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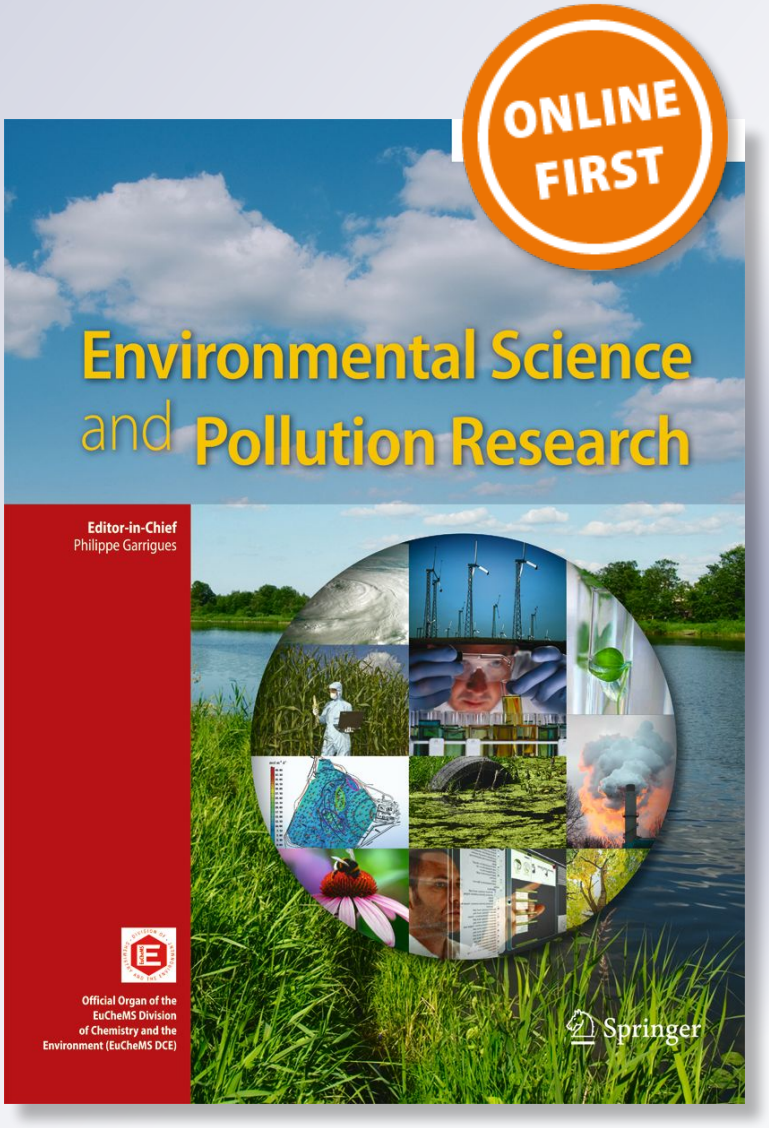

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RESEARCH ARTICLE

Measurement of personal and integrated exposure to particulate matter and co-pollutant gases

A panel study

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Abstract Personal exposure measurement can serve as an effective tool to understand the effect of exposure to air pollutants. Alternatively, exposure assessment using pollutant concentrations in different microenvironments and accurate time–activity information for the subjects can provide good information regarding human integrated exposure. A panel of 18 healthy students of Indian Institute of Technology (IIT) Kanpur in the age group of 18 to 30 years participated in the personal exposure measurements for particulate matter, CO, NO_2 and VOC during post-monsoon and pre-monsoon seasons. Overall, 432 h person exposure data was collected in this study. The major sources of particulate and gaseous co-pollutants were identified. These directly obtained personal exposure values were then compared to the indirectly estimated integrated exposure values. Personal and integrated exposures gave statistically similar results. Through this study, we have shown that integrated exposure values could closely estimate the personal exposure values for particulate matter that can significantly reduce time and cost involved in personal exposure studies. The lung parameters for all the subjects measured during the pre-monsoon and post-monsoon seasons showed statistically significant reduction during pre-monsoon. This was attributed to the high levels of coarse particles during pre-monsoon.

Keywords Personal exposure assessment · Microenvironment · Integrated exposure · Time–activity diary · Coarse particles · Lung parameters

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Introduction

Several studies in the past have linked air pollution to human health effects (Abbey et al. 1999; Filleul et al. 2005; McDonnell et al. 2000; Nafstad et al. 2004). Particulate matter (PM) and some gases are key constituents of polluted air. Past studies have reported association of PM with daily morbidity and mortality as a consequence of deteriorating heart and lung functions (Dockery et al. 1993; Jerrett et al. 2005; Pope et al. 1995, 2002, 2004). Gaseous co-pollutants also affect the cardiopulmonary system during high exposure events (Ackermann-Liebrich et al. 2007; Arif and Shah 2007; Chen et al. 2005; Samoli et al. 2006). Most of these studies used samplers near breathing zone for exposure quantification, which are not real-time (Zhu et al. 2010). These methods cannot accurately identify the different sources of pollutants.

There have been some recent studies exploring the effect of human activities on personal exposure. Apte et al. (2011) observed very high concentrations of the different fractions of particulates and black carbon inside auto-rickshaws in New Delhi, India. Ferro et al. (2004) showed an increase in exposure to PM due to different household activities. Dons et al. (2011) studied exposure to black carbon (BC) on eight couples. They found a strong association of BC exposure to transport microenvironments. Long et al. (2000) studied time series exposures to PM in different homes and discussed the major indoor sources of PM. Recently, a few

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studies (Dhondt et al. 2012; Beckx et al. 2009) used the activity-based models of personal exposure. These kinds of approaches are useful for studying the personal exposure of general population.

Panel study is one of the most common methods to study the short term and long term effects of air pollution (Englert 2004; Künzli et al. 2001). Personal exposure to pollutants is evaluated by measuring the concentrations of pollutants near the breathing zone of an individual using personal monitors/samplers. This is a direct approach in which the participant carries the sampling instruments with him/her all the time and maintains a time–activity diary. The diary can help in identification of the different sources of pollutants by comparing the time/event/activity from the diary and concentrations measured by the instrument for that particular time. This method of assessing personal exposure is expensive and requires ample time for data collection and analysis (Klepeis et al. 2001). An alternative method to find the exposure is termed as integrated exposure. This is an indirect method that consists of integrating the pollutant concentrations in different microenvironments as a function of time spent by an individual in that particular microenvironment (Lioy 1995; Monn 2001; Ott 1982). Stationary monitoring of pollutant concentrations is measured in the microenvironments where the subjects spend majority of their time. Time-weighted average of the measured concentrations provides the integrated exposure values of a pollutant. Time spent by the subject in a particular microenvironment is used for this calculation. This method needs validation with simultaneously measured personal exposure (Raymer et al. 2009) on a suitably selected panel to represent a community. Assessing personal exposure using stationary outdoor measurements is also an alternative way but outdoor concentrations of respective pollutants do not always represent the true personal exposures as on an average people spend more than 80 % of their time in indoor microenvironments (Clayton et al. 1993; Spengler and Sexton 1983). The pollutant concentrations can change significantly due to different indoor sources and ventilation patterns within different microenvironments (Ebelt et al. 2000; Janssen et al. 2000; Rojas-Bracho et al. 1999; Dons et al. 2011). Only in the case of good ventilation, will outdoor concentrations typically dominate over indoor concentrations as a result of high air exchange rates.

Here, we present a time series study of personal exposure to PM and gaseous co-pollutants for a panel of Indian Institute of Technology (IIT) Kanpur students during the post-monsoon (PoM) (September–October) of 2009 and pre-monsoon (PreM) (April–May) of 2010. Personal exposures were measured using a suite of real-time instruments for measuring PM and gaseous co-pollutants for a panel of IIT Kanpur students. A time activity diary was maintained by each subject of the panel during the measurement period. Separately, stationary monitoring with the same set of instruments was carried out in ten different microenvironments located within the IIT Kanpur campus that the participants commonly use. The time activity record of each participant provided the detailed information about the time they spent in the above sampled microenvironments. The personal exposure measurements demand time and money. In order to obtain personal exposure values in an inexpensive way demands a method that is quick and reliable. Integrated exposure just requires the time spent by an individual in different microenvironments and the pollutant concentrations in respective microenvironments. The integrated exposures were estimated for each subject within the panel using these time activity records. These estimated values for all the subjects for both the seasons were compared to the corresponding personal exposures measured for the panel. Integrated exposure statistically agreed with personal exposure values for PM concentrations, thus making the estimation of exposures for sub-groups of populations becomes quicker and cost effective.

Methodology

Site location

The study was carried out inside the premises of Indian Institute of Technology Kanpur (26.4°N, 80.2°E), India which is located on the northwest of Kanpur, a polluted industrial city, in the Indo-Gangetic plains (Chakraborty and Gupta 2010). The institute is located on the upwind side and has a campus which is much cleaner and greener as compared to the city centre which is 17 km away from the premises. The minimum and maximum daily temperatures varied between 16.2 °C and 41.3 °C during PreM and between 12.7 °C and 33.1 °C during PoM (India Meteorological Department, IMD). The study area was about 1.5 km^2 inside the residential campus having around 5,300 students (Fig. 1). Nearly all the students use bicycles for transit purposes. The peak motorized vehicle density is ~250 vehicles/h; these vehicles are mostly used by staff, visitors and faculty members.

Instruments used

Three instruments for monitoring personal exposure were used in this study for the real-time measurement of size-resolved PM from 0.3 to 20 μm, total submicron particle number concentration, and gaseous (carbon monoxide [CO], nitrogen dioxide [NO_2] and volatile organic compounds [VOCs]) concentrations. These were low noise, portable, battery operated instruments.

