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Assessment of personal exposure to inhalable indoor and outdoor particulate matter for student residents of an academic campus (IIT-Kanpur)

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Abstract

Human exposure to particulate matter can have significant harmful effects on the respiratory and cardiovascular system. These effects vary with number, size, and chemical composition of particulate matter, which vary significantly with space and time. The Indian Institute of Technology–Kanpur (IITK), Kanpur, India, is a relatively clean academic campus in the northwest of a heavily polluted city, Kanpur. The major objectives of the study were to evaluate total exposure of fine and coarse fractions of PM_{10} to a typical IITK student resident in different indoor microenvironments within the campus; to evaluate personal exposure to student residents during outdoor trips; and to evaluate personal exposure to a typical student resident carrying out routine activities. In order to account for all the sources of particulate matter exposure, measurements on several different days during the pre-monsoon season were carried out in the most common indoor microenvironments in the campus and during outdoor trips outside the campus. A 15-channel optical particle counter (model 1.108, GRIMM) was used to measure continuous real-time particle size distribution from 0.3 to 20 µm diameter. Using this instrument, exposure for 1 h at different indoor microenvironments was determined. Both the effects of location and activity, which, in turn, account for specific indoor sources and number of occupants, respectively, were carefully evaluated. Re-suspension of particles due to movement of people was found to be a major source of coarse particulate matter exposure. On the other hand, combustion sources led to elevated fine particulate levels. Chalk dust was found to be the major source of fine particulate matter in classrooms. Similar results on other sources of particulate matter are discussed in the paper. To assess the personal average size resolved particulate exposure on a student making a day trip outside the campus, study trips to most common public places in the city in a commonly preferred vehicle were made. Striking correlations between sources/activities and increase in fine and/or coarse particle concentration were clearly visible. To investigate the daily personal exposure and its relation to the activities of a typical student residing in the campus, a 24-h exposure study was done on a student who maintained a time-activity diary. The results provide insight into possible sources and their interaction with human activities in modifying the human exposure levels. A comparison between different microenvironments has been attempted for the first time in an Indian scenario using a real-time aerosol measuring instrument.

Keywords: *Academic campus; health effects; indoor air; personal exposure; PM10; real-time measurement*

Introduction

Studies show that high levels of airborne particulate exposure lead to heart and lung diseases and even lower life expectancy (Koenig 1999; Dockery et al. 1993). These ill effects depend on size, number, and chemical composition of respirable particles, which are highly variable with different sources and anthropogenic activities. Thus, it becomes essential to know the size distribution of particles present in the microenvironment so as to relate it to possible health risks to the occupants.

The outdoor environments carry all sizes of particulates ranging from ultrafine to coarse arising from different sources like vehicular traffic, road dust resuspension, dust storm, long-range transport, etc. The indoors predominantly have ultrafine and fine particles, mainly coming from the combustion sources like cooking and smoking. Some studies indicate that people suffer more from the effects of indoor air pollution than that from outdoor air pollution, mainly due to two reasons: First, the indoor air pollutant levels are higher than outdoor levels; second, most people spend 80–90% of their time

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in indoor environments (Splengler and Sexton 1983; Clayton et al. 1993). Past studies (Lofroth, Stensman and Brandhorst-Satzkorn 1991) have also related particulate levels to activities like cooking, cleaning, incense burning, etc.

Air pollution in general and particulate matter (PM) in particular have been shown to be associated with decrements in respiratory functions (Vedal et al. 1998). These studies often utilize only central monitoring site data, where the instrument is kept in a central location in the microenvironment. This does not accurately reflect the personal exposure to air pollutants as it does not consider the proximity of the individual to the source of pollutants and assumes uniform concentration at the monitoring site. There is also a lack of detailed information on indoor air pollution exposures. This has led to a number of air pollution studies (Monn et al. 1997; Rojas-Bracho et al. 2000; Sarnat et al. 2000; Andersen et al. 2005) primarily initiated to assess the relationship between outdoor, indoor and personal exposures. These studies suggest indoor and outdoor concentrations to be a poor representative of personal exposure.

Few studies from Indian origin (Kulkarni and Patil 1998, 1999, 2003; Kulkarni 2006; Saksena et al. 2007) indicate that the estimation of personal exposure of air pollutants to population is more relevant than the stationary ambient monitoring. Specifically, these studies have employed cyclones and passive badges to measure integrated personal exposure to PM, CO, and NO_x in urban settings. In addition, various indoor studies (Smith 2000; Balakrishnan et al. 2002; Andersen et al. 2005) have been carried out to assess the personal exposure of women to pollutants emitted from cooking activities and combustion of related fuels (Varghese et al. 2005). However, none of the Indian studies so far have used real-time instruments to measure personal exposure.

The human exposure to air pollutants is a function of space, time, and activity that a person is involved in (Ott 1982) and their vicinity to the source of pollutants. The simplest approach for estimating exposures is to measure pollutant concentrations in different microenvironments and then use time–activity diaries to estimate the contribution of each microenvironment to the integrated personal exposure as shown in Figure 1. The study assumes uniform concentration of particulate matter in each microenvironment. Efforts have been made to determine the human exposure to fine and coarse fractions of inhalable (PM_{10}) particulate pollutants in different indoor and outdoor microenvironments within IITK campus. Real-time size distribution measurements were made at different indoor microenvironments using an optical particle counter (OPC) (Grimm model 1.108). The OPC is a portable instrument that operates at a flow rate of 1.2 LPM (L/min) and sample resolution of 1 min average; it gives real-time concentration of aerosol particles in the size range 0.3–20 μm in 15 size bins. A detailed working principle of the instrument is given in Tripathi et al. (2006). The instrument is not operated in environments where relative humidity exceeds 75% and temperature lies outside 4-45˚C range, as its optical parts can get damaged. As a part of the study, the personal exposure was measured in terms of particle

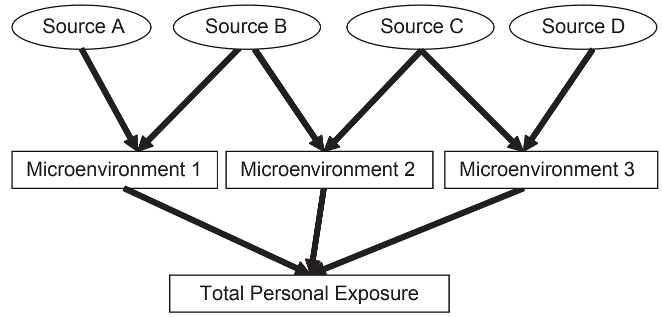

Figure 1. Schematic diagram to quantify integrated personal exposure. Particulate exposure in any microenvironment is affected by nearby sources. The time spent in each microenvironment, if known, can be used to quantify the total personal exposure.

number concentrations in different size bins during transit from IITK to the four most common public places (railway station, an open marketplace, a movie hall, and a shopping complex) outside the IITK campus. To find the average personal exposure for a typical student, PM measurements were carried out for 24-h period within the campus during two seasons (pre-monsoon and winter) on a total of 4 days by different subjects. The students (subjects) carried the OPC with its sampling inlet kept near the breathing zone during the entire study period while keeping a record of the time–location–activity to study the relationship among them. It is assumed that the sources affecting the average personal exposure to particulate matter for students following routine activities would not vary considerably during the different seasons unless a dust storm, rain, or any similar unforeseen event occurs that highly increases/decreases the ambient concentrations of particulate matter.

Method

Exposure to pollutant is defined as the event when a person comes in contact with the pollutant at a particular instant of time (Ott 1982). Thus, in measurement of human exposure, the person is treated as a receptor of environmental pollutants. The principles involved in assessing the exposure were:

- To measure the pollutant concentrations in the different microenvironments.
- To record the time–location–activity data of the participant carrying the instrument during the complete study period with inlet near breathing zone.

Site location

The IITK campus (26.43 °N, 80.33 °E) is located in the industrial city of Kanpur toward the northwest and mostly upwind side of Kanpur and is 142 m above mean sea level. It is about 17 km away from the railway station on the Grand Trunk road. It is worth mentioning that the campus has a much cleaner and greener environment compared to the rest of the Kanpur city. The study was conducted in and around the IITK premises.

