levels was 35, 19 and 10 kg/m^2 wood equivalent respectively. Ignition source in the form of gasoline-soaked polyurethane basket of size 0.15 m × 0.15 m × 0.3 m corresponding to fire load of 21.12 MJ was used. Initial ventilation was provided at ground floor by opening a single glass panel (1200 × 400 mm), whereas no ventilation was provided in the first and second floors. Table 1 shows a brief timeline of events during the test.

During the test it was observed that glass panels failed in intact form instead of cracking and breaking. Post-fire investigations suggested that this was due to failure of silicon sealant and pressure tapes used for fixing the panels. Also, when temperature reached above 680°C, due to melting of aluminium, combustible polyethylene core was exposed to fire and charred. It also initiated secondary fire at the ground-floor level, enhancing the severity of the event. Overall, it can be concluded that the full-scale real-fire test demonstrated visually similar behaviour to some of the recent façade fires, and highlighted the vulnerability of combustible façade panels to fire, in addition to giving insights into possible fire spread and façade failure mechanisms.

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Monitoring of total volatile organic compounds and particulate matter in an indoor environment

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Indoor air pollution in the workplace is considered as one of the most potential environment risks to an occupant’s health. Office employees are exposed to airborne pollutants that include particulate matter (PM), volatile organic compounds (VOCs), gases chemicals and microorganisms originating from indoor and ourdoor sources. Exposure to PM and VOCs is likely to be higher in the workplace than outdoors due to the amount of time people spend in the indoor environment. A weekly monitoring of VOCs and PM with sampling period of 8 h was carried out in an indoor (office) environment in order to evaluate the exposure to pollutant concentration. The sampling was carried out with the help of a Grimm dust monitor and potable VOC monitor for PM and VOCs respectively. The results clearly show that exposure to PM and VOCs is much higher in an office building.

Keywords: Indoor environment, particulate matter, office, volatile organic compounds.

INDOOR air pollution is considered as a critical issue for human health since individuals spend a significant part of the day in indoor environments: offices, schools, colleges, residential and commercial buildings[1]. Office employees spend most of their time inside their office building, where the indoor environment has a direct influence on their performance and productivity as well as their well-being. Therefore, it is important to develop a good and healthy working environment in workplaces[2]. However, indoor air quality (IAQ) has received considerably less attention compared to outdoor air quality until last decade[1]. Poor IAQ can be especially harmful to children, the elderly, and those with cardiovascular and chronic respiratory diseases. In developing countries, the problem of indoor air pollution far outweighs the ambient air pollution[3,4]. Employees are exposed to different pollutants such as particulate matter (PM), volatile organic compounds (VOCs), oxides of nitrogen (NO_x), carbon monoxide (CO), etc. typically attributed to indoor sources as well as infiltration of outdoor air. Several studies have consistently ranked indoor air pollution as an important environmental health problem quality[1–7]. Good IAQ can

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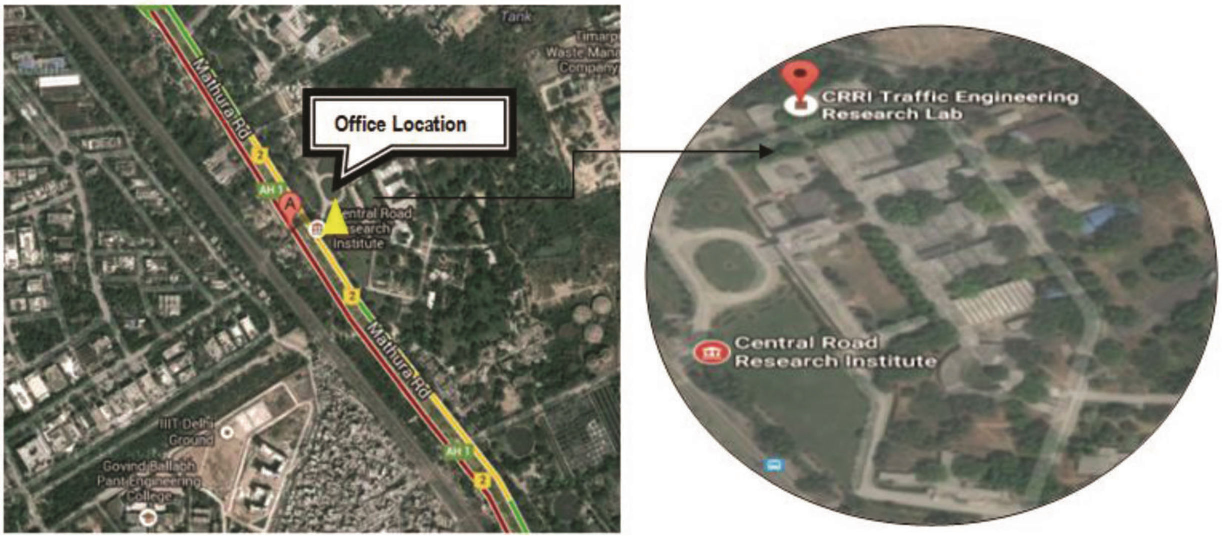