Condensation particle counter (CPC model 3007, TSI Inc.) measures the submicron (PM_1) particle number

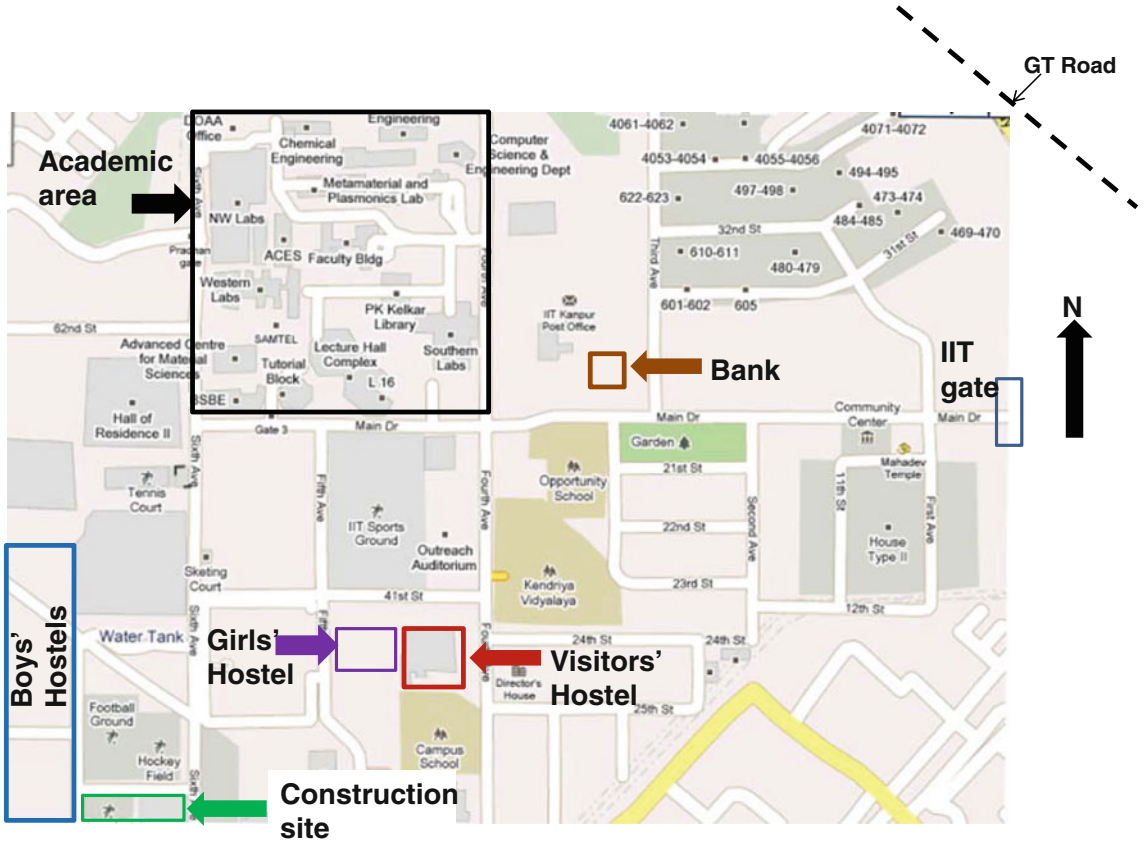


Fig. 1 Location of different microenvironments within IITK campus (adapted from www.maps.google.com). Map not drawn to scale

concentration in the size range of 0.01–1 μm with a sampling flow rate of 0.7 litre per minute (LPM). The performance and particle detection efficiency of the instrument are provided elsewhere (Hameri et al. 2002). The instrument was factory calibrated just before the PreM experiment and was frequently checked for zero count by placing a High Efficiency Particulate Air (HEPA) filter at the inlet.

Optical particle counter (OPC; model 1.108, Grimm) measures size resolved particle number concentrations at a sampling flow rate of 1.2 LPM. The working principle of the instrument and required environmental conditions are described in detail elsewhere (Devi et al. 2009; Tripathi et al. 2006). By assuming a spherical shape and particle density of 1.6 gcm^{-3} (Pitz et al. 2003) for all the particles, the number concentrations (cm^{-3}) were converted into mass concentrations ($\mu g m^{-3}$). This conversion was only applicable for OPC as it measures in different size bins and not for CPC as it measures total number concentrations for aerosol between 0.01 and 1 μm. The OPC was factory calibrated before the start of this study and was frequently checked for zero count using an HEPA filter at the inlet.

Multiple gas monitor (IAQRAE Gas Monitor, Model PGM-5210; RAE Systems Inc.), measures the concentration of CO, VOC and NO_2. This instrument measures CO in the range of 0–500 ppm with a resolution of 1 ppm, NO_2 in the range of 0–20 ppm with a resolution of 0.1 ppm and VOC from 0 to 2000 ppm with a resolution of 0.1 ppm. CO and NO_2 were measured using specific electrochemical sensors whereas for VOC detection a photoionization detector with a 10.6 eV lamp (MultiRAE Plus PGM-50 user manual) was employed. The instrument was factory-calibrated for all the sensors of gas measurements prior to embarking on this study.

A temperature and humidity sensor stick (Testo 605 H1) was also used to measure temperature and relative humidity. It measures temperature in the range of −20 °C to 70 °C and relative humidity in the range of 5–95 %.

Sampling precautions and data quality assurance and control

The inlets of the instruments were kept near the breathing zone of the subjects to avoid discrepancies in the personal exposure values. Diffusion losses of particles while sampling with the OPC and CPC were minimized by using sampling probes of smaller lengths. During transit, the participants used bicycles as usual which minimized their exposure to PM and gases from self driven motorized vehicles. All instruments were checked for leaks with HEPA filter. The instruments were operated only when the ambient temperature was well within the range of optimum operating

temperature of the instruments and at low RH. Each night during the experiment period, the instruments were inspected for any errors, data was transferred and batteries were recharged. CPC cartridge was refilled at appropriate time intervals to maintain even supersaturations. OPC filters were replaced at regular intervals to avoid clogging of filters and to maintain the suitable flow rates. None of the data was discarded and all the peaks in the data were studied with the corresponding recorded activity using the time–activity diary. Care was taken to make sure the instrument was kept near the breathing zone of the subjects even when they were in sitting position.

Description of panel

In this study, a panel of 22 students in the age group of 18 to 30 years was selected. All the selected students were Indians. Later on, data for four students was discarded as three of them were discovered to be smokers and one had poor lung parameters. The panel, finally, consisted of 18 healthy students, of which 16 were males. All students resided inside the residential halls (or hostels; see Fig. 1 for their locations) within the institute campus. The study was carried out during PoM of 2009 and PreM of 2010 for the same set of subjects. Therefore, a total of 432 h person exposure time was available for subsequent analyses.

Sampling setup

Personal exposure sampling was carried out with the help of a shoulder bag in which all the instruments were carefully arranged with the sampling inlets out (Fig. 2). The instruments were battery powered during transit and were connected to electric wall outlets whenever possible to recharge the instrument batteries. The bag was equipped with a mini-exhaust fan to vent off any heat generated by continuously operating the instruments inside the bag for long durations.

Since only one set of sampling instruments was available, personal exposure study on subjects were carried out only during weekdays (Monday–Friday) when the subjects were active. The duration of sampling by each subject was 12 h from 0700 to 1900 hours IST (Indian Standard Time). Each subject carried out personal exposure study once in a season duly recording the time–activity data for the sampling duration in a logbook along with frequent records of the temperature and RH. For instance, if subject #1 carried out the sampling on Monday, he/she maintains the logbook with time–activity data and at the end of the day, the instrument data was downloaded and the batteries were charged overnight. Then the same set of instruments was provided to the subject #2 at 7:00 AM on the next day. This was repeated with the rest of the subjects during the weekdays and the same set of instruments was used for outdoor sampling from 7:00 AM to 7:00 PM LST (Local Standard Time, which is same as IST) during the weekends to obtain the ambient concentrations of pollutants. This strategy was followed for both the seasons.

Stationary measurements within different microenvironments

Microenvironment monitoring was carried out to estimate the integrated exposure of a person by taking the time weighted average concentration of pollutants (Eq. 1) (Ott 1982). Pollutant concentrations in the microenvironment depend on their sources like cooking and smoking, and air exchange ratio.

$$E = \frac{\sum_{j=1}^{n} C_j T_j}{\sum_{j=1}^{n} T_j}. \quad (1)$$

where E denotes the time-weighted average exposure, C_j is the average concentration of pollutants in j microenvironment, and T_j is the average time spent by individual in j microenvironment.

For example, a subject spends t_1 time in any microenvironment 1 with pollutant concentration of C_1, and t_2 time in microenvironment 2 with pollutant concentration

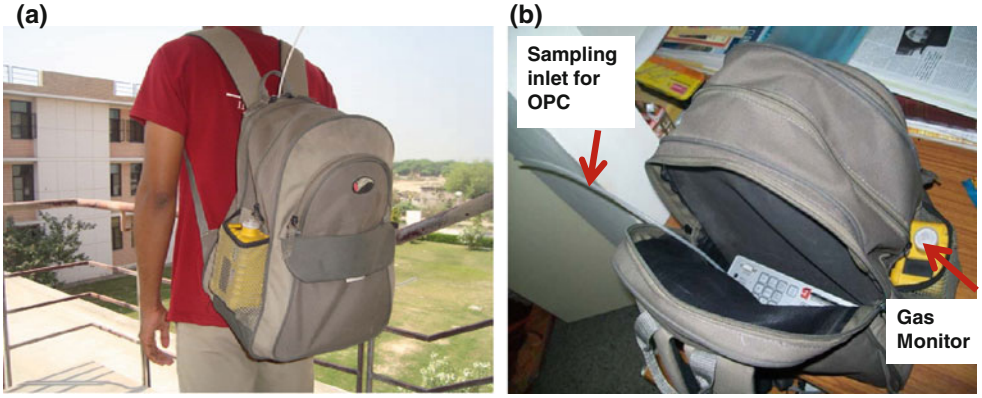


Fig. 2 **a** A subject wearing the sampling bag with relative instruments installed; **b** the arrangements of instruments inside the bag

t_2 and so on. The integrated exposure is estimated as $(t_1 \times C_1 + t_2 \times C_2 + \cdots)/((t_1 + t_2 + \cdots)$. The time spent by each subject was obtained from the respective time–activity diaries that were maintained during the personal exposure study. In this type of integrated exposure estimation, the information about the time and magnitude of peak concentration are lost within the total time period due to the averaging of concentrations. Whereas personal exposure is defined as the exposure, which is measured continuously, even during transits, in the proximity to the subject. Useful statistics like duration, magnitude and source of short-term peaks can be obtained if real-time personal exposure measurements instead of microenvironment monitoring are carried out (Martin 1995).

The ten most common microenvironments where the panel, representing the student community of the institute, regularly visit (80 % of their time spent) were chosen : living room, faculty building (FB; professor office), computer centre (CC), IIT gate (traffic junction), bank, hostel dining hall, environmental chemistry laboratory (lab), class room, canteen and motor transport section (MT). Out of these ten chosen microenvironments, three (IIT gate, canteen and MT) were outdoor environments, but can affect the average personal exposure to a great extent even. A few minutes spent in these microenvironments can increase the personal exposure significantly due to very high concentration of pollutants in the vicinity (Devi et al. 2009). Irrespective of their locale, similar physical characteristics make the exposure levels in these microenvironments quite similar (Klepeis et al. 2001). Therefore, the microenvironment concentrations of pollutants in living rooms of all the students should be similar. This applies to dining halls, offices, classrooms, etc. Since only one set of instruments was available, the personal exposure and integrated exposure measurements were not carried out simultaneously.

