Indoor Environmental Quality Assessment in a Newly Renovated Office Building in Delhi City

Sunil Gulia, Prachi Goyal, and S. K. Goyal

Abstract Healthy indoor environmental quality in the offices is a key factor for good health and productive work output. The ventilation facilities, construction materials and design of the buildings are the key factors to influence the indoor environmental quality, i.e., thermal comfort and pollutant concentrations. The present study attempted to evaluate the indoor environmental quality of a newly renovated office building in Naraina Industrial area using sensor based monitors. The study measured $PM_{2.5}$, relative humidity and temperature in different indoor micro-environments of the building including canteen area. The monitoring is carried out in indoor as well as outdoor environment using real time sensors based affordable monitor during one week period in September, 2022. The data analysis includes pollutant concentrations with and without operation of the ventilation system, indoor/outdoor ratio of pollutants, indoor air quality during working and non-working hours etc. The study also emphasized on the emission of pollutants due to cooking practices in the canteen area. The findings of the study highlight the effect of ventilation rate in the office building, office and canteen activities and infiltration of outdoor pollution.

Keywords Fine particulate matter · Indoor/Outdoor ratio · Office canteen · Indian cooking practice

1 Introduction

Breathing in clean air is the precondition for the survival of a healthy life. But with the rapid industrialization, development and changes in the living standards; natural factors and more of anthropogenic activities have rendered the ambient and indoor air unfit for intake [1, 9, 10]. Indoor air pollution in particular has not been discussed much in India due to non-availability of standards as well as monitoring guidelines unlike ambient air. Air quality in homes, institutions, hospitals, and other

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public buildings where people spend their lives should be pollutant free for the healthy survival [2, 5]. The indoor air pollution includes the occurrence of dangerous materials/agent such as carbon monoxide, sulphur dioxide, nitrogen oxides, VOCs and various micro-organisms [3, 4, 8]. Numerous sources are present in indoor spaces which again vary based on types of building and its use. In residential buildings, household emission (kitchen emission) is the major source of air pollution whereas in office buildings, the level of indoor pollution is generally less as there is no direct kitchen emission and thus, comparatively less exposure spectrum. However, there can be other sources which continuously emit pollutants both particulate matter and gases. Some of the sources in office building are (i) emission from cleaning practices; (ii) occupant-related sources such as smoking, office equipment, canteen activities, paper products and dirt/pollens; and (iii) newly built building i.e., construction adhesives, carpets, tiles, plywood/compressed wood, wall panels, etc. [6, 7]. In addition to the indoor sources, infiltration from outdoor pollution is one the major reasons for poor indoor air quality in the buildings. It is also observed that the frequent lack of causal connections between subjective complaints and certain indoor pollutants are being neglected which are usually followed by costly restoration and rehabilitation measures.

The present study is an attempt to assess the particulate matter ($PM_{2.5}$) pollutant along with thermal comfort parameters in a newly renovated office building located in one of the Industrial areas in Delhi. The study compared the $PM_{2.5}$ levels in different indoor environments in office building including canteen and compared with outdoor pollutant concentrations in terms of Indoor/Outdoor ratio and correlation analysis. Further, Pollutant levels are correlated with types of activities in indoor environment and their volume. In the end, efforts have been made to evaluate the emission from cooking activities inside the canteen area.

2 Materials and Methodology

The office building considered in the present study is located in the Naraina industrial area in Delhi where most of the activities belong to printing industries and retail of Iron sheets. The area is highly crowded witnessing continuous movement of heavy diesel trucks which are being used in the transport of Iron/Steel. There are not much combustion related activities or emission from stacks observed in the area. The building is 20 years old and renovated with modern infrastructure recently (3 months before the monitoring). It is a double storey building with total height of 7–8 m above the ground level. The building is also surrounded by the low income population. The details of indoor spaces, sensor locations and possible sources are given in Table 1 and shown in the form of photographs in Plate 1.

The monitoring was carried out during September 9–16, 2022 at 7 indoor spaces and 1 at roof using affordable sensor based air quality monitors. The AQ monitor is selected through a rigorous calibration process by comparing four different make sensor based monitors with validated portable monitor and continuous ambient air

Table 1 AQ monitoring locations and possible sources

S. No	Sensor code	Location Name & its description	Use of indoor space and related activities	Expected pollution load wrt to reception area
1	S1	Canteen (2–3 m away from cook stove) 1st floor	Cooking emission, emission from LPG, Cleaning/Sweeping of floor, Dusting activities, Newly Painted Walls	High
2	S2	canteen (Adjacent to cook stove) 1st floor	Cooking emission, emission from LPG, Cleaning/Sweeping of floor, Dusting activities	High
3	S3	Canteen sitting area (common area separated by wall & door from kitchen) 1st floor	Cleaning/Sweeping of floor, Dusting, Microwave, Oven, Painted Walls, re-suspension of dust due to movement of staffs, office staff used to sit during lunch time	Low
4	S4	Office room 1 (OR-1) (Regular movement of staffs) 1st floor	Cleaning/Sweeping of floor, Dusting, Xerox Machine, movement of people frequent here; Air Conditioned room	Low
5	S5	Reception (Regular movement of staffs- Higher than OR-1) 1st floor	Large area, connected with stairs and open window; Connected with toilet door; Cleaning/ Sweeping of floor 2–3 times in a day, Dusting, High movement of staff & visitors	Reference room
6	S6	Office room 2 (OR-2) 3–4 staff siting 1st floor	Closed room, 2–3 staffs siting area, Air Conditioned room, closed room	Low
7	S7	Office room 3 (OR-3) single staff sitting ground floor	Closed room, 1 staff siting area, closed, Air Conditioned room, ground floor	Low
8	S8	Roof 1st floor roof	Frequent Open burning, Kitchen exhaust, diesel Locomotive movement, Vehicles movement in the surround area	High