Monitoring exposure in indoor and outdoor environments

Monitoring for particulate matter exposure was conducted for a 1-h period in each indoor microenvironment. In the hostel dining area and television (TV) room, particulate matter measurements were done during peak and lean hours of human activities to study the relationship between different activities and corresponding particulate matter emissions in different size range. Similar monitoring was done in classrooms, a campus restaurant, and a photocopier shop. Monitoring was not done in canteens because most of the canteens are in an open area where the exposure will be similar to that of the ambient environment. The OPC was placed at a height near the breathing zone in these microenvironments for continuous monitoring of particulate matter. The data below 10 µm diameter (i.e., PM_{10}) were used for the study, as this range comprises the inhalable particles. To ease the analysis, the particles were subdivided into two size modes: fine (0.3–2.5 µm) and coarse (2.5–10 µm) fractions of PM_{10}. The arithmetic mean sizes of the size bins of the OPC were taken to divide the particles into different modes. By assuming a spherical shape and particle density of 1.4 $g cm^{-3}$ (Pitz et al. 2003) for all the particles, the number concentration of particles (L^{-1}) was converted into mass concentration ($\mu g\, m^{-3}$) for further analysis. It should be kept in mind that since the fine particles are very small, even a large increase in their number concentration will cause a little increase in their mass concentration.

Monitoring exposure during trips

The particulate matter exposure to students going outside the campus was studied by making different trips to various commonly visited places by them. The most frequently used public transport vehicle by students (six-seater auto rickshaws) was chosen for the exposure study during these trips. These trips were typically 4–5 h long, made during peak travel hours of the students, such as in early afternoon to evening hours of the day. Continuous exposure measurements were taken while traveling in these vehicles and at commonly traveled places such as movie halls, shopping malls, railway stations, and open marketplaces. The time–location data along with any nearby activity such as building construction, vehicle exhaust, etc. influencing the particle concentrations during trips were recorded.

Twenty-four-hour personal exposure study

To assess the average personal exposure of a student carrying out routine activities, 24-h monitoring studies were carried out on different students of IITK campus during different seasons. All the students of IITK reside inside the campus in hostels. The hostels are quite near to each other and have similar facilities. Thus, it can be safely assumed that most of the students have similar routine activities. The 24-h personal exposure monitoring study was done by a typical student who carried along an OPC during the complete study period with the inlet near the breathing zone. During the study period, student noted down time–location–activity to determine the exposure for that person at different locations like dinning hall, classroom, computer lab, etc., and during different routine activities such as dusting of room, transit from hostel to academic area (classroom), etc. The study is applicable to nonsmoker student residents living on the campus.

Results

Indoor micro-environmental sampling

The study was done during the pre-monsoon season. The particulate sampling was carried out in different microenvironments such as in hostel dining hall, photocopier shop, etc. for 1 h where most of the windows remain closed. Monitoring in the classroom was done for three different days in the same week to account for exposure due to different sizes of classrooms. The temperature and relative humidity (RH) during the sampling days were 28 ± 1.6°C and 31 ± 3.3%, respectively. Thus, there were negligible variations in the meteorological conditions for the different days on which these measurements were carried out.

Hostel dining hall

All students have meals in their respective hostel dining halls, which are of similar size and can accommodate roughly same number of students during meals. The dining hall serves meals three times a day: 0730–0930 h for breakfast; 1230–1400 h for lunch; and 1930–2100 h IST for dinner. Measurement for particulate matter exposure was carried out for 1-h duration with 6-s time resolutions during the periods of maximum activity (lunchtime) and no activity (empty) between lunch and dinner to account for the variation in the exposure due to activity. The instrument was kept on the dining table so that the exposure near the breathing zone can be quantified. The kitchen is adjacent to the dining area and is connected with it through a door and a service window. Most of the windows in the dining hall remain closed all the time. There is no carpet in the dining hall and its floor is cemented. Figure 2a shows the average particle number distribution of 1 h for active (80–100 students) and non-active (empty) conditions and provides good insight into the effect of activity on aerosol concentration and size distribution. The variations in the particle number/mass concentrations in different size ranges during the study period are shown with errors bars of one standard deviation (±1 σ). The number distribution for both active and non-active (empty) conditions, shown in Figure 2a, is stable, as the variation in all sizes is always less than 10% of the average number concentration. A considerable increase in the number concentration of particles in coarse mode is observed during the active period. It is interesting to see that the number concentration for particles less than 500 nm is actually higher in the non-active period than in the active period of the dining hall. Such an increase in the number concentration of the fine particles, which was monitored 2 h prior to serving of meals, was due to cooking activity in the adjacent kitchen. In the active dining hall, the mass distribution in the coarser particle range shows considerable variations (Figure 3a), which indicates that the coarse particle mass concentrations vary widely with human activity/movement that led to resuspension of particles.

Hostel television (TV) room

With increasing ease of access of computers and Internet to students, it was noted that students started reducing their time watching TV. Still, considerable numbers of students watch TV in the evenings. Exposure assessment was carried out in the TV room for 1 h each in empty (non-active) and

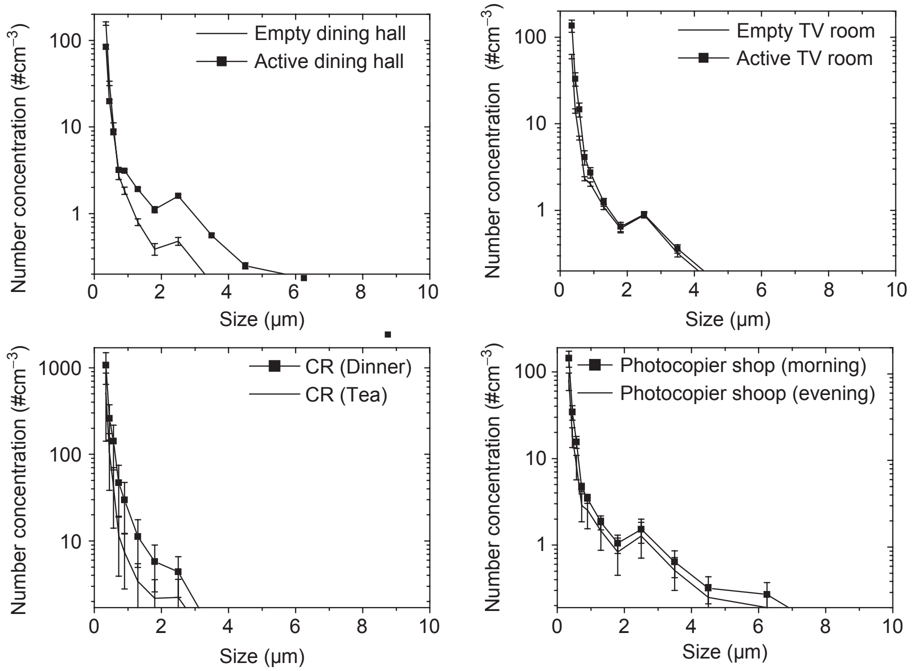

Figure 2. Particle number concentrations and size distributions in different microenvironments at different conditions/time: (a) dining hall, (b) TV room, (c) campus restaurant (CR), and (d) photocopier shop. The error bars are variation in the number concentrations shown as one standard deviation.