Description of microenvironments

Indoor microenvironments

The indoor microenvironments are enclosed space. The windows and doors are the points for air exchange with the outdoor ambient environment. Few indoor microenvironments commonly used by the students were considered for this study. Office rooms in FB are artificially air-conditioned areas with computers and printers. These offices are somewhat protected from outdoor pollution like vehicular exhaust due to their location and partial filtration due to air conditioners (Devi et al. 2009).

Classrooms are of two sizes in IIT Kanpur. The bigger ones are lecture halls with a maximum capacity of 300 students. These are artificially air-conditioned spaces. The lecture halls are equipped with a blackboard and a projector for teaching purpose. The windows and doors are kept closed during teaching. The smaller classrooms are for tutorial purposes with a maximum capacity of 30 students. The only mode of teaching is writing on board with non-dust chalks. The windows and doors are open during teaching enabling air exchange. Chalk dust and dust resuspension are the major sources of particulate exposures in classrooms. The time series of fine and coarse particle exposure in big and small classrooms are given by Devi et al. (2009).

Computer centre is a centrally air-conditioned building with big rooms equipped with computers. There are several smaller rooms with a few computers and printers in the same building. The sampling was carried out in one such room with about ten computers and a printer. The major sources of PM were dust resuspension from movement of students and ultrafine particles (UFP) emitted from the printer. Sometimes people were found smoking inside the building which resulted in buildup of CO concentration indoors and lead to higher CO exposure.

Environmental chemistry laboratory (Lab) houses a range of chemicals used for experiment purposes. The Lab has a big hall with working tables where experiments are carried out. Sampling was carried out in this hall. The hall is not artificially air-conditioned, and only few windows are kept open. The air-exchange rate, although not estimated in this study, must be very low. The major sources of PM exposure were the chemical fumes.

Living rooms are the rooms where students reside. Living rooms are single occupancy rooms which are not artificially air-conditioned. The living rooms of the participant subjects were distributed in different residential halls that are closely located. There was construction activity going on near the residential halls which happened to be one of the main sources of fine PM. Apart from this, the activities carried out by the room inmates were the other sources of PM.

Bank was one of the indoor microenvironment where students visit. Bank is artificially air-conditioned. The major sources of PM are particle resuspension and emission from printers.

Outdoor microenvironments

The outdoor microenvironments that students usually visit are canteen, Motor Transport (MT) section and IIT main entrance gate (IIT gate). Canteens primarily use liquified petroleum gas (LPG) for cooking purposes. Thus, they become the major sources of CO, NO_x and PM. MT has a few shops that sell snacks which are cooked with stoves that use charcoal as fuel. Thus, CO and PM were found in high concentrations in this area. Environmental tobacco smoke was another major pollutant in this microenvironment. IIT gate is a traffic junction, thus, becoming the major source of PM, CO, and NO_x.

Results and discussions

Inter-seasonal comparison of pollutant exposures

The personal exposure data for all the pollutants was analyzed for the time–activity of subjects from the logbook to identify the major sources of pollutants during PreM and PoM. Two different kinds of exposure assessments—personal and integrated—were carried out at different tme periods and compared to see if integrated exposure assessment is comparable to personal exposure to some extent with no statistically significant difference among the assessment methods.

The time activity data for all the subjects were studied individually to identify the specific sources of pollutants in PreM and PoM seasons. The time–activity plots for all the subjects (S1 to S18) were analyzed and discussed in subsequent sections. Although ideally we should have shown plots for all the subjects but we intentionally chose those three subjects S1, S4 and S9 for which significant peaks in exposure could be seen correlated with different human or microenviornmental activities. Increase in pollutant exposures due to different sources/activities can be seen in these plots. During the PoM study, the CPC could not be used because of some technical reasons. Exposures to VOC and NO_2 were below detection limit of the instrument most of the times.

Table 1 provides the average PM mass and number concentrations for different particle sizes and gaseous pollutant concentrations for the panel. The fine and ultrafine particle exposures in PoM are twice higher than the PreM concentrations. The ambient concentrations during PoM were also significantly higher than PreM (Table 2). Some of the subjects spent longer time in canteens, MT and environmental chemistry laboratories during the PoM than the PreM season. These factors may have increased the average fine particle exposure. The coarse particle exposures were higher in PreM season. High concentration of transported dust, resuspension from dry soil, etc., increased the ambient concentration to certain extent that can be clearly seen in Fig. 4 and Table 2. PM_1 average concentrations ranged between 9,276 and 34,726 cm^{-3} (refer to Table S2b). PM_1, being very small in size, can penetrate deep into the lungs affecting the pulmonary system. Such high concentrations of PM_1 can significantly affect the human health depending on their toxicity. Although there are evidences of the effects of PM on human cardiopulmonary system, size resolved effects are still being explored. Some studies found clear association of effect of UFP on human health (Brown et al. 2001; Donaldson et al. 2002; Valavanidis et al. 2008). For some, evidence of health effects due to fine/ultrafine particles is still unclear (Harrison and Yin 2000).

The personal exposure to CO was comparatively higher than that of VOC and NO_2. Minimum exposure value was found for the subjects S6 (please refer to Table S2b). The average exposure to CO for the subjects during PreM ranged between 739 and 7,503 ppb.

Time series analyses of data are very important to understand the sources of pollutants. Sometimes the exposure time to a source is so small that can be observed only by time series. In order to depict the influence of sources/activities on exposure, three out of 18 subjects were chosen purely on the basis of which subjects showed interesting exposure–activity relationship in the graphical form. The personal exposure to fine PM concentration for S1 measured by OPC was found higher in PreM season than in PoM season, since in PreM season the subject spent more time in laboratories where various kinds of chemicals are used (Fig. 3a and b). The outdoor coarse particle concentrations were up to two times higher in PreM than PoM which could add to the PM exposures in PreM in addition to the dust and vehicular emissions. The outdoor fine particle concentration, measured using stationary monitoring with the same set of instruments, for PreM and PoM were similar (Fig. 4a). The coarse fraction of PM was higher during the PreM. During morning time, higher PM exposure was detected in the living room due to the burning of incense sticks similar to Devi et al. (2009) where burning of one incense stick produced 11.2 $\mu g m^{-3}$. The characteristic smoke size

Table 1 Personal exposure for panel to PM and gaseous pollutant in both seasons

Pollutants	Subjects *N*	Pre-monsoon Average ± Std.	Post-monsoon Average ± Std.	*p* value
PM_1 (#/cc)—from CPC	18	17,656±7,014	NA	NA
$PM_{2.5}$ (#/cc)	18	177.7±147.4	422.8±359.3	0.02
PM_1 ($\mu g/m^3$)	18	12±9	24±21	0.04
$PM_{2.5}$ ($\mu g/m^3$)	18	30.5±2.7	37±26	0.35
$PM_{2.5–10}$ ($\mu g/m^3$)	18	52.9±17.2	34.5±20.4	0.01
CO (ppb)	18	2,795±1845	266±519	0.00
VOC (ppb)	18	50±52	BDL	NA
NO_2 (ppb)	18	16.5±11.7	1.0±4.3	0.00

Table 2 Statistical comparison of mass concentration of fine and coarse fraction of ambient particulate matter during pre-monsoon and post-monsoon seasons

Pollutant	Ambient-PreM ($\mu g m^{-3}$)	Ambient-PoM ($\mu g m^{-3}$)	p value
$PM_{2.5M}$	22.17±2.41	28.9±5.12	0.03
$PM_{2.5–10M}$	23.95±3.55	45.07±7.65	0.00

distributions of incense stick smoke and other indoor combustion sources have been extensively characterized earlier by Roy et al. (2009). At MT, canteen and road, CO concentrations were detected due to cooking, combustion activities and vehicular emissions. A handful of shops present in MT use charcoal as the fuel for cooking which remain the major source of CO. The exposure to NO_2 was found only in mess and canteen that use LPG (Kandpal et al. 1995) and on road dominated by diesel, gasoline and CNG (Compressed Natural Gas) vehicles emitting UFP and gaseous pollutants like CO, VOC, NO_x (Gupta et al. 2010; Hesterberg et al. 2008).

The personal exposures to PM for subject S4 as measured by OPC were comparable in both the seasons (Fig. 3c and d). The living room of the subject was more than 100 m away from the construction site indicating the ambient concentration near his room generally will not be affected by construction activities as reported by Devi et al. (2009), who showed that the particulate mass concentration decreased exponentially and reached the background levels around 80 m from the boundary of the construction site. The subject spent the majority of his time in the laboratory in both seasons. This indicates that major contribution of fine PM to personal exposure may be due to the aerosol formed from various chemicals used in the laboratory. PM_1 was higher on roadsides from vehicles. The higher concentrations of UFP as recorded by CPC were found in mess, canteen and on road due to cooking and combustion activities, respectively. CO exposure was found higher in PreM season than in PoM. The ambient concentration of CO (Fig. 4b) showed very high variability and did not show seasonal dependence for PreM and PoM. Thus, the higher exposure of CO during PreM could be attributed to subject's activities and proximity to sources. The peak value of CO exposure was found in the mess. In PreM season, the minimum exposure to CO was found in the lab. Again similar to other subjects, the exposure to NO_2 was found only in mess, canteen and on-road. Exposure to VOCs was found higher in mess and canteen. VOC exposure was also detected in the lab.

The personal exposure to PM measured for subject S9 by OPC was found slightly higher in PreM season than in PoM season due to higher exposure values in the living room in PreM. The average ambient PM concentration in PreM was higher than PoM. The peak values of PM were found in canteen in PoM season and in mess and on road during PreM. The construction activities were going on near students' hostels which greatly affected the indoor room concentration owing to good ventilation. This difference was also reflected in mass concentrations. $PM_{2.5}$ mass and number concentrations in canteen were largely a result of local activities. Students were found spending relatively more time in canteens during PoM than PreM causing higher exposure to $PM_{2.5}$. The coarse mode particle number and mass concentrations in living room were comparable during both the seasons as $PM_{2.5–10}$ particles were mainly a result of resuspension of floor dust and other mechanical processes. Unlike $PM_{2.5}$, $PM_{2.5–10}$ mass concentrations were more during PoM in the canteen which could be mainly due to soil dust resuspension. Microenvironments like CC, dining hall, class room, FB and laboratories were poorly ventilated due to which the change in PM concentrations (both mass and number) did not strongly depend on the ambient conditions. In such locations, indoor sources played the role of modifying the PM properties. Microenvironments like IIT gate, living room, MT and canteen were considerably affected by ambient concentrations in addition to the dominant combustion sources. UFP exposure measured by CPC was detected higher in canteen and on road. UFP peaks were also found in the room during the use of incense (Roy et al. 2009). In the lab, UFP exposure was constantly varying likely due to poor ventilation conditions. The personal exposure to CO was found higher in PreM season as compared with those during PoM. In PoM, peak exposure to CO was found in the canteen and on road while a constant exposure to CO was found in the laboratory likely due to poor ventilation. In PreM, exposure to CO was detected higher in the canteen and on-road and higher exposure was observed in the laboratory (Fig. 3e). Exposures to VOC and NO_2 were below detection limit during PoM season. However, in PreM higher values of NO_2 and VOC were detected both in canteen and on road.