quality stations in the previous work of the author which is under consideration of publication. The device is capable of monitoring particulate matter along with ambient temperature and relative humidity. It is light scattering based sensor mounted in a compact steel case and portable in nature. It can operate at 0–50 °C and 10–95% relative humidity conditions. The device needs calibration on an yearly basis to remove the drift that comes due to aging effect. The measurement range of the sensor is 1–2000 $\mu g/m^3$ with time resolution of 40 s.

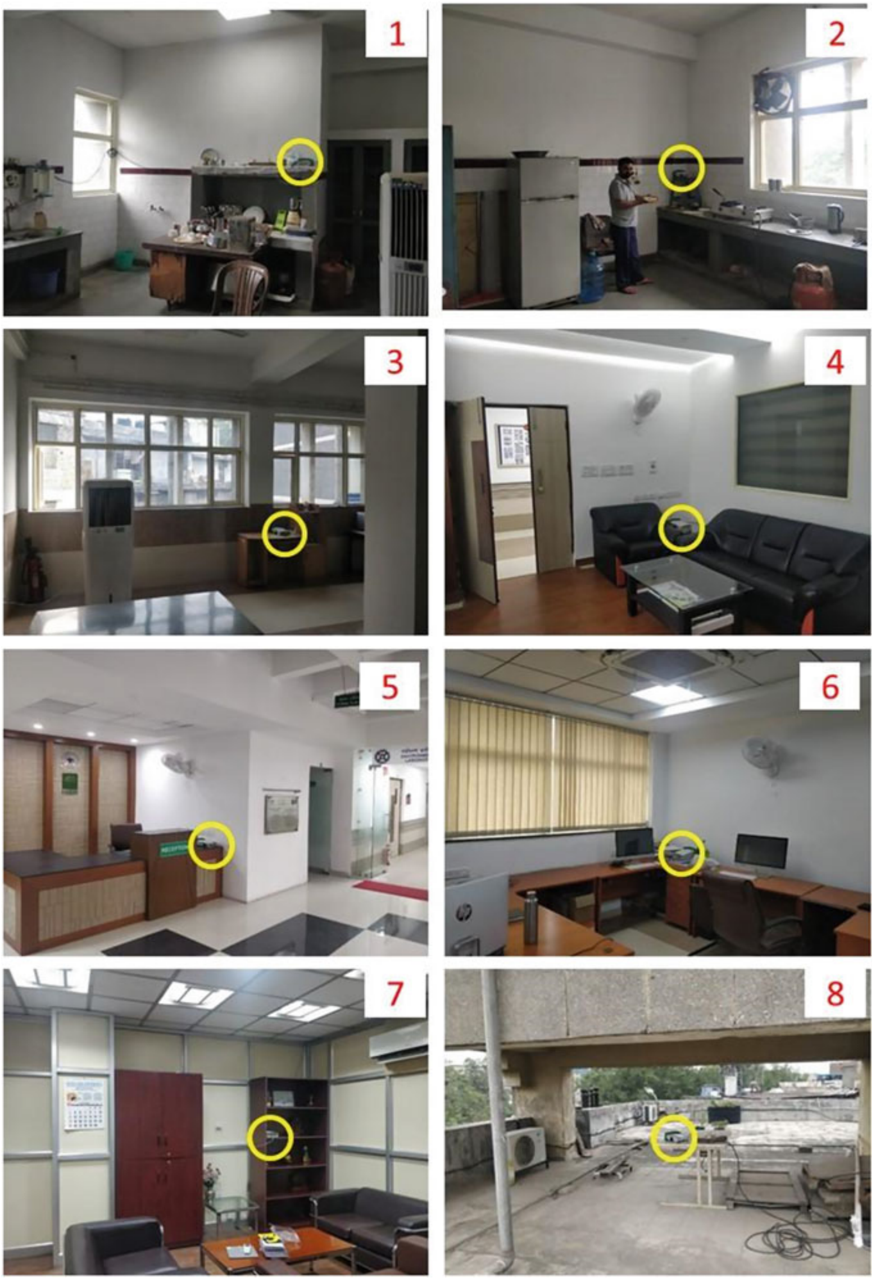

Plate 1 Photographs showing locations of AQ monitor and indoor spaces

3 Results and Discussion

3.1 *$PM_{2.5}$ Concentration in Indoor and Outdoor Environments of the Building*