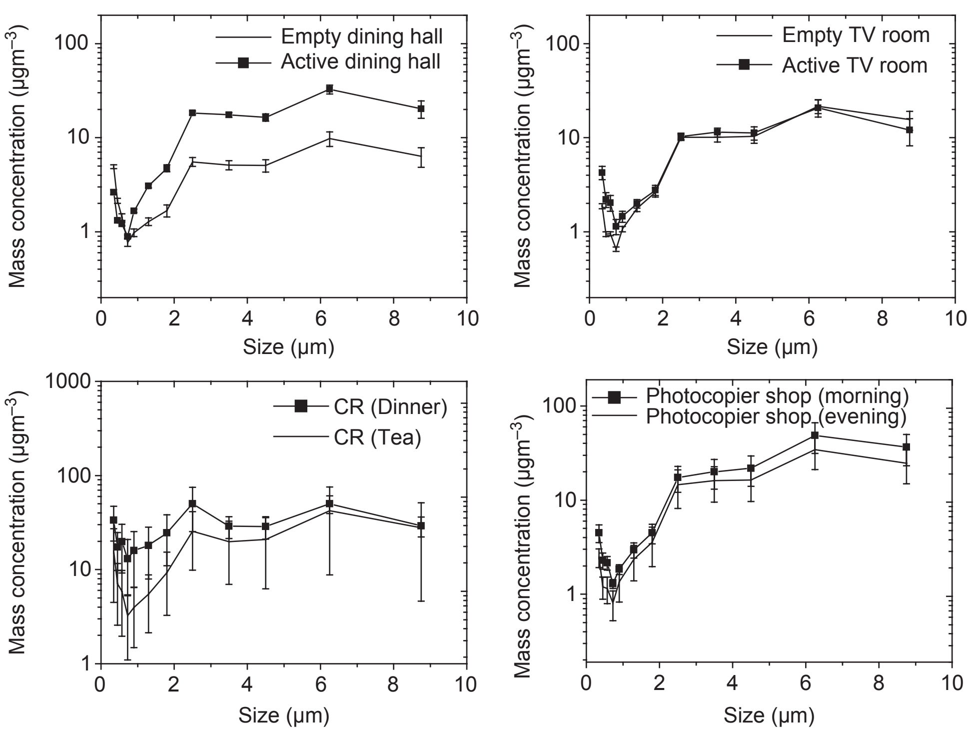

Figure 3. Particle mass concentrations and size distributions in different microenvironments at different conditions/time: (a) dining hall, (b) TV room, (c) campus restaurant (CR), and (d) photocopier shop. The error bars are variations in the mass concentrations shown as one standard deviation.

active conditions to study the effect of number of occupants and type of human activities on exposure. The instrument was kept in the lap of a person sitting on a chair with the sampling probe near the breathing zone. All windows in the TV room remain closed. The carpet laid in the room was very old. The ceiling fan was kept off during the study to prevent any effects from upward movement of particles from the carpet induced by it. Figure 2b shows the particle number size distribution of TV room with and without activity. The variations in different sizes shown are obtained in a similar fashion for the TV room (one standard deviation, ±1 σ). In the empty TV room, because of no human activity, the particle number distribution shows small variations following an almost constant pattern with time. However, there is slight variation in the coarse particle mass concentration, which is more prominent in the case of the active TV room with 8–12 students than that in the empty one, suggesting resuspension of coarse dust particles hidden in the carpet. The overall particle size distributions are almost identical for both the cases and any significant effect of human activity on particulate exposure is almost absent. Another point worth mentioning is that the sampling for the active TV room was carried out during dinner time. As the dining hall is located near the TV room, within 15 m distance, it is not surprising that the fine particle concentration (Figure 2a) measured in the TV room has concentrations similar to that in dining hall. Finally, from Figure 2b, it can be seen that for both the cases, coarse mode particle number concentration is much lower compared to the fine mode particle number concentration. In Figure 3b, large variability in coarse particle mass concentration is seen in the active TV room, as was seen in the case of the active hostel dining hall.

Campus restaurant (dinner and tea time)

Students frequently have food and parties in the campus restaurant either for tea (1600–1800 h IST) or for dinner (1900–2200 h IST); the number of visitors is very much less during lunch. Thus, an exposure assessment was done during tea and dinner time for 1 h each for 3 different days to find its effect on exposure to customers (students) with respect to their number and the amount of activity. The instrument was kept on the dining table similar to the dining hall case. From Figure 2c, it can be noticed that there is considerable variation in particle size distribution with time during teatime. Due to the presence of old carpeting in the restaurant, particle resuspension led to an increase in the number of coarse particles. During teatime in the campus restaurant, the numbers of occupants (5 to 15 persons) varied considerably over a few minutes. This is quite expected, as people spent about 20–25 min for tea vis-à-vis 45–60 min for dinner. In addition, the movement of people was also quite significant during teatime, which led to substantial variation in particle distribution in the coarse mode. Thus, large error bars in the range 60% to 83% of the average are seen in both particle number (Figure 2c) and particle mass distribution (Figure 3c). During the sampling period, occupants were far greater (40 to 45 persons) during dinner time than during tea time (5 to 15 persons). However, as people stay for a longer time during dinner, smaller error bars, which were about 20% to 60% of the average in the particle number concentration, are observed, indicating a stable particle concentration in the coarser range. Elevated cooking activity during dinnertime, due to more number of customers and their demands, might have led to higher fine particle number concentration during dinnertime than that during teatime.

Photocopier shop morning and evening time

Most of the students go to this shop frequently to make copies of their study materials. The shop has two photocopier machines and can accommodate only about 7–10 people at a time. Exposure study was done during morning and evening time for 1 h each with 6 s resolution, with the instrument kept on a table in the middle of the shop. Figure 2d shows that in the morning hours, the shop has higher particle number concentrations in both fine and coarse mode. This is so because during the photocopying process, lots of fine particles are released from the toner, which is filled during morning hours. Toner used in the photocopying process is a plastic-based powder that is heated to fuse it with the paper. The powdery particles that escape become a source of fine particles. The number and mass concentrations of the fine particulate emitted from the photocopier machines were about 3.5 times less than those produced during cooking in the campus restaurant. Routine cleaning up of the shop in the morning just before the sampling may also have led to increased coarse particle concentration. Figure 2d also shows that the variation in number concentration, especially in the coarse fraction during the morning time, is little more than that during evening time. This may be due to the lower number of customers (students) recorded in the evening time (4 to 5 persons) as compared to the morning time (7 to 8 persons). But the difference is more prominent in terms of mass concentration (Figure 3d) in the coarse mode.

Classroom

Monitoring in the classrooms was done in both lecture and tutorial classes to get a fair comparison of the exposure of students in different sizes of classrooms with the same mode of teaching (chalk and board). Lectures are held in big halls with a maximum capacity as high as 300 students. Tutorial classes are held in small classrooms with a maximum capacity of 40 students. Both lecture halls and tutorial classes were monitored three times in the same week and with similar timing (1600 to 1700 h in lecture hall and 0800 to 0900 h in tutorial class). The instrument was kept on the table in front of a student with the instrument sampling inlet near the breathing zone. The results are plotted in Figure 4. The number of students during monitoring was 32 ± 2 in the lecture hall and 12 ± 1 in tutorial class. Chalks and board were the only mode of teaching during the study in both the classrooms. The fine particle concentration in both the class rooms is stable as seen from Figure 4a. In Figure 4b, the deviation in mass concentration of very fine particles (0.3 μm) is remarkably higher, which indicates that non-dusting chalk

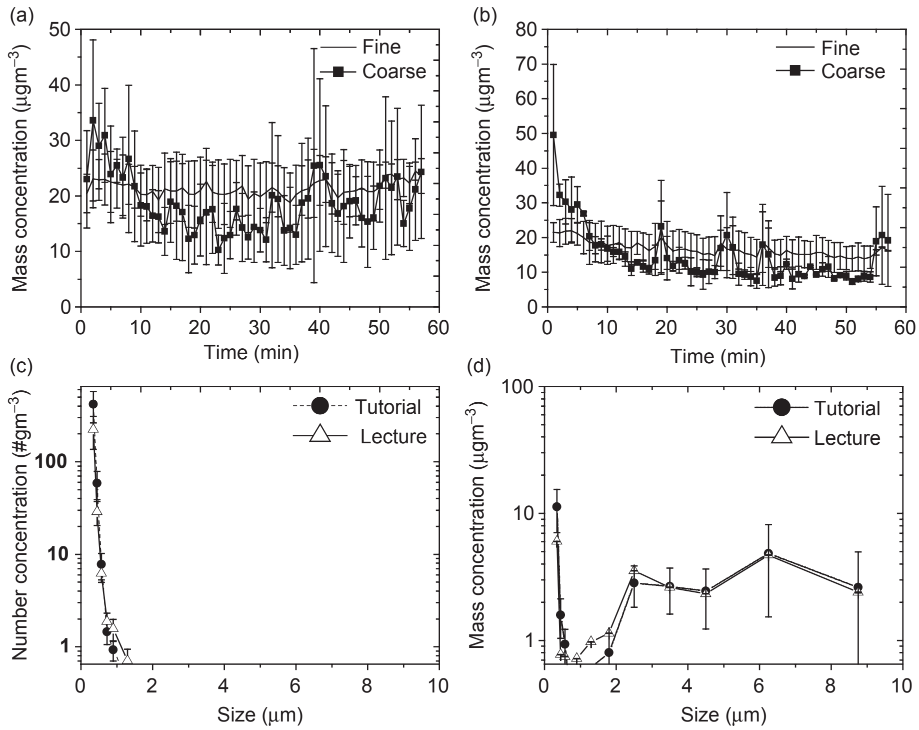

Figure 4. Time series total PM mass concentrations in (a) tutorial class and (b) lecture hall of fine and coarse particulate matter; (c) and (d) are number and mass distributions in different classes. The error bars are variations in the PM number and mass concentrations shown as ±1 σ.