Figure 1. Location of the monitoring site in the Central Road Research Institute.

improve overall work performance by minimizing absentees in the organization, whereas poor IAQ can negatively affect profits at the cost of absenteeism of its employees and low productivity[8]. Office environments have changed rapidly with the advent of electronic equipment like laser-jet printers, inkjet printers, photocopying machines, scanners, multipurpose working machines, etc. Extensive use of office equipment not only contributes to indoor pollution, but is also associated with health issues such as a headache, mucous irritation and dryness in the eyes, nose and throat; and dry and tight facial skin[9–11].

There are different types of indoor air pollutants which could cause discomfort to office employees and their appearance is changing rapidly with time. VOCs and airborne PM are the most common indoor pollutants which have been studied thoroughly in the workplace environment[9,12–15]. Laser printers, inkjet printers, photocopying machine and multi-task devices are well-known sources of ultra-fine particles ($d < 0.1$ mm) and VOCs in the office environment[9,11,12]. Several factors, including outdoor pollutant concentration, air exchange rate and ventilation mechanism contribute significantly to indoor air pollution. Cigarette/tobacco, smoke, cleaning/dusting activities, air-fresheners, emission from building materials, furnishings and consumer products are the predominant sources of indoor VOCs and PM_5 (refs 11, 16, 17). The number and habits of inhabitants are significant sources of indoor air pollution. According to Raaschou-Nielsen *et al.*[18], concentration of $PM_{2.5}$ was 2.8 times higher in houses where people smoked.

This study provides data on the temporal variability of airborne VOCs, PM_{10}, $PM_{2.5}$ and PM_1 levels at randomly selected office rooms and corridors. An 8 h based real-time monitoring of pollutants enabled us to examine the effect of office activities on the levels and composition of airborne PM and total VOCs (TVOCs) and also provide useful information about exposure levels to office employees.

Monitoring was done within the premises of CSIR-Central Road Research Institute (CRRI), New Delhi (Figure 1). The building complex is situated along National Highway 2 (NH-2) Delhi–Mathura Road and lies in the southeast zone of Delhi. NH-2 registers heterogeneous traffic, where average vehicle speed varies between 35 and 60 km/h. The office building was fully air-conditioned with sealed windows. PM_{10}, $PM_{2.5}$, PM_1 and TVOCs were monitored inside the office building at three different locations – an office room (room 1: 4 m high, 3 m wide, 3.5 m long), environmental laboratory (room 2: 4 m high, 4 m wide, 4.5 m long), and a corridor (4 m high, 2 m wide, 7 m long). Room 1 had two laptops and one printer which placed on a table at a height of 1.15 m. Another test was performed in room 2 with three desktops, a laptop, one laser printer and some chemicals.

Sampling was performed between 9:30 am and 5:00 pm to account for the exposure during office hours in the selected rooms and corridor. Continuous measurements of PM (PM_{10}, $PM_{2.5}$, PM_1) and meteorological factors (temperature and humidity) were made using an optical laser aerosol spectrometer (LAS; Dust Monitor 1.108, Grimm Technologies, Inc., Ainring, Germany) at one-minute interval.