A discussion follows on the exposure sources for all the subjects in the panel. Combustion, chemical fumes, chalk dust in classrooms and vehicular emissions were found to be the major sources of $PM_{2.5}$. Spending more time in these microenvironments increased the average fine particulate exposure to subjects like S13 and S14. Long et al. (2000) also found that indoor sources of PM are typically short-term, high-concentration events that emit primarily ultrafine and coarse mode particles. They also found that more than 50 % of particles thus generated by volume are ultrafine and the particle concentration increases by 7- to 100-folds. In this study, we found that daily average personal exposure values for the panel showed large variations. The ratio of average personal to ambient concentrations during the PreM of fine particle mass concentration varied from 0.2 to 1.2 and the ratio for coarse particle mass concentration varied from 0.5 to 5. The ratio of average personal to ambient

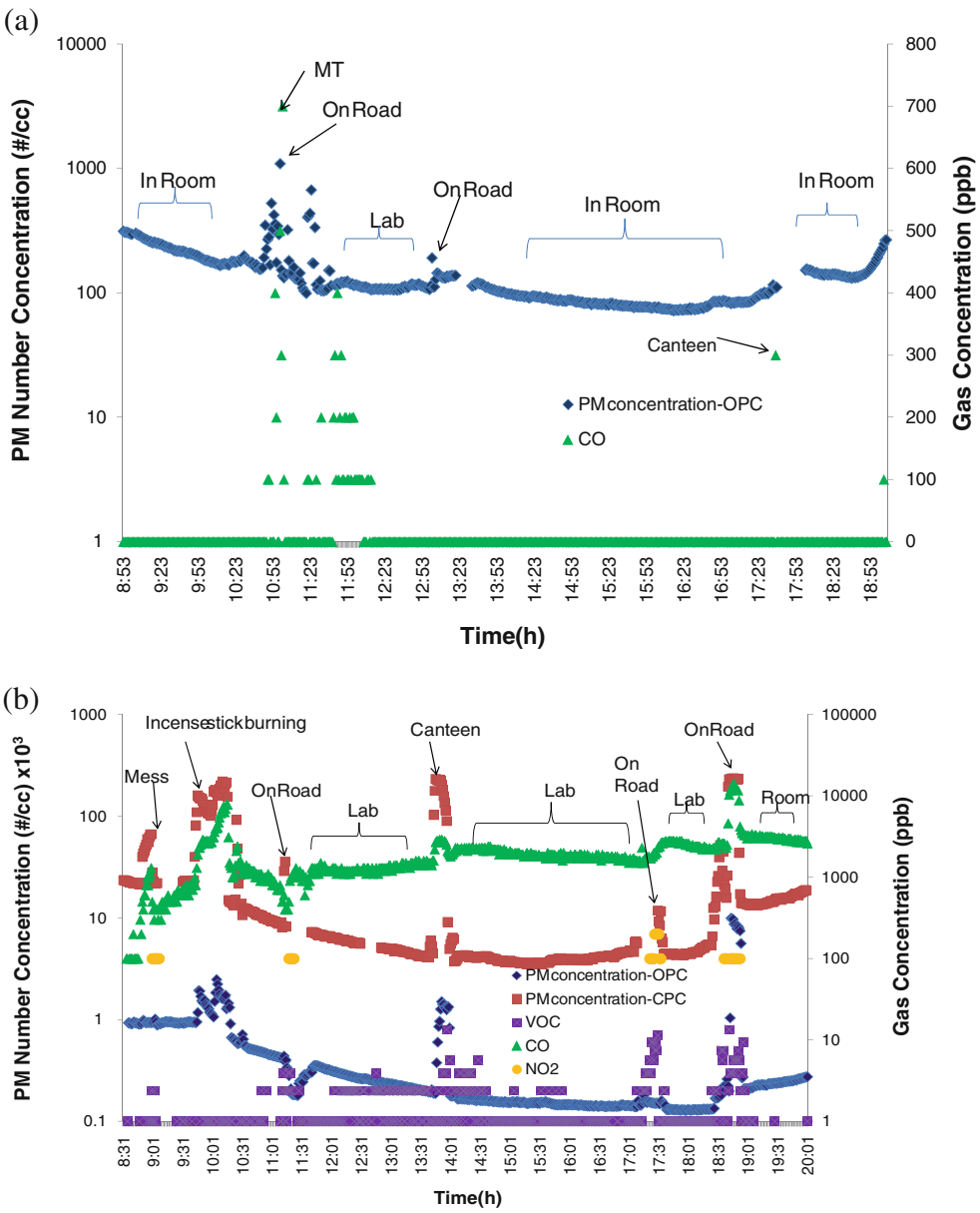
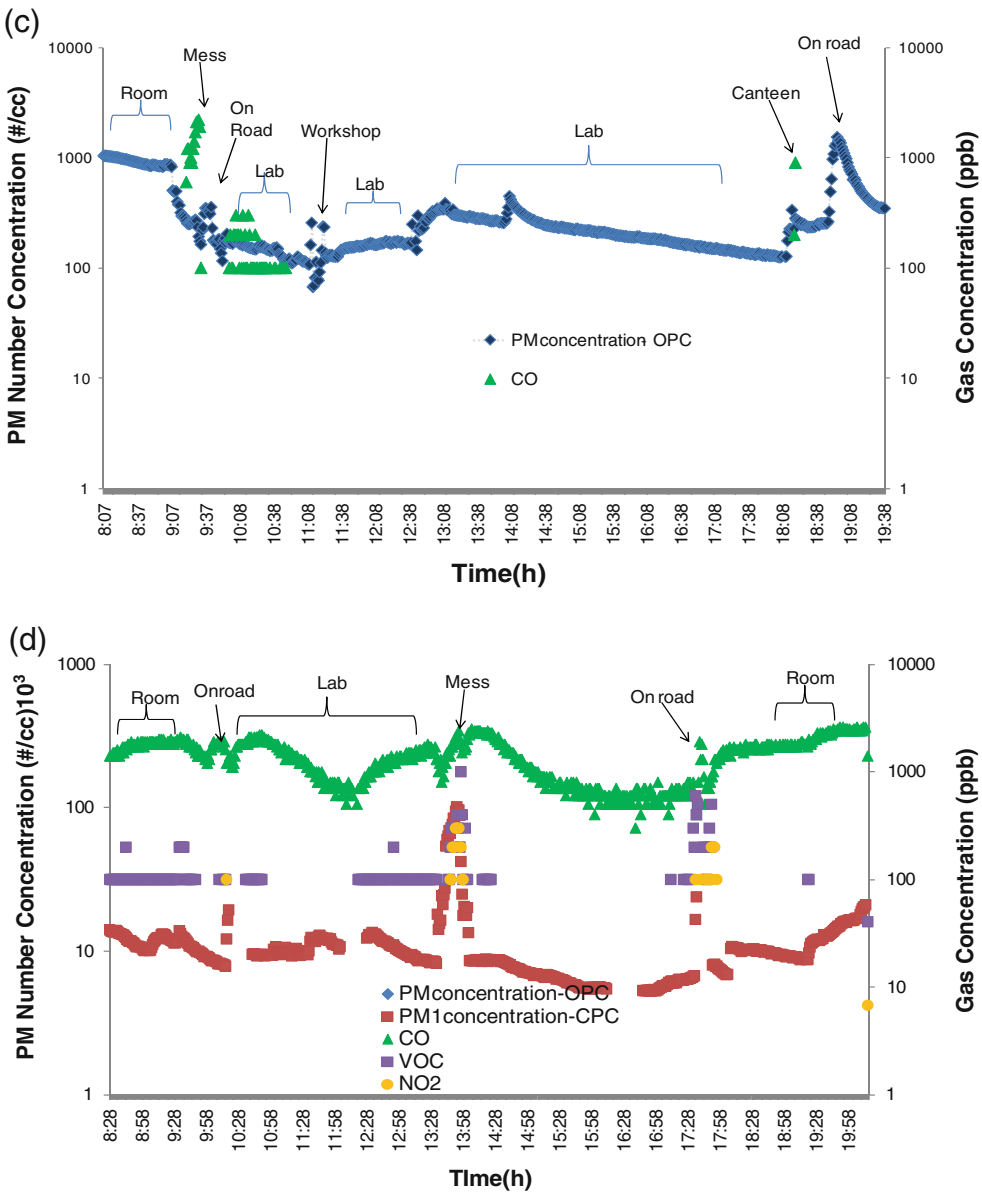


Fig. 3 Personal exposures related to different activities for individual subjects (S1, S4 and S9) in post-monsoon (**a**, **c**, **e**) and pre-monsoon seasons (**b**, **d**, **f**). *This figure show results for only three out of 18 subjects and illustrates strong relationship between different activities and exposure level

concentrations during the PoM of fine particle mass concentration varied from 0.4 to 5 and the ratio for coarse particle mass concentration varied from 0.4 to 4. The personal exposure data for both the seasons showed large variations that can be attributed to different sources and the duration of the exposure. The subjects of the panel spend their time in the same microenvironments, but the large differences in personal exposure were due to the time durations they spend in each microenvironment as they were greatly different. Combustion activities in canteen and chalk dust in classroom contributed to fine fraction of PM to a large extent (Devi et al. 2009). Use of chemicals and chemical fumes are the sources of fine PM in the laboratory. Spending more time in poorly ventilated small classrooms with a capacity of 30 students where non-dust chalks were used for teaching led to an increase in the average personal exposure to fine particles for subject 13. The average fine particle exposure further increased when the subject spent more time in transit due to vehicular emissions. The subjects like S1 and S2 who spent majority of their time in laboratory during the PreM were exposed to more fine particles. Minimum exposure to $PM_{2.5}$ was found for the subjects S5 and S16 during both the seasons who had spent most of their time in artificially air-conditioned CC. Subjects who spent more time in artificially air-conditioned buildings like CC showed minimum exposure to PM_1. CC is artificially and centrally air-conditioned round-the-clock. The main source of fine particles in CC is the laser printer which the students