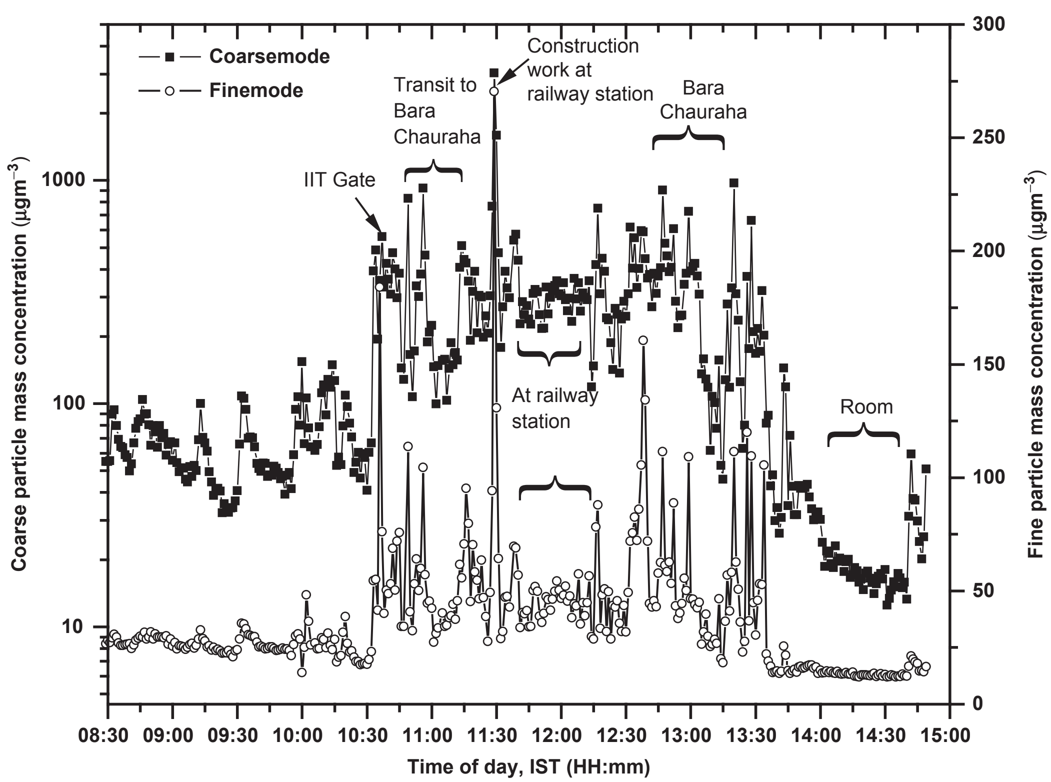

Figure 5. Mass concentrations of fine and coarse particulate matter during railway station trip. Coarse particle mass concentration is in $\log_{10}$ scale and fine particle mass distribution is in linear scale.

used for writing emits very fine particles; a similar finding is also reported by Majumdar and William (2008). The fine particle concentration variation is prominent in the tutorial class, which indicates that smaller rooms are greatly affected by any small source of pollutants. We can infer that in big classrooms like lecture hall, fine particles emitted from chalk during writing on the board do not have much effect on the fine particle concentration. The same figure also shows that human movement causes large variability in the coarse particle distribution. Figure 4, c and d, shows average particle mass concentration in both size modes in lecture and tutorial class for 1-h duration each. Coarse mode particle concentration increases many times when students enter the class in the beginning but later stabilizes as the suspended particles are removed by dry deposition.

Particulate sampling during outdoor trips

Compressed natural gas (CNG, consisting of mostly methane)-powered six-seater auto rickshaws are the mode of public transportation most frequently used by students of IITK, and hence these vehicles were used for the study. During the outdoor trip studies, the OPC was carried by a student on the shoulder with the sampling probe near the breathing zone. The data was stored every 6 s in the memory card of the instrument. Thus, even a small source/activity could be detected using a detailed time–location–activity diary.

Railway station (Kanpur Central)

The most common means of transport for students to go to their hometowns is the railways. The railway station is located around 16 km from IIT–Kanpur. The most common means of transport for students from the IITK campus to railway station is a six-seater auto rickshaw (Vikram auto, running on CNG) to Bara Chauraha (a major downtown traffic junction), followed by a 10- to 15-minute cycle rickshaw ride to the railway station. Measurements were taken during transit and at the railway station. A time–location–activity diary was maintained during the entire sampling period. Every peak in Figure 5 corresponds to a different activity. It can be seen that near traffic junctions, namely, IIT gate and Bara Chauraha, the peaks corresponding to coarse particles are higher, which could be due to resuspension of road dust. The peaks in fine particle mass concentration can be attributed mainly to the vehicle exhaust since there were no other combustion sources around. Thus, with an increase in the vehicular traffic, both the fine and coarse particle concentration increases. In addition to the various human activities, a major building demolition and construction work were carried out near the entrance of the railway station. This demolition process caused high coarse particle mass concentration at the entrance. At the railway platform, fine particle concentration was fairly low as majority of the trains passing at that time were running on electric power.

Shopping mall (Globus)

The shopping mall fascinates the students, with the facility of shops selling clothes, gifts, and food that they are most interested in. This shopping mall is among the biggest and most modern malls opened recently in the city and attracts large number of youth. The Globus mall is centrally air-conditioned, multi-storied, and has a central atrium along with peripheral arrangement of shops. Measurements were taken during the transit from IITK to the shopping mall and in the Globus. It can be seen in Figure 6 that with increase in vehicular traffic, both fine and coarse fractions show high peaks. The observed peaks in coarse fractions in a clothing shop and fast food restaurant (McDonald's) may be due to movement of people. The fine fraction peak in McDonald's was due to the combustion sources (cooking). Outside the gift shop, small peaks in both coarse and fine particulate mass are seen. This can be attributed to fine particle generation from some semivolatile organic compounds originating from fancy candles, perfumes, gifts etc. The coarse particle

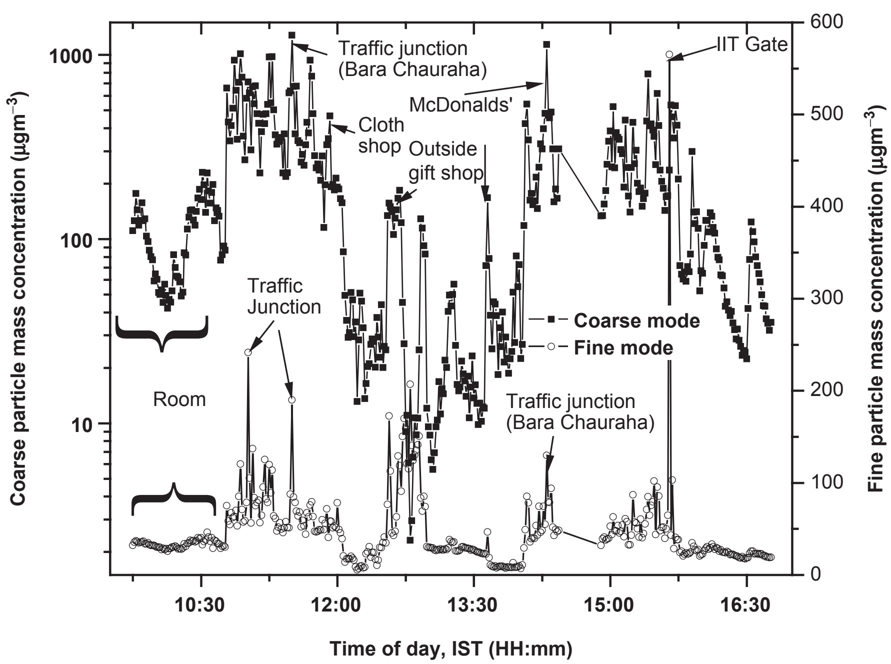

Figure 6. Mass concentrations of fine and coarse particulate matter during shopping mall trip. Coarse particle mass concentration is in $\log_{10}$ scale and fine particle mass distribution is in linear scale.

concentration in the gift shop may have peaked due to the presence of soft toys and movement of people etc.