The instrument was calibrated and certified annually in the factory. The measurement accuracy is 5%. The instrument works on the principle of light scattering of a single particle hit by a laser beam. The scattered signal from the particle passes through the laser beam and is collected approximately at 90° by a mirror and transferred to a recipient-diode. The signal of the diode is fed, after a corresponding reinforcement, to a multi-channel

Table 1. Summary of temperature, humidity and indoor pollutant concentration and standard deviation (SD) for room 1, room 2 and corridor of an office

Indoor	Minimum–maximum	Median	Mean ± SD
Room 1			
PM_{10} (μg/m^3)	18.3–77.8	43.4	42.8 ± 15.3
$PM_{2.5}$ (μg/m^3)	15.1–64.4	32.8	32.6 ± 12.5
PM_1 (μg/m^3)	11.2–50.3	25.9	24.8 ± 9.7
VOCs (ppm)	0.1–170	15.5	38.7 ± 53.8
Temperature (°C)	25.7–39.8	28.8	29.4 ± 2.7
Humidity (%)	42.5–60.6	45.0	47.0 ± 4.6
Room 2			
PM_{10} (μg/m^3)	27.3–88.2	45.3	48.1 ± 14.9
$PM_{2.5}$ (μg/m^3)	20.4–60.7	35.1	35.0 ± 10.9
PM_1 (μg/m^3)	13.7–52.7	29.9	28.9 ± 10.0
VOCs (ppm)	488.7–959.8	582.7	596 ± 149.6
Temperature (°C)	25.6–31.5	29.6	29.0 ± 1.7
Humidity (%)	46.1–65.9	57.9	56.4 ± 6.3
Corridor			
PM_{10} (μg/m^3)	43.6–254.3	68.3	83.4 ± 44.7
$PM_{2.5}$ (μg/m^3)	34.9–209.4	52.8	65.0 ± 37.3
PM1 (μg/m^3)	29–150	47.0	57.8 ± 29.9
VOCs (ppm)	33–119	65.74	65.4 ± 21.6
Temperature (°C)	29.2–31.7	30.7	30.5 ± 0.6
Humidity (%)	55.9–72.4	62.4	62.8 ± 4.2

size classifier. A pulse height analyser then classifies the signal transmitted in each channel. The ambient air is drawn into the instrument by an internal volume-controlled pump at a rate of 1.2 l/min. The sampled air passes through the sample cell, past the laser diode detector and is collected onto the 47 mm filter paper, so that gravimetric analysis can be performed.

The concentration of TVOCs in the office was monitored using a portable handheld VOC monitor (MiniRAE 2000, RAE Systems, USA). The operating range of the instrument is 50 ppb to 5000 ppm with a resolution of 50 ppb and 3% accuracy. The instrument was calibrated and certified annually with three-point calibration in the factory. It monitors TVOCs using a photo ionization detector (PID) with a 9.8 eV gas discharge lamp and factory-calibrated with standard calibration gas. The PID works with the UV lamp ionizing the vapour to be sampled; the resulting charge of the sample is converted into a current by the detector and a concentration reading is displayed on the meter.

Table 1 provides a summary of PM and VOCs concentrations. Average temperature and relative humidity during the monitoring period are 29.7°C and 58.4% respectively.

PM is an indicator which directly contributes to IAQ in the workplace. From Table 1, we can see that $PM_{2.5}$ contributes significantly to the total amount of PM_{10}. The indoor concentration of room 1 varied between 18.3 and 77.8 μg/m^3 for PM_{10}, 15.1 and 64.4 μg/m^3 for $PM_{2.5}$ and 11.2 to 50.3 μg/m^3 for PM_1. The indoor concentration of room 2 was in the range 27.3–88.2 μg/m^3 for PM_{10}, 20.4–60.7 μg/m^3 for $PM_{2.5}$ and 13.7–52.7 μg/m^3 for PM_1. The concentration observed in the corridor varies between 43.6 and 254.3 μg/m^3 for PM_{10}, 20.4 and 60.7 μg/m^3 for $PM_{2.5}$ and 29 and 150 μg/m^3 for PM_1. Lower concentrations are observed during the noon and higher concentrations during morning and evening when the office is crowded. Figure 2 *a* and *c* shows a peak around 10:30 am; this might be due to the dusting carried out in the room and corridor at the same time. The concentration of PM in the corridor was very high, which may be because of activities like smoking, dusting and cleaning being carried out in the location. In addition to the above-mentioned activities, others such as digging of soils and putting up tents were carried out; also the humidity on that day was high (69%). Hence higher concentrations of PM were recorded in the office.