Fig. 3 (continued)

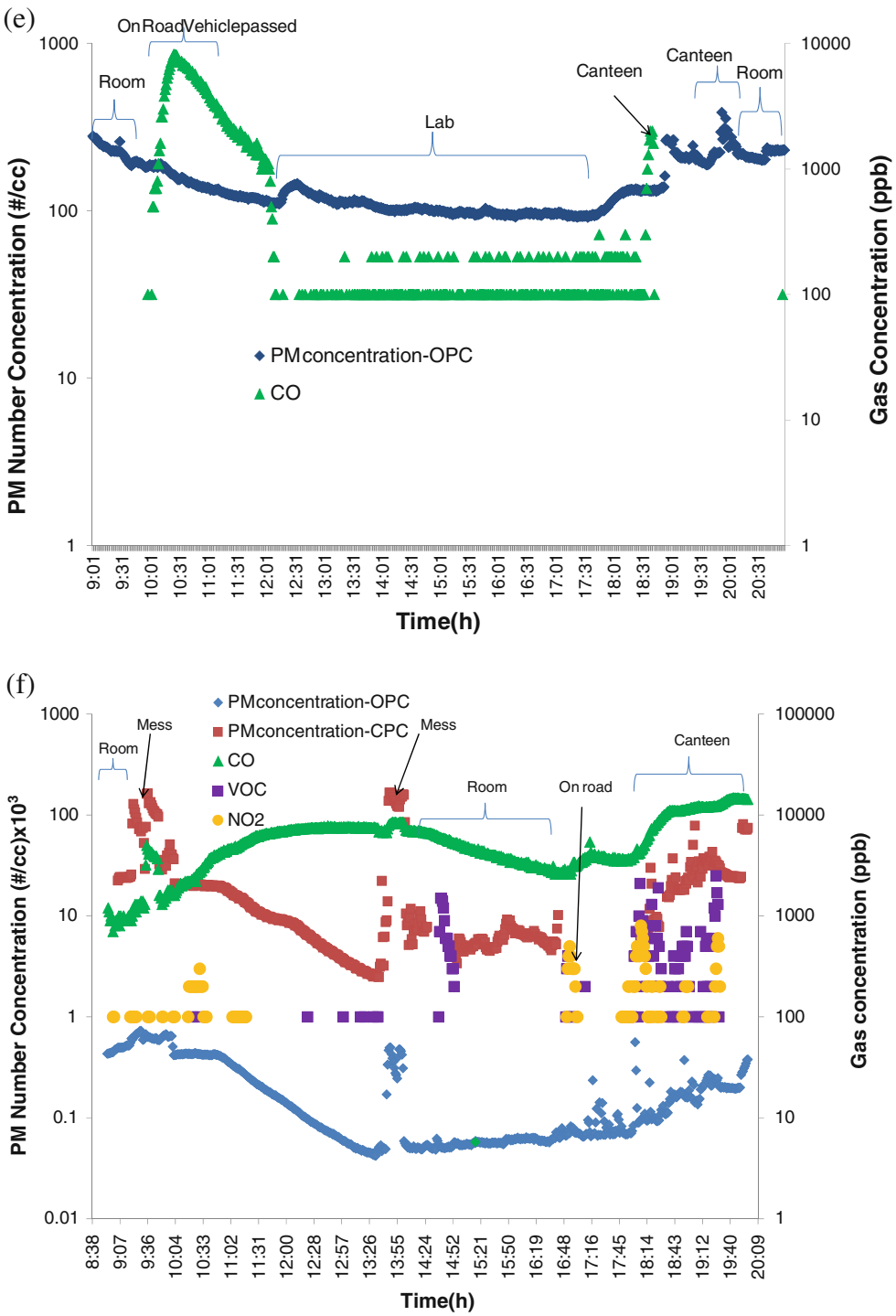


use for printing. The average $PM_{2.5}$ exposure for the rest of the subjects ranged from 13.9 to 60.2 $\mu g m^{-3}$ during PoM and from 13.1 to 64.5 $\mu g m^{-3}$ during PreM.

Vehicular emissions are one of the major sources of CO. Subjects like S17 and S18 who spent more time on roads were exposed to higher CO concentrations with values of 1,419 and 1,795 ppb, respectively, during PreM as compared to other subjects. Higher variability in CO exposure indicated its source dependency. Surprisingly, exposure to CO in CC was also found to be higher, with a value of 7,503 ppb when subject S5 spent the majority of his/her time in that microenvironment. It was noticed that a few people were frequently found smoking inside the building as well as near the air intake for the building ventilation system. This also explains the high concentration of measured VOC exposure for the subject S5. VOC exposure for the rest of the subjects ranged between 10 and 99 ppb.

The inter-seasonal comparison of $PM_{2.5}$ mass which was measured during both the seasons showed varying concentrations in microenvironments with good ventilation and similar concentrations in poorly ventilated and artificially air-conditioned microenvironments. For instance, large variability was seen in ventilated rooms during both the seasons, which were largely affected by construction activities (Muleski et al. 2005). However, poorly ventilated places like FB and bank, showed insignificant variations in $PM_{2.5}$ mass as they were least affected by outdoor sources. There were exceptions to this especially when the source was much stronger than the background ambient concentrations like at IIT gate and MT where the $PM_{2.5}$ primarily depended

Fig. 3 (continued)



on these sources and the ambient concentrations make insignificant difference.

The inter-seasonal comparison of $PM_{2.5–10}$, i.e., the coarse particle mass showed high dependence on the resuspended particle either from road dust by vehicles or in indoors by human activities. The personal exposure PM measurements showed coarse/fine ratio of 0.75–3.5 during PreM and 0.5–2 during PoM season. The average PreM coarse/fine ratio given by Devi et al. (2009) was 2.0, which is also within the range given in this study. The PM_{10} mass concentration for the panel ranged from 25 to 125 $\mu g m^{-3}$ during PreM and from 17 to 160 $\mu g m^{-3}$ during PoM, respectively. The average PM_{10} concentration during PreM given by Devi et al. (2009) was 46.6 $\mu g m^{-3}$, which lies within the range of this study. The difference between the mean $PM_{2.5}$ mass exposures among the seasons for the subjects was not statistically significant as seen from the results of paired *t*-test. The fine PM mass emitted from

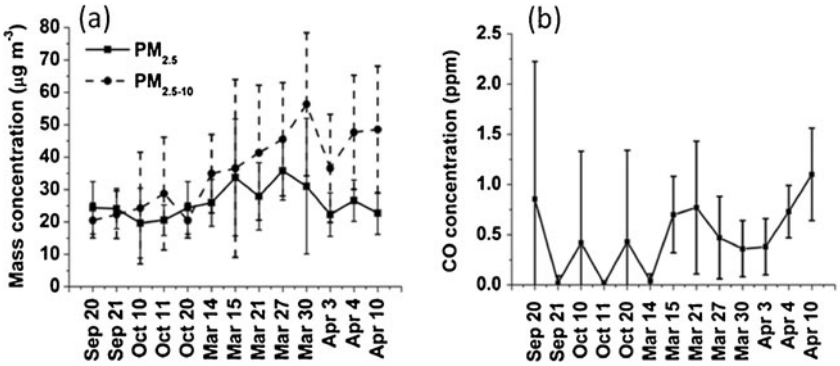


Fig. 4 Ambient PM mass concentration and CO concentration for post-monsoon (September 20–October 20) and pre-monsoon (March 14–April 10)

indoor sources like combustion, photocopier, printers, and chalk powder, remained similar irrespective of season in case of poor ventilation (Brown 1999; He et al. 2007; Majumdar and William 2009). However, $PM_{2.5}$ mean number concentrations show statistically significant difference (p= 0.024) for the two seasons with higher mean concentrations in PoM. Most of the subjects spent a significant amount of their time in canteen and MT in PoM where combustion activities were predominant leading to an increase in the fine particle exposure. Owing to their small sizes, these particles contribute significantly to number concentrations, but they barely contribute to mass concentrations. Similarly, very high temperatures lead to dry conditions during PreM and increase the resuspension of coarse soil particles which add upon

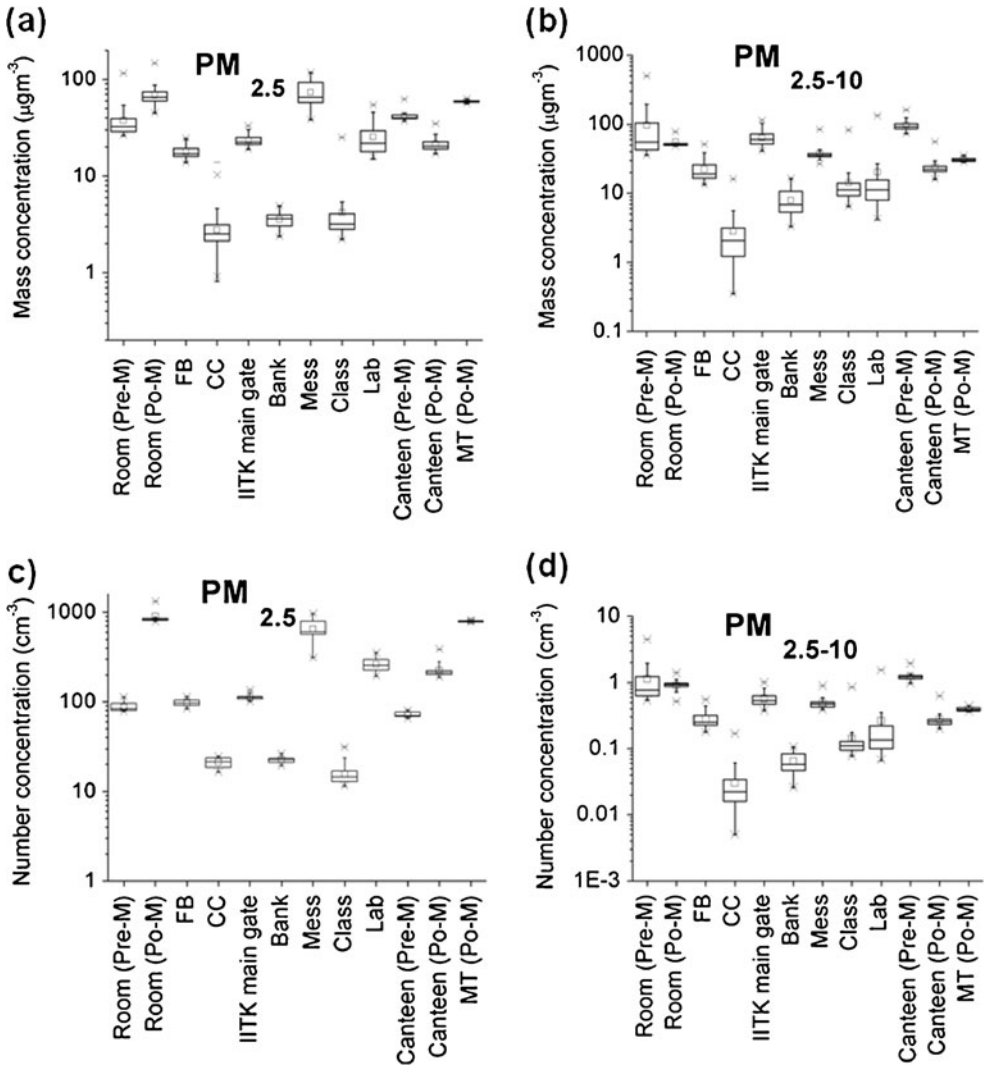


Fig. 5 Box plot of mass concentrations and number concentrations of $PM_{2.5}$ and $PM_{2.5–10}$ within different microenvironments

the anthropogenic emissions. This explains the significant differences in the mean exposures of PreM and PoM for the particulate mass.