Open marketplace (Naveen Market)

Naveen Market attracts students for shopping, as it has all kinds of air-conditioned (AC) and non-A/C shops for clothes, footwear, electronics, etc. on both sides of the road. A trip was made to an open market in a diesel-powered bus instead of a six-seater auto rickshaw. Figure 7 shows that the variation in particle mass concentration during this transit was similar to that during a railway station trip. Naveen Market is among the most popular and busy markets within the city and has a mix of small open marketplace shops, as well as a number of big air-conditioned shops for various items. Inside the main market, due to human activity and vehicular traffic, the measurements showed high peaks corresponding to coarse particle mass concentration. These peaks may correspond to the dusting/cleaning of shops and resuspension of soil dust from the pedestrian pavements. The peaks in fine mode during the trip were mainly because of combustion sources such as vehicular exhaust, push-cart vendors cooking and selling foodstuffs, diesel-based electricity generators outside the shops, etc. Surprisingly, a peak in the fine particle concentration was noticed inside an air-conditioned automatic teller machine (ATM). This could be due to prior use of ATM by a person either wearing a strong perfumed cloth or being a cigarette smoker. Both fine and coarse fraction were found to be very low in air-conditioned shops. During the later part of the sampling period, there was a dust storm, which showed an increase in both coarse and fine particle mass fraction by almost two times the background level, followed by drizzling which scavenged the particles considerably, as seen in the Figure 7.

Movie hall (Gurudev Palace)

Gurudev Palace is a single-screen, air-conditioned movie hall. Its floor is simply cemented with no carpeting. Since it is only about 5 km from the IITK campus, this place is the first choice of the campus residents. For the entire trip, the higher concentrations in both fine and coarse particles were only found during the transit (Figure 8). As the people entered the hall the coarse particle concentration increased due to resuspension of particles but decreased to a minimum with time due to dry deposition. No combustion sources like smoking were found inside the movie hall.

Twenty-four-hour personal exposure sampling

Personal exposure can be very different from both indoor and outdoor ambient concentration, as it depends on the proximity of the individual to the sources like vehicular exhaust, construction site, combustion sources, etc. and activities like cooking, dusting, etc. To evaluate the diurnal personal exposure of a typical IITK student, a study was carried out for 24 h by 4 students on 4 days in different seasons. Students carried an OPC on their shoulder with sampling inlet near the breathing zone throughout the study period and kept track of time–location–activity to relate different activities and sources to their personal exposure. The time–exposure plot thus obtained is provided in Figure 9 (a–d). Several peaks were obtained during different activities, which are marked in the plot. The fine and coarse fraction concentrations are very low when no activity takes place, such as during sleep

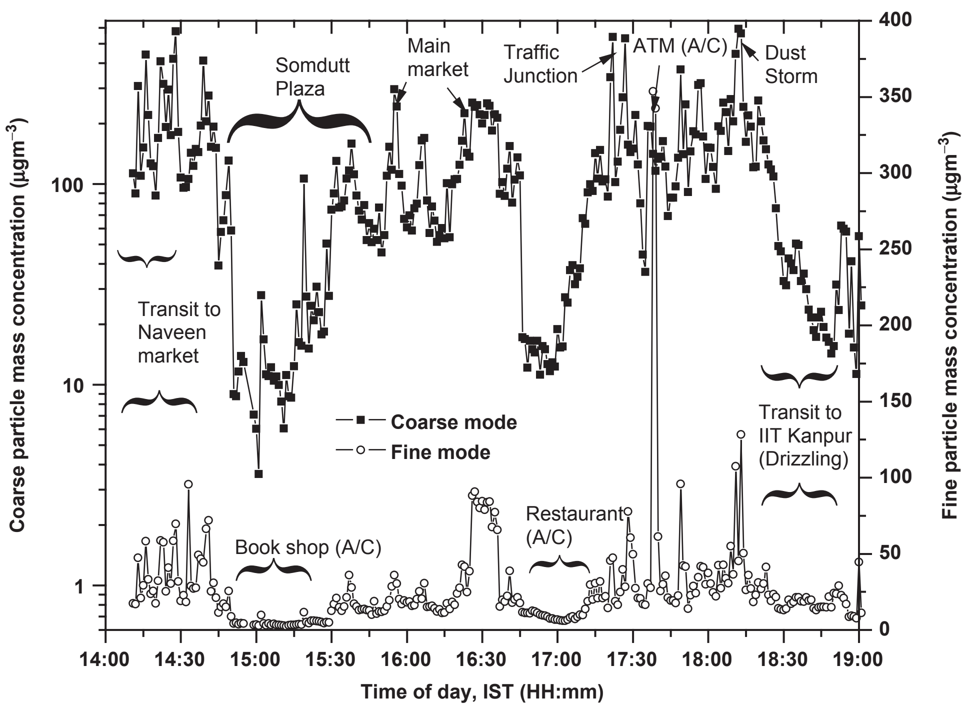

Figure 7. Mass concentrations of fine and coarse particulate matter during open marketplace trip. Coarse particle mass concentration is in $\log_{10}$ scale and fine particle mass distribution is in linear scale.

hours. The activities like cleaning and dusting increase the coarse particle concentration. It can also be seen that burning incense sticks causes the emission of fine particles, leading to higher fine mode mass concentration. The particle number concentration is also very high during the peak hours in the dining hall and considerably decreases after that.

The particle mass concentration inside a small classroom with open windows with a capacity of about 30 students (Figure 9a) can also be observed. The results are very similar to the tutorial class microenvironment discussed in the previous section. Similarly, Figure 9a also shows the particle mass concentration inside an air-conditioned computer lab.

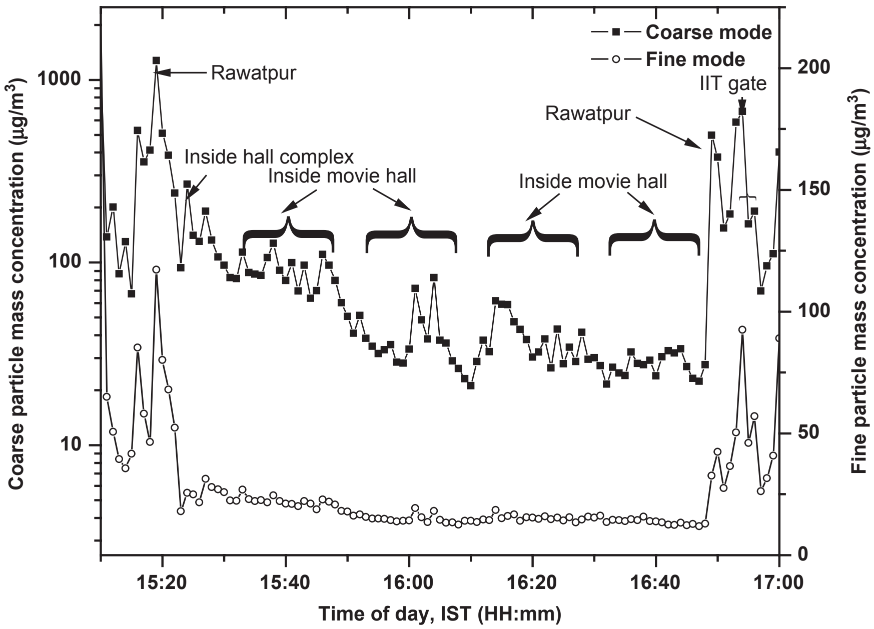

Figure 8. Mass concentrations of fine and coarse particulate matter during movie hall trip. Coarse particle mass concentration is in $\log_{10}$ scale and fine particle mass distribution is in linear scale.