The average concentration of TVOCs in room 1, room 2 and corridor was found to be 38.7, 582.7 and 65.7 ppm respectively (Figure 3). The average concentration of TVOCs is generally higher due to poor ventilation because the windows and doors are mostly closed. The concentration during the monitoring period in room 1 and room 2 was found to be in the range 4.1–75 and 488.7–959.8 ppm respectively. The reason for the higher concentration in room 2 may be the use of air/room-fresheners, chemicals, printers, computers, detergents and also due to wall seepages. Also, more wooden furniture density and use of chemicals in room 2 compared to room 1 could have contributed to higher TVOCs level. TVOCs

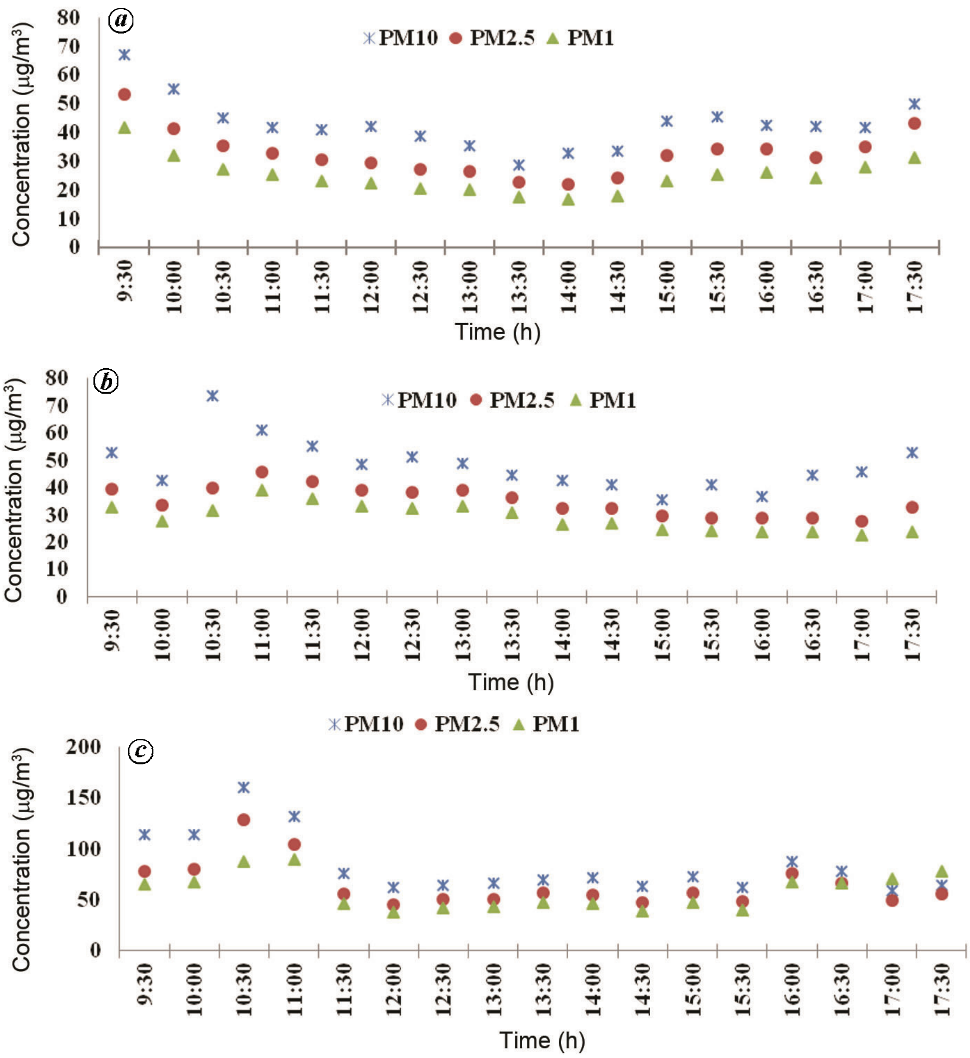

Figure 2. Temporal variation of airborne particles during office hours in (***a***) room 1, (***b***) room 2 and (***c***) corridor.