The PM mass concentrations showed large variability within subjects during both the seasons. Also, marginal seasonal differences in PM mass concentrations were observed as expected (Chakraborty and Gupta 2010). The time–activity diary shows that the maximum time a person spends in a given microenvironment decides the average personal exposure to a specific pollutant. The instantaneous high exposure for a couple of minutes during activities like dusting, at traffic junctions, etc., slightly increases the average personal exposure values. However, as the time spent in similar microenvironments and activities increases, the average personal exposure values considerably goes up.

Comparison of measured personal exposure and estimated integrated exposure to PM and gaseous co-pollutants

Personal exposure to a pollutant in a microenvironment will depend on the proximity of the person to the sources in addition to the factors discussed above. Once the pollutant concentrations in the microenvironment were measured considering the above factors, the personal exposure measured may be closer to the estimated integrated exposure. Transit environments like roads and corridors were not considered during the analysis. The traffic in these roads could be compared to rural roads. The students spend only 5 % of their time on these roads. Moreover, vehicles pass once in a while during non-peak hours (peak hours are 8:30–9:30 AM and 5:00–6:00 PM). So the variations in PM and CO concentrations are very high. For instance, the PM_{10} concentration on the road during PoM for subjects was 26.2±36.7 $\mu g m^{-3}$ and CO concentration was 449±1,499 ppb. Considering the insignificant amount of time spent by students on roads and high variations in pollutant concentrations, we ignored the time spent on roads for estimation of integrated exposure.

Although personal exposure measurements using personal monitors/samplers give accurate results, the method demands ample time and cost. In this section, we estimate the integrated exposure for each subject using microenvironment concentration data measured from 2009 to 2010 for both the seasons and compare the average personal exposure values for each pollutant. It should be noted that microenvironment measurements were carried out during the study period/season but not simultaneously with personal exposures measurements.

Number and mass concentrations of $PM_{2.5}$ (fine fraction), $PM_{2.5–10}$ (coarse fraction) and PM_{10} (inhalable fraction) were measured using OPC in different microenvironments

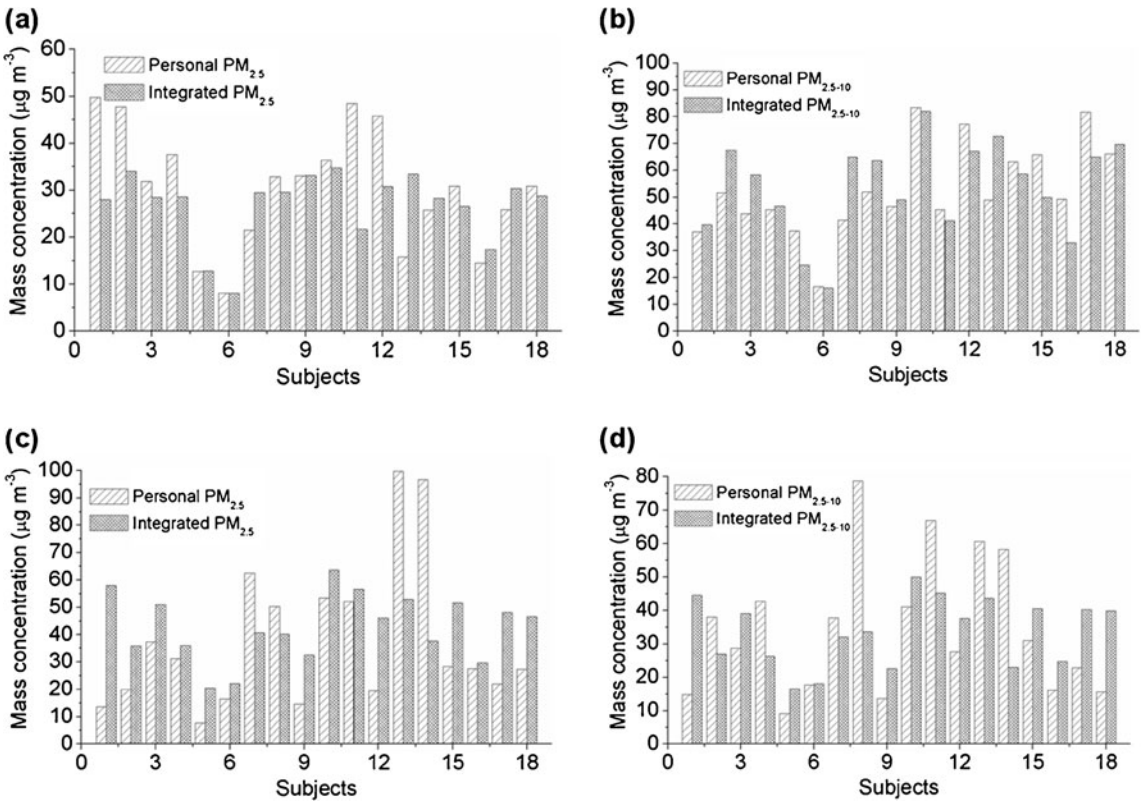


Fig. 6 **a**, **b** Personal and integrated particulate matter mass concentrations of $PM_{2.5}$ and $PM_{2.5–10}$ for individual subjects for the pre-monsoon season; **c**, **d** the same properties for the post-monsoon season

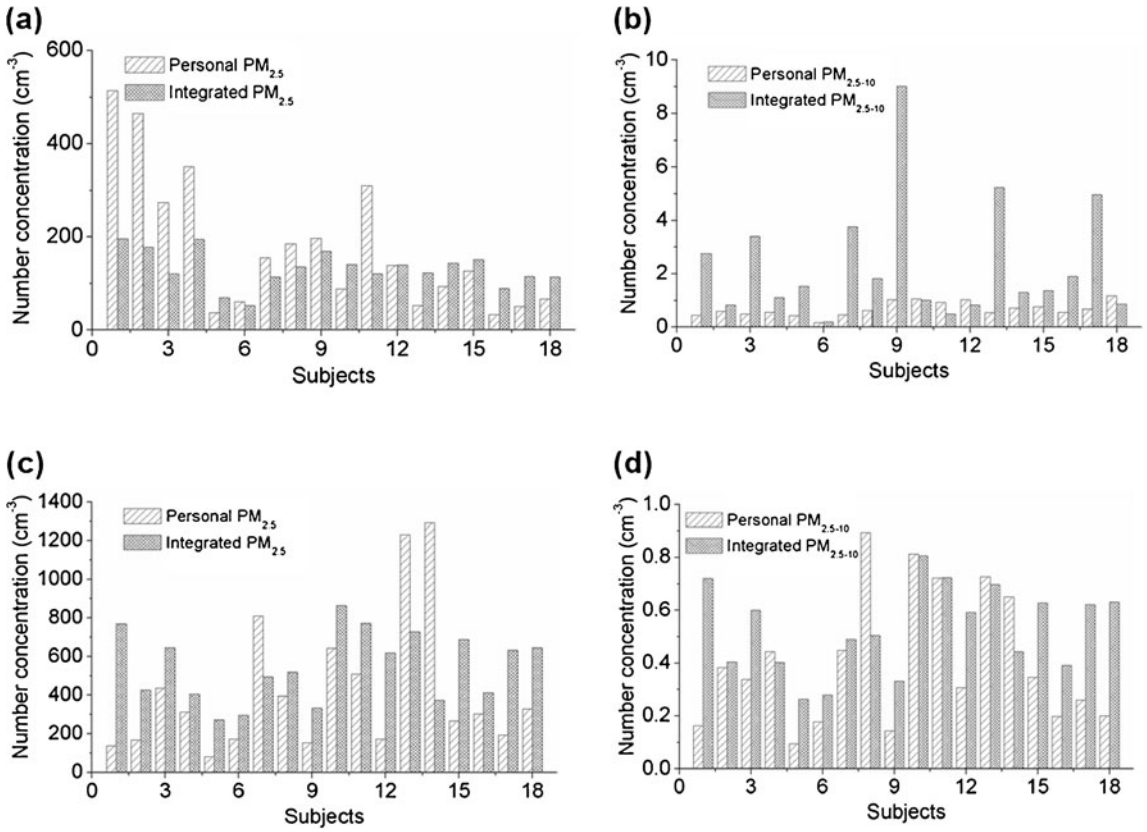


Fig. 7 **a**, **c** Personal and integrated particulate matter number concentrations of $PM_{2.5}$ and $PM_{2.5–10}$ for individual subjects during the pre-monsoon season; **b**, **d** the same properties during the post-monsoon season