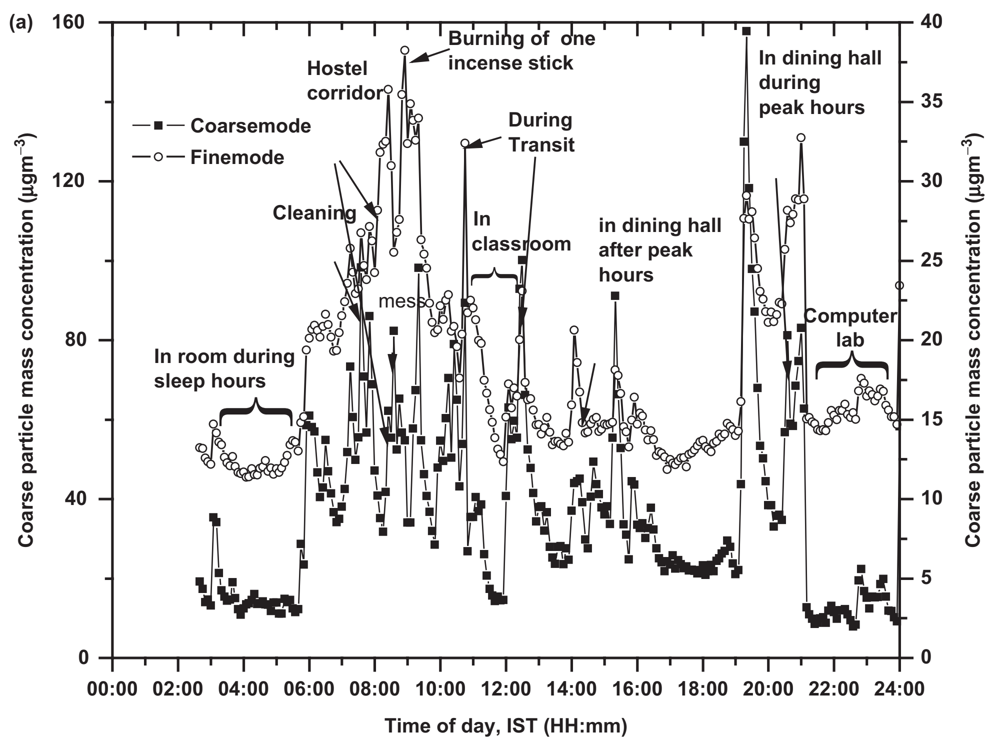

Figure 9. (a) Mass concentrations of fine and coarse particulate matter during 24-h personal exposure study during the pre-monsoon season. Both coarse and fine particle mass concentration are in linear scale.

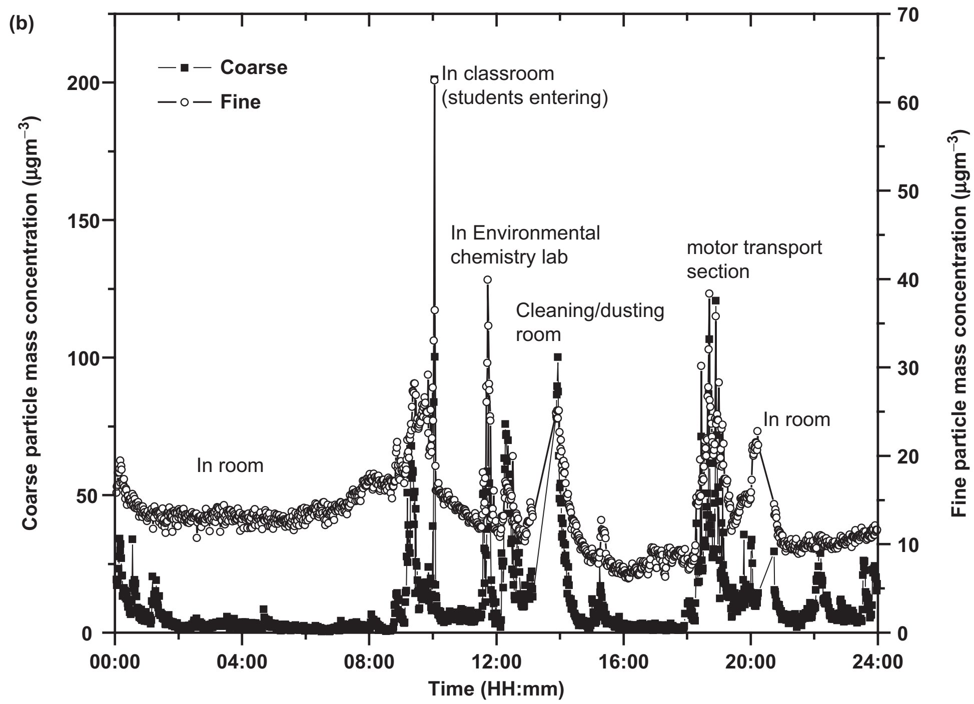

Figure 9. (b) Mass concentrations of fine and coarse particulate matter during 24-h personal exposure study during the winter season. Both coarse and fine particle mass concentration are in linear scale.

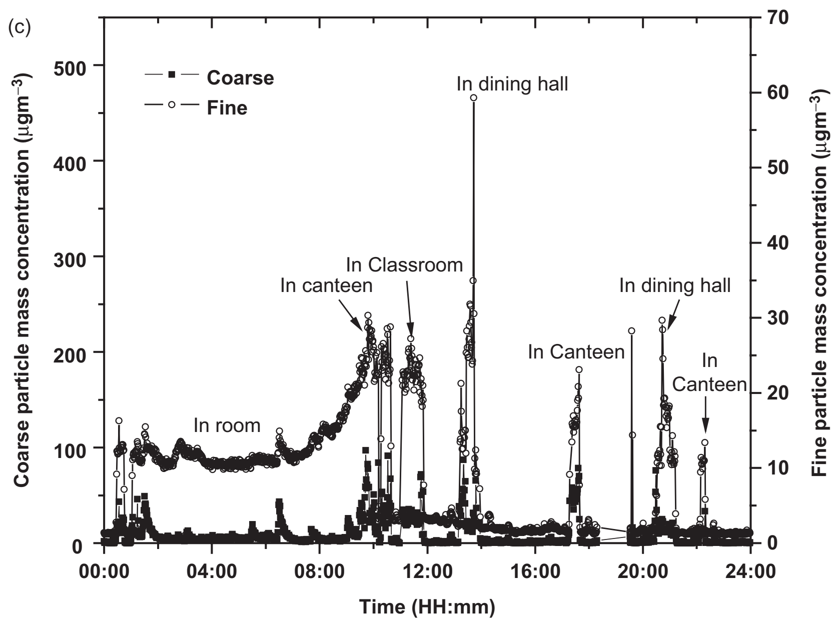

Figure 9. (c) Mass concentrations of fine and coarse particulate matter during 24-h personal exposure study during the winter season. Both coarse and fine particle mass concentration are in linear scale.

The fine and coarse fractions are very low. Moreover, occasionally the fine particle mass concentration exceeds that of coarse fraction. This could be due to the toner released during printing and photocopying in the computer lab contributing to the fine particle mass.

Figure 9, b and d, shows the Motor Transport section, which has the institute bus stand within the campus, with some small tea shops that use charcoal as fuel leading to higher fine particle mass concentration. In the environmental chemistry laboratory, in Figure 9, b and d, a number of chemicals are used causing higher fine fraction of PM, formed mainly due to gas to particle conversion. Since about 10–12 students were working in the laboratory during sampling, the coarse fraction also shows a peak. This is likely due to resuspended dust or any other mechanical activity being carried out at that time. Thus, it can be observed that sources/

activities like dining hall, motor transport section (bus stand with small tea shops using charcoal as fuel), environment chemistry laboratory, and incense stick burning shows higher fine particle mass concentration. Similarly, sources/activities like dining hall and motor transport sections show higher coarse particle mass concentration. Although the sources are same, the absolute exposure values are different. Janssen (1999) found that personal exposure to fine particles is highly correlated to outdoor ambient concentration. Thus, a variation in the ambient fine particulate concentration can change the personal exposure absolute values even though the sources/activities remain the same. This exercise provided us with a glimpse of the variability in personal PM exposure and how it varies between subjects, due to different activity patterns, and for different seasons. However, any generalized conclusion made regarding the exposure of all IITK students will not be fair at this stage.

