.5}$ concentrations by 37 µg m^{-3} in homes with smokers [15]. Other studies that have carried out continuous monitoring indoors have identified smoking as a major indoor particle source. For example, Invernizzi et al. found increased $PM_{2.5}$ concentrations in the smoking area of a restaurant in Italy [16], and Lai et al. in EXPOLIS study concluded that smoking increased indoor $PM_{2.5}$ concentrations [17]. Wallace in a review study also identified smoking as the largest indoor source of fine particle concentrations [7].

Conclusion

In the absence of indoor air pollution source the outdoor air particulate is the most important factor for indoor particulate concentration. Sources such as smoking, cooking and resuspension of indoor particulate matter are the most important factors for indoor particle concentrations.

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