concentration during the monitoring period in the corridor was in the range 33–119 ppm. In the morning hours, TVOCs level was found to be higher in both the rooms because they were closed in the evening. With passage of time, the TVOCs level was found to drop inside the rooms due to temporary increase in ventilation condition. During lunch hour, the floors were wiped with disinfectants; this might have contributed to increase in the TVOCs concentration in the afternoon in both the rooms. The TVOCs concentration increased in the evening hours in room 2; this may be due to the use of chemicals in the laboratory.

The main sources of PM and TVOCs in indoor environments are human activities, personal care products (deodorants), smoking, cleaning products, room/air-fresheners, building products, and outside air pollution. Various types of printers, scanners and photocopying machines are widely used in offices which are potential sources of indoor pollutants producing VOCs, ozone[9,13,19] and particulate emissions[9,12]. Re-suspension of settled particles (larger than 1 µm) from surfaces is common[14,15]. Additionally, dusting and pesticide spray (aerosols) inside offices contributes to higher concentration of TVOCs[1]. According to Szigeti *et al.*[15], particles from the outdoor are still the most important source of $PM_{2.5}$ in the offices compared to indoor-generated particles. Smoking during office hours is considered as a significant indoor source of benzene, toluene, xylenes (BTX), $PM_{2.5}$ and PM_1 (ref. 20). Also, the close proximity of an office to busy roads with considerable density of vehicular traffic increases PM and TVOCs concentration indoors[21].

As seen in Figure 4, $PM_{2.5}$ and PM_1 indoor levels were greater than outdoor levels, while similar indoor and outdoor PM_{10} levels were observed at the monitoring location. Chao and Wong[22] concluded that higher indoor PM concentrations are found in Asian countries, especially

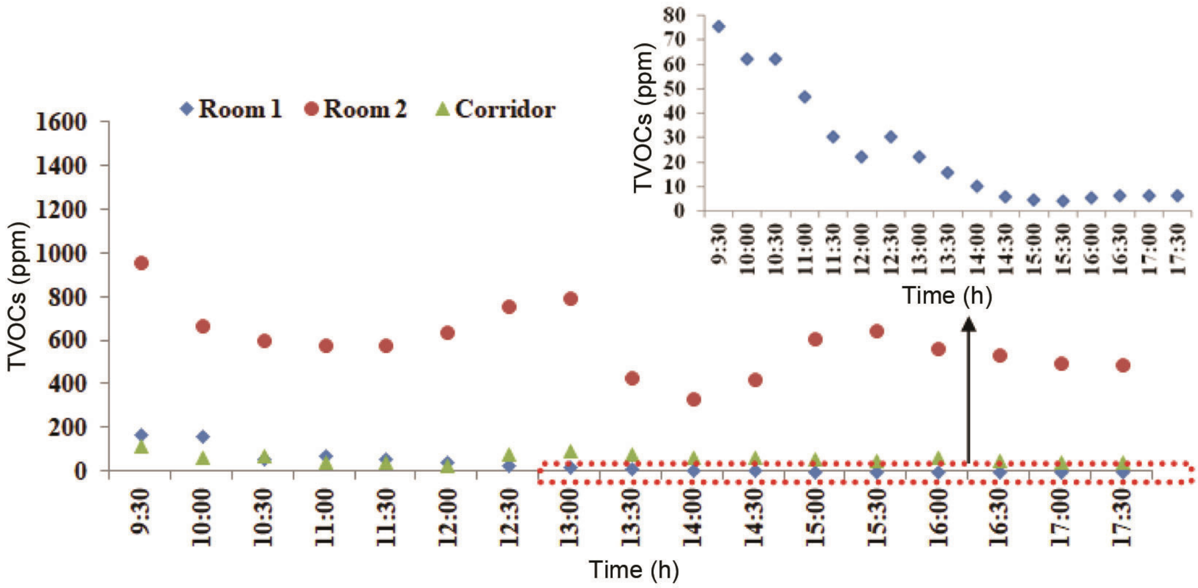

Figure 3. Temporal variation of volatile organic compounds during office hours in room 1, room 2 and corridor.