Particle number concentration with time

Table 1 provides a summary of the fine and coarse particle mass concentrations and the ratio of the fine to coarse particles recorded for all the indoor and outdoor measurements carried out in the study.

Discussion

The study was carried out for college students (18 to 30 yr of age) during the pre-monsoon season. During the study, personal exposure to coarse fraction was found to be higher than the fine fraction except when a strong source of fine particles is present, like combustion, vehicles exhaust, etc. The results obtained for indoor microenvironments and during outdoor trips are discussed next in detail.

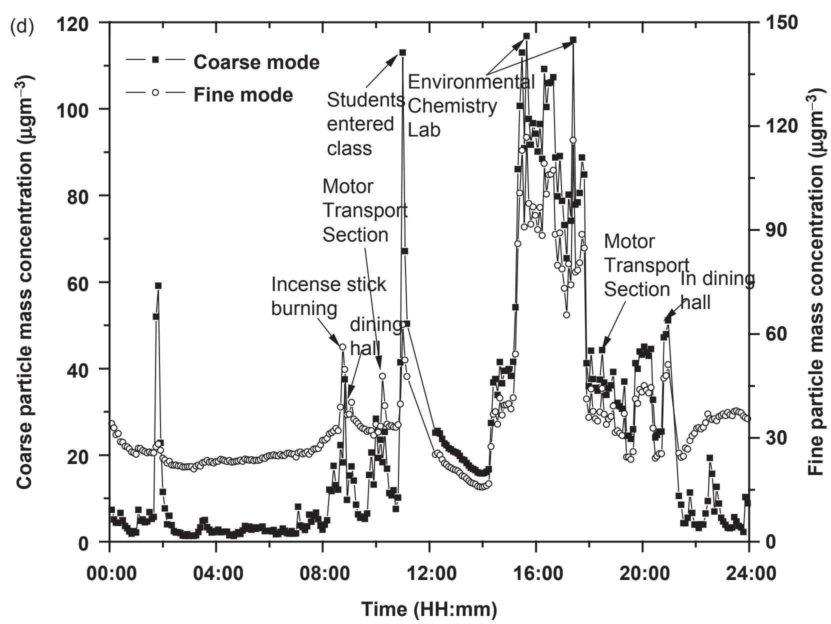

Figure 9. (d) Mass concentrations of fine and coarse particulate matter during 24-h personal exposure study during the winter season. Both coarse and fine particle mass concentration are in linear scale.

Table 1. Average fine and coarse PM mass concentrations at different microenvironments.

		PM Mass concentration (μgm^{-3})				
Sl. No.	Microenvironment (ME)	Total	Coarse mode	Fine mode	Fine/coarse ratio	Typical time spent in each ME (HH:mm)
1	Dining hall (empty)	38.6	22.6	16.1	0.7	00:00/day
2	Dining hall (active)	103.5	74.5	29.0	0.4	01:00/day
3	TV room (empty)	66.5	49.3	17.1	0.4	00:00/day
4	TV room (active)	70.1	47.6	22.5	0.5	01:00/week
5	Campus restaurant (teatime)	160.5	95.1	64.9	0.7	00:30/month
6	Campus restaurant (dinnertime)	282.7	117.5	165.2	1.4	04:00/month
7	Photocopier shop (morning)	140.7	109.0	31.7	0.3	00:20/week
8	Photocopier shop (evening)	101.9	78.3	23.6	0.3	00:30/week
9	Railway station trip	244.5	208.1	36.4	0.17	Occasional (4–5 h)
10	Open marketplace trip	115.9	93.6	22.3	0.24	Once or twice a month
11	Shopping mall trip	243.6	196.2	47.4	0.24	Occasional (4–5 h)
12	Movie hall trip	127.7	105.7	22.0	0.21	Once or twice a month
13	Diurnal exposure (pre-monsoon)	46.6	31.1	15.5	0.49	Daily

In indoor microenvironments

Table 1 shows that both fine and coarse mass concentrations for empty dining hall are much lower than that for active dining hall. But Figures 2a and 3a show that number and mass concentrations of particles < 500 nm in empty conditions are higher than in active conditions. Since both kitchen and dining halls are connected to each other, based on previous studies (Weiner 1989; Wigzell 2000), it can be said that the difference in particle mass concentrations in both size modes in kitchen and dining hall will be small if integrated over a 12-h period. In other words, an increase in the fine mode particle concentration in the empty dining hall from cooking activities in the adjacent kitchen can be due to the turbulent mixing between the two rooms.

The mass concentrations of particles are comparable for both empty and active TV room. This may be due to much less presence of students (8–12) in the active TV room. This led to a very similar coarse mode concentration even though the particle concentration was higher in some coarse size bins.

The campus restaurant has the highest total particle mass concentration. This can be due to combustion sources, particle resuspension from carpets, and other human activities. Also, in the campus restaurant during dinnertime, unlike other sites, the ratio of fine to coarse fraction is more than 1, which suggests the presence of a strong source of fine particles such as combustion from cooking using liquefied petroleum gas (LPG, consisting of mostly butane) during teatime and both LPG and charcoal during dinnertime. In a previous study (Levy et al. 2000), monitoring was carried out at different microenvironments in the United States, including restaurants (fast food, coffee shop, small pizza place), and found a median concentration of 17 μg m^{-3} for PM_{10}. The value is about 10 times less than that found during teatime in the campus restaurant in our study. Such a huge difference in the concentration could be due to different cooking patterns, ventilation, and no air conditioning.

To check for the effect of air conditioning, a comparison between a centralized air-conditioned (A/C) room and a non-air-conditioned room was done. All the windows and doors in both rooms were closed. The result is shown in Figure 10. Fine particulate mass concentration in the A/C room was about 6–7 times lesser than in the non-A/C room. Coarse particle mass concentration is also less in the A/C room. Although it can be said that within an A/C room, fine and coarse particle concentrations are less as compared to a non-A/C room, a detailed study is required to quantify the percentage removal of particles by an air conditioning system.

The higher proportion of coarse particles in the photocopier shop in the morning could be attributed to the sweeping and dusting activity prior to sampling. The fine particles were emitted by toners and there was no other source of fine particles in the vicinity.

During outdoor trips

The particle concentrations during the outdoor trips are shown in Table 1. The ratio of fine to coarse particle mass concentrations for different outdoor trips ranged from 0.17 to 0.24. This strongly suggests exposure to much higher concentrations of coarse particles than fine particles. In addition, during the sampling, the numbers for both fine and coarse fractions of PM_{10} are 2–5 times higher than those seen inside IITK campus.

For the railway station trip that lasted for 4.5 h, the coarse particle concentration is nearly 6 times more than the fine particle concentration. The total particle concentration at a major traffic junction (Bara Chauraha) was found to be 800 μg m^{-3}, which is about 3 times higher when compared to Mumbai (Kulkarni 2006), where it was recorded as 254.4 ± 73.9 μg m^{-3}. The peak concentrations of coarse and fine particles from IIT Gate to Bara Chauraha are due to vehicular pollution and road dust resuspension. In Kanpur, the majority of the roads are paved but the by-lanes and the area adjacent to the roads are dry, unpaved surfaces. Also, the roads have lots of potholes and due to out-of-track driving problems there are high concentrations of both fine and coarse PM fractions. While going through the demolition and construction site that was a part of the railway station, high coarse particle concentration with an average concentration of 2594 μg m^{-3} was seen.

A separate sampling exercise was carried out to study the role of new construction as a source for fine and coarse particle concentration. The concentration was highest near the batch plant, with a concentration of fine and coarse particulate 1479 μg m^{-3} and 4428 μg m^{-3}, respectively, with a total concentration of about 5907 μg m^{-3}. The boundary of the site was about 100 m from the batch plant. It is observed (Figure 11) that down the boundary of the construction site, the total particle concentration exponentially decreased with distance and attained background concentration (fine 12.49 μg m^{-3} and coarse 12.39 μg m^{-3}) at 80 m.