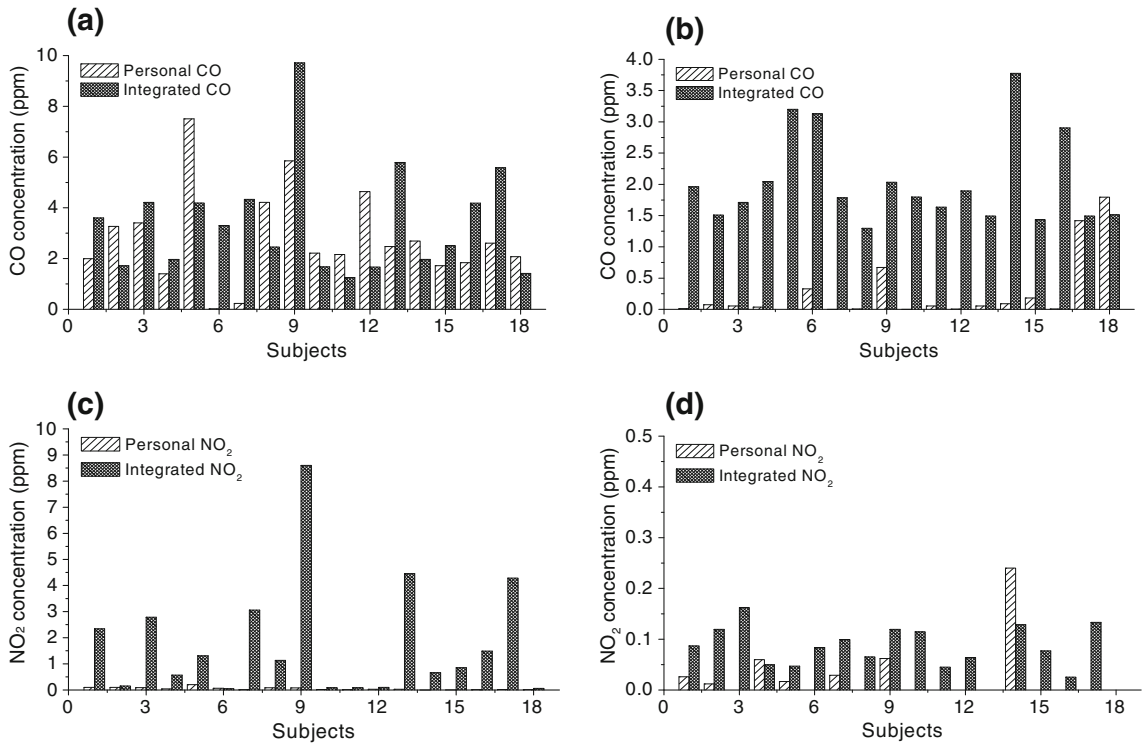


Fig. 8 **a**, **c** Personal and integrated concentrations of CO and NO_2 in individual subjects for the pre-monsoon season, and **b**, **d** the same properties for the post-monsoon season

Table 3 Statistical comparison of measured personal exposure to estimated integrated exposure for particulate matter and gaseous co-pollutants during different seasons

Pollutant	Season	Measured personal exposure	Estimated integrated exposure	*p* value
$PM_{2.5M}$	PreM	30.5±12.7 μgm^{-3}	36.72±9.72 μgm^{-3}	0.052
	PoM	37.8±26.8 μgm^{-3}	37±9.63 μgm^{-3}	0.89
$PM_{2.5–10M}$	PreM	52.9±17.2 μgm^{-3}	56.5±18.5 μgm^{-3}	0.28
	PoM	34.5±20.4 μgm^{-3}	26.6±8.6 μgm^{-3}	0.09
PM_{10M}	PreM	83.4±24.3 μgm^{-3}	89.7±27.6 μgm^{-3}	0.21
	PoM	72.3±44.1 μgm^{-3}	90.8±30.9 μgm^{-3}	0.11
$PM_{2.5N}$	PreM	177.7±147.4	131.6±38.7	0.13
	PoM	422.8±359.3	550±181.4	0.16
$PM_{2.5–10N}$	PreM	0.68±0.26	2.35±2.23	0.01
	PoM	0.41±0.25	0.53±0.16	0.03
CO	PreM	2.79±1.84 ppm	3.42±2.12 ppm	0.27
	PoM	0.26±0.52 ppm	2.03±0.72 ppm	0.00
NO_2	PreM	0.05±0.05 ppm	1.78±2.22 ppm	0.00
	PoM	0.02±0.01 ppm	0.08±0.05 ppm	0.00

during the measurement seasons (Fig. 5). One-hour measurement with 1-min resolution was carried out in each microenvironment as explained by Devi et al. (2009).

The integrated exposures estimated were tested for significance of difference of means using paired *t*-test at 95 % confidence level with personal exposure data. Figures 6 and 7 shows the comparison of personal and integrated exposure to PM in terms of mass and number concentrations and Fig. 8 shows the comparison of personal and integrated exposure to gaseous co-pollutants. The statistical comparison of personal and integrated exposure using paired *t*-test is given in Table 3. The personal exposure for PM mass concentrations measured by a subject showed a much better match to the integrated exposure for PM during PreM season than PoM season although data during both the seasons shows no significant change between the means in paired *t*-test. On the contrary, integrated exposure did not compare well with the personal exposure results for gases as the former was estimated primarily for indoor microenvironment concentrations, gases like CO and NO_2 were emitted mainly from tailpipes of vehicles which were not extensively considered for our integrated and personal exposure comparison study (Han and Naeher 2006; Patel et al. 2010). The strength of vehicle exhausts as a source varies greatly depending on the number of vehicles and proximity to the road. This can be easily ascertained in a traffic junction but inside the institute premises, this data was highly uncertain.

Effect of personal exposure on respiratory health of cohort

FEV_1 and absolute FEV_1/FVC values during both the seasons were normal for all subjects as shown in Table 4 but FVC values showed slightly restricted ventilatory impairment on two subjects during PreM and on four subjects during PoM. Reduction in lung parameters with increased particulate exposure has also been identified in the past studies (Penttinen et al. 2001). The inter-seasonal variability shows significant difference between the means of FVC (p=0.018) and FEV_1 (p=0.002) having lower values during the PreM than PoM, but the mean peal expiratory flow rate (PEFR) for the cohort showed no significant difference (p=0.659) between the seasons (Table 4). During the PoM season, the exposure to fine fraction ($PM_{2.5}$) was higher than coarse fraction as subjects spent considerable time in MT and canteens in addition to mess and during transit on roads. However, this was not explicitly seen from the lung parameters during PoM as they were higher than the PreM.

Low FVC and FEV_1 values during PreM can be attributed to significantly high personal exposure to coarse fraction particles during the PreM (p=0.006) as is also seen from the high concentration of ambient coarse fraction in PM

Table 4 Summary statistics of lung parameters for the panel for pre-monsoon and post-monsoon seasons

Parameters	FEV_1	FVC	PEFR
Mean ± SD (pre-monsoon)	3.41±0.52	3.15±0.46	7.92±1.46
Mean ± SD (post-monsoon)	3.54±0.56	3.28±0.48	7.82±1.19
p value	0.018	0.002	0.659
t-Test for difference of pre-monsoon and post-monsoon mean	Statistically significant	Statistically significant	Statistically not significant

(Fig. 4a). Although the fine particle exposure was found to be higher during PoM owing to the activities of subjects, the effect was not seen on lungs. This is because the effects of fine particles can also be chronic. Recent studies on 14 subjects found association of high concentrations of fine particles with reductions in FVC and FEV_1, and no significant association was observed for coarse particle fraction (Graff et al. 2009). A few other studies have showed that coarse mode particles can cause adverse effects on lungs leading to hospital admissions (Burnett et al. 1997; Anderson et al. 2001; Brunekreef and Forsberg 2005). Toxicology of coarse particles, which varies regionally and seasonally, plays a vital role in causing inflammation of lungs by producing lung macrophages (Becker et al. 2003) which could have led to lower lung parameters in PreM than PoM. The seasonal changes may also include bio-aerosols like bacteria and pollen, which were not measured in this study. During the PreM, desert dust get transported from deserts in northwest of India and mixes with local anthropogenic aerosols (Chinnam et al. 2006; Dey et al. 2004). These mineral-rich dust could have affected the FVC values for the young adults in this cohort (Green et al. 2008).

Conclusions

Two distinct methods for exposure measurements were employed in this study for a panel of 22 students representing the student community of IIT Kanpur. The study was carried out for two distinct seasons: PreM and PoM, and altogether 432 h of person exposure data were analyzed. The subjects of the panel spend their time in the same microenvironments, but large differences in personal exposures were found due to differences in the time durations they spend in each microenvironment which varied greatly.

The time and effort involved with a typical personal exposure monitoring technique are much higher compared to the integrated exposure stationary monitoring; the two methods were compared using statistical methods. Our results suggest that integrated stationary monitoring in different microenvironments and time–activity data of individual subjects agree well with the personal exposure values for PM with no statistically significant difference but showed significant differences for co-pollutant gases (CO and NO_2). Thus, the estimation of exposures for sub-groups of populations becomes quicker and cost-effective for PM.

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References

Abbey DE, Nishino N, McDonnell WF, Burchette RJ, Knutsen SF, Lawrence BW, Yang JX (1999) Long-term Iinhalable particles and other air pollutants related to mortality in nonsmokers. Am J Respir Crit Care Med 159(2):373–382

Ackermann-Liebrich U, Dietrich DF, Gemperli A, Liu LS, Schindler C, Gaspoz J et al (2007) Long-term effect of no_2 exposure on heart rate variability: results of the sapaldia study. Epidemiology 18(5): S134–S135

Anderson HR et al (2001) Particulate matter and daily mortality and hospital admissions in the west midlands conurbation of the United Kingdom: associations with fine and coarse particles, black smoke and sulphate. Occup Environ Med 58:504–510

Apte JS, Kirchstetter TW, Reich AH, Deshpande SJ, Kaushik G, Chel A, Marshall JD, Nazaroff WW (2011) Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India. Atmos Environ 45(26):4470–4480

Arif A, Shah S (2007) Association between personal exposure to volatile organic compounds and asthma among US adult population. Int Arch Occup Environ Health 80(8):711–719

Becker S et al (2003) Response of human alveolar macrophages to ultrafine, fine, and coarse urban air pollution particles. Exp Lung Res 29:29–44

Beckx C, Int Panis L, Arentze T, Janssens D, Torfs R, Broekx S, Wets G (2009) A dynamic activity-based population modelling approach to evaluate exposure to air pollution: methods and application to a Dutch urban area. Environ Impact Assess Rev 29 (3):179–185

Brown SK (1999) Assessment of pollutant emissions from dry-process photocopiers. Indoor Air Int J Indoor Air Qual Clim 9(4):259–267

Brown DM, Wilson MR, MacNee W, Stone V, Donaldson K (2001) Size-dependent proinflammatory effects of ultrafine polystyrene particles: a role for surface area and oxidative stress in the enhanced activity of ultrafines. Toxicol Appl Pharmacol 175(3):191–199

Brunekreef B, Forsberg B (2005) Epidemiological evidence of effects of coarse airborne particles on health. Eur Respir J 26:309–318

Burnett RT, Cakmak S, Brook JR, Krewski D. (1997) The role of particulate size and chemistry in the association between summertime ambient air pollution and hospitalization for cardiorespiratory diseases. Environ Health Persp 105:614–620