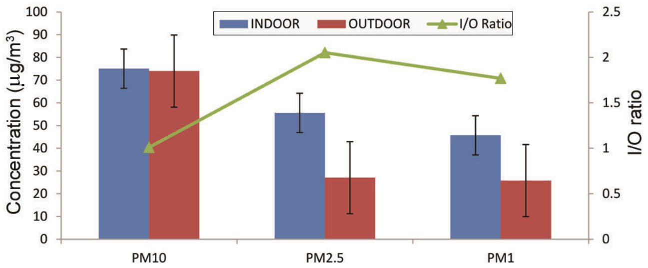

Figure 4. Indoor versus outdoor particulates concentration.

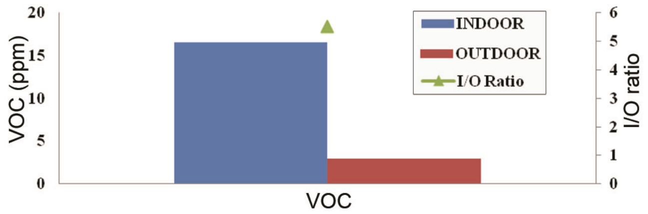

Figure 5. Indoor versus outdoor total volatile organic compounds concentration.

near sites which are close to traffic areas. Also, smaller particles are emitted generally through combustion processes, whereas the main source of coarse particles is resuspension caused by the presence of people and their movement[23,24]. Tobacco smoking is one of the essential sources of ultrafine particles which results in increasing concentration of such particles during office hours[1,12]. Figure 5 shows the mean indoor and outdoor VOCs concentration and indoor/outdoor ratio monitored in the office. The results show that exposure to indoor TVOCs values is higher than the outdoor. Indoor activities, ventilation and duration of human occupancy all influence indoor air quality during monitoring, as do meteorological factors and outdoor VOCs. One possible explanation for elevated TVOCs concentration is due to the painting activity being carried out in the office. Also, there is decrease in ventilation during summer when the windows are closed and air-conditioners are used frequently. Thus, TVOCs may accumulate at higher concentrations as a result of lower ventilation, persistent TVOC sources indoors and VOCs entering from the outside air[25].

I/O ratio represents the relationship between indoor and outdoor concentrations[26]. The I/O ratio of PM_{10}, $PM_{2.5}$, PM_1 and VOCs was 1.01, 2.053, 1.77 and 5.5 respectively, at the sampling location. A value >1 indicates that there is a strong indoor source for $PM_{2.5}$, PM_1 and VOCs. At the study site I/O ratio of PM_{10} was 1.01, indicating equal indoor and outdoor levels. I/O ratio can approach unity if the penetration factor is much closer to 1 and if average exchange rates are higher[27]. The high indoor PM and TVOCs levels may be attributed to the higher penetration ratio of outdoor-generated sources and due to the presence of indoor sources during measurements[24].

PM and TVOCs were monitored for an office building which is situated near a heavy traffic site in New Delhi. In this study, TVOCs and airborne PM concentration were found to be high because of close proximity of the building to busy roads, emissions from the office equipment, dusting and cleaning activities, smoking activities, poor ventilation and use of air/room-fresheners during office hours. In addition, higher VOCs concentration was mentioned in room 2 followed by room 1 and the corridor, which might be due to the use of air-freshener, chemicals, soaps, detergents and more office equipment.

Further research is needed to characterize the source emissions of PM and TVOCs in order to identify the contribution from various sources both indoor as well as outdoor. Similar studies must be conducted in office environments at different locations in order to identify hazardous sources that may be contributing to poor IAQ and adversely affecting the performance or attendance of employees.

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