For the open marketplace trip, the ratio of fine to coarse particle concentration was 0.24. The use of diesel-based electric generators in most of the shops increased the

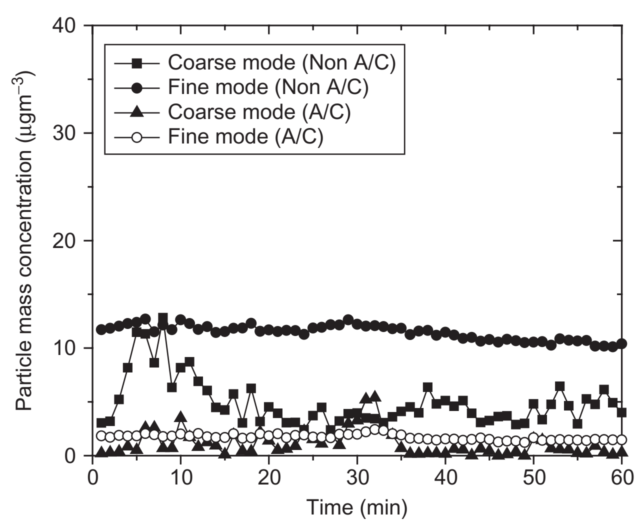

Figure 10. Mass concentrations of fine and coarse particulate matter in rooms with and without air conditioning.

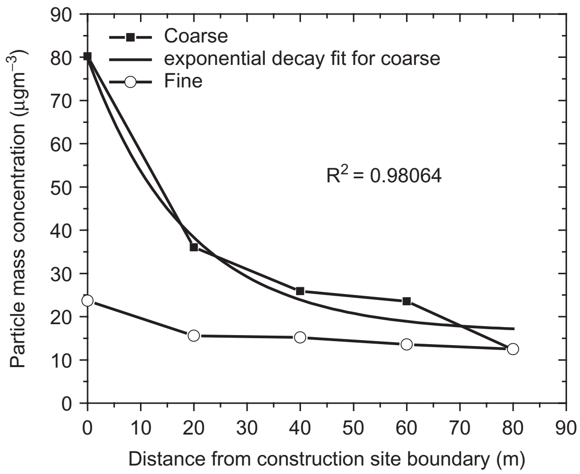

Figure 11. Mass concentrations of fine and coarse particulate matter away from boundary of construction site.

Table 2. Average fine and coarse PM mass concentration in different sites and due to different activities

Sl. No.	Activity	Coarse particle, μg m^{-3}	Fine particle, μg m^{-3}
1	Book shop (a/c)	10.4	3.5
2	Restaurant (a/c)	12.8	6.4
3	Living room (pre-monsoon)	11.6	10.3
4	Dusting/cleaning	84.2	19.9
5	One incense stick burning	32.76	11.2
6	Hostel dining area (peak hours)	73.7	22.5
7	Railway platform	280.1 ± 21.2	43.2 ± 5.6
8	Traffic junction	745 ± 170	81 ± 27
9	Dust storm	507.2	109.9
10	Demolition and construction site	2594	231.7
11	Small classroom (tutorial class)	16.1 ± 6.9	18.3 ± 4.16
12	Big classroom (lecture hall)	12.6 ± 3.46	14.3 ± 4.05
13	Shopping mall	34.1 ± 35.5	36.6 ± 38.4
14	Movie hall	37.1 ± 18.3	13.5 ± 2.2

proportion of fine fractions. The dust storm that occurred during the later part of the sampling contributed to a total particle concentration of 310 μg/m^3. A dust storm during the pre-monsoon season is an occasional event in Kanpur. Since such an exposure study is on college students, they may experience mild symptoms like irritation to eyes and upper respiratory tract. Other symptoms like allergic reaction, asthma attacks, breathing-related problems, and reduced life span can be safely ignored, as healthy adults (college students) do not experience these. However, we did not carried out any health measurements while collecting PM measurement. This should be carried out in future studies.

The movie hall trip, which lasted for 2 h, showed minimum variation in both fine and coarse fractions inside the hall during the show time due to low human activity. The particle concentration inside the hall was only 50 μg/m^3.

The fine particle mass concentration observed in the shopping mall was 36.6 ± 38.4 μg/m^3 (Table 2), which is comparable to results of a study carried out in an urban mall (36 μg/m^3) in Boston by Levy et al. (2002). From Tables 1 and 2, the total particle concentrations in the shopping mall and movie hall are about one-fourth of the total particle concentration for the trips. Thus, the personal exposure during transit (vehicle exhaust, road dust resuspension, emission from road-side fast food corners, etc.) is a major contributor to the total particle concentration during the trips. To add to this, the personal exposure during the railway station trip and that for the shopping mall are very similar. The reason for such similar exposure is that to reach both these places—railway station and shopping mall—one has to go via Bara Chauraha, which is heavily loaded with fine and coarse particles. This has led to the very high total exposure, about twice that of the movie hall and the open marketplace trip.

In addition, Table 2 provides the fine and coarse particle mass concentrations at various locations and during different activities obtained during different trips and personal exposure study. Some of these activities lasted only for a few minutes, like the dust storm, or dusting/cleaning. Since a real-time instrument was used, the contribution of these sources and activities to particulate exposure could be discovered.

Health effects due to exposure to various sources

The exposure study was carried out on college students (18 to 30 yr of age) living on an academic campus. Table 1 shows the average amount of time a student spends in each microenvironment and during outdoor trips. The time a student spends in microenvironments with elevated exposure is too low to cause any serious symptoms in healthy adults except eye irritation and occasional coughs. When a student goes on an outdoor trip, the elevated exposure persists for 4–6 h. This may show symptoms like eye and upper throat irritation to healthy students and may aggravate lung diseases like asthma and acute bronchitis. However, a detailed study needs to be carried out that carefully looks at the relation of acute health effects and short-term exposure to air pollutants within Kanpur region.

Strengths and limitations of the study

This study gives some significant information on the exposure of particulate matter to the student community and relates it to students' day-to-day activities. The exposure was studied for fine fraction ($PM_{0.3–2.5}$) and coarse fraction ($PM_{2.5–10}$) simultaneously. Through this study we were successful in assessing the effects of activity on the particulate exposure in the range of 0.3 to 10 μm; however, for the particles < 0.3 μm, assessment is not done due to instrumental limitations.

Chemical analysis for identification and quantification of the composition of the airborne particulate matter was not done. However, this should not significantly limit the study, as many studies (Department of Health 1995) around the globe concluded that exposures to PM_{10} are more strongly related to health effects. Chemical composition varies significantly with geographical location. In spite of this, it is legitimate to say that for both developing and developed countries, with a 10-μg m^{-3} increase in PM_{10} concentration, daily mortality increases by approximately 1% (Harrison and Yin 2000), which indicates that particle concentration is itself a strong indicator. Knowing its true chemical composition can definitely be very important.

Conclusions

Indoor micro-environments study

During the sampling period, the measurements carried out in different microenvironments were quite stable and hardly any major variation was found, except those at the campus restaurant. Also, from the preceding results, it can be clearly seen that different human activities mostly increases the proportion of coarse particles. The presence of carpet led to resuspension of coarse dust particles most likely hidden in the carpet, while combustion sources are the main cause of increase in fine particulate matter. The number concentration for particles less than 500 nm (very fine particles) is actually higher in the empty dining hall than in the active dining hall. This can be attributed to the changes in cooking activity and pattern before and during the serving of meals inside the dining hall. During the photocopying process, the toner releases fine particles, thus leading to corresponding increase in fine particle concentration.

Outdoor trips

Several interesting conclusions can be drawn from the four outdoor trips. Both the fine and coarse fractions increase in the case of heavy vehicular traffic and in major traffic junctions. Coarse particles show a very high peak near the construction site, during the dust storm. Prominent peaks in coarse particles were seen near traffic junctions, cloth shops, human activity, etc. Similarly, besides vehicular exhaust, fine particles also showed a peak near diesel-based electricity generators, near push-cart vendors for foodstuffs, and in gift shops (perfumes, fancy candles). Both fine and coarse particles were less in air-conditioned places.

Diurnal sampling study

On the basis of the diurnal plots obtained for the personal exposure study, it is found that the fine particle exposure is higher near combustion sources and in smaller classrooms where chalk is used for writing. But this exposure is only for a short duration. Coarse particle concentration was higher due to resuspension of dust from movement of people.

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