Chakraborty A, Gupta T (2010) Chemical characterization and source apportionment of submicron (PM(1)) aerosol in Kanpur Region, India. Aerosol Air Qual Res 10(5):433–445

Chen LH, Knutsen SF, Shavlik D, Beeson WL, Petersen F, Ghamsary M, Abbey D (2005) The association between fatal coronary heart disease and ambient particulate air pollution: are females at greater risk? Environ Heal Perspect 113(12):1723–1729

Chinnam N et al (2006) Dust events in Kanpur, northern India: chemical evidence for source and implications to radiative forcing. Geophys Res Lett 33

Clayton CA, Perritt RL, Pellizzari ED, Thomas KW, Whitmore RW, Wallace LA, Ozkaynak H, Spengler JD (1993) Particle Total Exposure Assessment Methodology (PTEAM) study: distributions of aerosol and elemental concentrations in personal, indoor, and outdoor air samples in a southern California community. J Expo Anal Environ Epidemiol 3(2):227–250

Devi JJ, Gupta T, Tripathi SN, Ujinwal KK (2009) Assessment of personal exposure to inhalable indoor and outdoor particulate matter for student residents of an academic campus (IIT-Kanpur). Inhal Toxicol 21(14):1208–1222

Dey S et al (2004) Influence of dust storms on the aerosol optical properties over the Indo-Gangetic basin. J Geophys Res-Atmos 109

Dhondt S, Beckx C, Degraeuwe B, Lefebvre W, Kochan B, Bellemans T, Int Panis L, Macharis C, Putman K (2012) Health impact

assessment of air pollution using a dynamic exposure profile: implications for exposure and health impact estimates. Environ Impact Assess Rev 36:42–51

Dockery D, Pope A, Xu X, Spengler J, Ware J, Fay M, Ferris B, Speizer F (1993) An association between air pollution and mortality in six U.S. cities. N Eng J Med 329(24):1753–1759

Donaldson K, Brown D, Clouter A, Duffin R, MacNee W, Renwick L, Tran L, Stone V (2002) The pulmonary toxicology of ultrafine particles. J Aerosol Med 15(2):213–220

Dons E, Int Panis L, Van Poppel M, Theunis J, Willems H, Torfs R, Wets G (2011) Impact of time–activity patterns on personal exposure to black carbon. Atmos Environ 45(21):3594–3602

Ebelt ST, Fisher TV, Petkau AJ, Vedal S, Brauer M (2000) Exposure of chronic obstructive pulmonary disease (COPD) patients to particles: relationship between personal exposure and ambient air concentrations. J Air Waste Manag Assoc 50:174–187

Englert N (2004) Fine particles and human health—a review of epidemiological studies. Toxicol Lett 149(1–3):235–242

Ferro AR, Kopperud RJ, Hildemann LM (2004) Elevated personal exposure to particulate matter from human activities in a residence. J Expo Anal Environ Epidemiol 14(Suppl 1):S34–S40

Filleul L, Rondeau V, Vandentorren S, Le Moual N, Cantagrel A, Annesi-Maesano I, Charpin D, Declercq C, Neukirch F, Paris C (2005) Twenty five year mortality and air pollution: results from the French PAARC survey. Occ Environ Med 62(7):453–460

Graff DW, Cascio WE, Rappold A, Zhou H, Huang Y-CT, Devlin RB (2009) Exposure to concentrated coarse air pollution particles causes mild cardiopulmonary effects in healthy young adults. Environ Health Persp 117:1089–1094

Green DA et al (2008) Mineral dust exposure in young Indian adults: an effect on lung growth? Occup Environ Med 65:306–310

Gupta T, Kothari A, Srivastava DK, Agarwal AK (2010) Measurement of number and size distribution of particles emitted from a mid-sized transportation multipoint port fuel injection gasoline engine. Fuel 89(9):2230–2233

Hameri K, Koponen IK, Aalto PP, Kulmala M (2002) The particle detection efficiency of the TSI-3007 condensation particle counter. J Aerosol Sci 33(10):1463–1469

Han XL, Naeher LP (2006) A review of traffic-related air pollution exposure assessment studies in the developing world. Environ Int 32(1):106–120

Harrison RM, Yin J (2000) Particulate matter in the atmosphere: which particle properties are important for its effects on health? Sci Total Environ 249(1–3):85–101

He C, Morawska L, Taplin L (2007) Particle emission characteristics of office printers. Environ Sci Technol 41(17):6039–6045

Hesterberg TW, Lapin CA, Bunn WB (2008) A comparison of emissions from vehicles fueled with diesel or compressed natural gas. Environ Sci Technol 42(17):6437–6445

Janssen NAH, Hartog JJ, Hoek G, Brunekreef B, Lanki T, Timonen KL, Pekkanen J (2000) Personal exposure to fine particulate matter in elderly subjects: relation between personal, indoor, and outdoor concentrations. Air Waste 50:1133–1143

Jerrett M, Burnett R, Ma R, Pope C, Krewski D, Newbold K, Thurston G, Shi Y, Finkelstein N, Calle E (2005) Spatial analysis of air pollution and mortality in Los Angeles. Epidemiology 16(6):727–736

Kandpal JB, Maheshwari RC, Kandpal TC (1995) Indoor air pollution from domestic cookstoves using coal, kerosene and LPG. Energy Convers Manag 36(11):1067–1072

Klepeis NE, Nelson WC, Ott WR, Robinson JP, Tsang AM, Switzer P, Behar JV, Hern SC, Engelmann WH (2001) The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J Expo Anal Environ Epidemiol 11(3):231–252

Künzli N, Medina S, Kaiser R, Quénel P, Horak F, Studnicka M (2001) Assessment of deaths attributable to air Pollution: should we use risk estimates based on time series or on cohort studies? Am J Epidemiol 153(11):1050–1055

Lioy PJ (1995) Measurement methods for human exposure analysis. Environ Heal Perspect 103(Suppl 3):35–43

Long CM, Suh HH, Koutrakis P (2000) Characterization of indoor particle sources using continuous mass and size monitors. J Air Waste Manag Assoc 50(7):1236–1250

Majumdar D, William S (2009) Chalk dustfall during classroom teaching: particle size distribution and morphological characteristics. Environ Monit Assess 148(1–4):343–351

Martin LW (1995) Monitoring of exposure to air pollution. Sci Total Environ 168(2):169–174

McDonnell WF, Nishino-Ishikawa N, Petersen FF, Chen LH, Abbey DE (2000) Relationships of mortality with the fine and coarse fractions of long-term ambient PM_{10} concentrations in nonsmokers. 10(5): 427–436.

Monn C (2001) Exposure assessment of air pollutants: a review on spatial heterogeneity and indoor/outdoor/personal exposure to suspended particulate matter, nitrogen dioxide and ozone. Atmos Environ 35(1):1–32

Muleski GE, Cowherd C, Kinsey JS (2005) Particulate emissions from construction activities. J Air Waste Manag Assoc 55(6):772–783

Nafstad P, Håheim LL, Wisløff T, Gram F, Oftedal B, Holme I, Hjermann I, Leren P (2004) Urban air pollution and mortality in a cohort of Norwegian men. Environ Health Perspect 112(5)

Ott WR (1982) Concepts of human exposure to air pollution. Environ Int 7(3):179–196

Patel MM, Chillrud SN, Correa JC, Hazi Y, Feinberg M, Deepti KC, Prakash S, Ross JM, Levy D, Kinney PL (2010) Traffic-related particulate matter and acute respiratory symptoms among New York City area adolescents. Environ Heal Perspect 118(9):1338–1343

Penttinen P, Timonen KL, Tiittanen P, Mirme A, Ruuskanen J, Pekkanen J (2001) Number concentration and size of particles in urban air: effects on spirometric lung function in adult asthmatic subjects. Environ Health Persp 109:319–323

Pitz M, Cyrys J, Karg E, Wiedensohler A, Wichmann HE, Heinrich J (2003) Variability of apparent particle density of an urban aerosol. Environ Sci Technol 37(19):4336–4342

Pope C 3rd, Thun M, Namboodiri M, Dockery D, Evans J, Speizer F, Heath C Jr (1995) Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am J Respir Crit Care Med 151(3):669–674

Pope C, Burnett R, Thun M, Calle E, Krewski D, Ito K, Thurston G (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287(9):1132–1141

Pope C, Burnett R, Thurston G, Thun M, Calle E, Krewski D, Godleski J (2004) Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. Circulation 109:71–77

Raymer JH et al (2009) Microenvironmental characteristics important for personal exposures to aldehydes in Sacramento, CA, and Milwaukee, WI. Atmos Environ 43:3910–3917

Rojas-Bracho L, Alba N, Suh H, Koutrakis P, Oyola P (1999) Characterization of personal exposures to oxidant and particulate air pollution in Santiago. Epidemiology 10(4):68

Roy AA, Baxla SP, Gupta T, Bandyopadhyaya R, Tripathi SN (2009) Particles emitted from indoor combustion sources: size distribution measurement and chemical analysis. Inhal Toxicol 21 (10):837–848

Samoli E, Aga E, Touloumi G, Nisiotis K, Forsberg B, Lefranc A, Pekkanen J, Wojtyniak B, Schindler C, Niciu E, Brunstein R, Dodič Fikfak M, Schwartz J, Katsouyanni K (2006) Short-term effects of nitrogen dioxide on mortality: an analysis within the APHEA project. Eur Respir J 27(6):1129–1138

Spengler JD, Sexton K (1983) Indoor air pollution—a public health perspective. Science 221(4605):9–17

Tripathi SN, Tare V, Chinnam N, Srivastava AK, Dey S, Agarwal A, Kishore S, Lal RB, Manar M, Kanwade VP, Chauhan SSS, Sharma M, Reddy RR, Gopal KR, Narasimhulu K, Reddy LSS, Gupta S, Lal S (2006) Measurements of atmospheric parameters during Indian Space Research Organization Geosphere Biosphere Programme Land Campaign II at a typical location in the Ganga basin: 1. Physical and optical properties. J Geophys Res Atmos 111(D23)

Valavanidis A, Fiotakis K, Vlachogianni T (2008) Airborne particulate matter and human health: toxicological assessment and importance of size and composition of particles for oxidative damage an.d carcinogenic mechanisms. J Environ Sci Health C Environ Carcinog Ecotoxicol Rev 26(4):339–362

Zhu X, Ma F, Luan H, Wu D, Wang T (2010) Evaluation and comparison of measurement methods for personal exposure to fine particles in Beijing, China. Bull Environ Contam Toxicol 84(1):29–33