The statistical summary (average and standard deviation) of $PM_{2.5}$ concentrations along with temperature and relative humidity are given in Table 2. The average concentrations of $PM_{2.5}$ were found to be 28 $\mu g/m^3$ at S1 (4–5 m away from cook stove) and 24 $\mu g/m^3$ at S2 (near cook stove) sensor which are located in Canteen. The higher value at S1 compared to S2 might be due to vertical rise of smoke from the cook stove due to buoyancy and settling away as reflected by S1. Whereas temperature was found higher at S2 as compared to S1 and vice versa for RH which is due to cook stove heating. In the canteen sitting area, the concentration was comparatively low i.e., 19 $\mu g/m^3$ as this area is separated from the cooking area by a wall with closed door whereas temperature is similar to kitchen area, but relative humidity is less. Further, the average $PM_{2.5}$ concentrations in office rooms were in the range of 23–28 $\mu g/m^3$ which is found slightly lower as compared to the reception area i.e., 30 $\mu g/m^3$, respectively. It is also observed that there is not much change in temperature and relative humidity between them. The average $PM_{2.5}$ concentration at roof was also found more or less in a similar range as found in indoor spaces i.e., 28 $\mu g/m^3$. Further, the average concentration of $PM_{2.5}$ was derived from hourly data of CAAQMS located at IITM Campus in Pusa (which is 3.5 km as per arial distance from the study site) in east side and the level was found to be 28.3 $\pm$ 18 $\mu g/m^3$ which is well matching with the roof sensor's observation. The correlation coefficient value between CAAQMS and Sensor monitored $PM_{2.5}$ concentrations were found to be significant i.e., 0.63. This significant correlation and more or less similar average $PM_{2.5}$ concentration develop the confidence that the sensor can provide reliable data and measurement can be used for evaluation of effectiveness of management strategies/control action.

Time series plot of hourly average $PM_{2.5}$ concentration in different Indoor spaces and roof of the building is presented in Fig. 1.

3.2 *Indoor-Outdoor (I/O) $PM_{2.5}$ Concentration Ratio*

Ratio of indoor and outdoor concentrations (I/O ratio) was calculated using hourly average data for the study period for each indoor sensor and is given in Fig. 2. The I/O values were found > 1 for sensors located at Canteen (S1), Reception (S5) and Office room (S7) and minimum for sensors located at the canteen siting area.

Table 2 Summary of $PM_{2.5}$ and thermal parameters at different locations

Sensor number	Sensor locations	Daily average ± standard deviation		
		$PM_{2.5}$ (µg/m³)	Temperature (¹C)	Relative humidity (%)
S1	Canteen	28 ± 18	34 ± 2	61 ± 5
S2	Canteen	24 ± 16	35 ± 2	59 ± 5
S3	Canteen sitting area	19 ± 13	35 ± 2	56 ± 6
S4	Office room 1 (OR-1)	23 ± 11	32 ± 2	65 ± 15
S5	Reception	30 ± 20	32 ± 2	62 ± 6
S6	Office Room 2 (OR-2)	26 ± 16	30 ± 4	58 ± 6
S7	Office Room 3 (OR-3)	28 ± 15	31 ± 2	57 ± 7
S8	Roof	28 ± 13	31 ± 4	67 ± 13
9	CAAQMS, IITM Pusa	28 ± 18	–	–

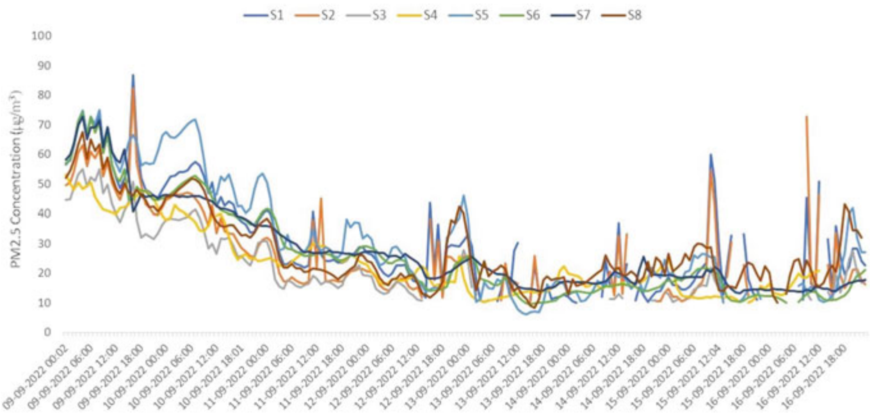

Fig. 1 Time series plot of hourly average $PM_{2.5}$ concentration in different Indoor spaces and roof of the building

3.3 Diurnal Profile of Indoor and Outdoor $PM_{2.5}$

The pollution related activities in the indoor as well as outdoor environment changes throughout the day and accordingly pollution levels vary. With respect to indoor activities in the office building, the office operates from 9:00 am to 6:00 pm in a typical working day; where generally cleaning and dusting takes place during morning hours, whereas in canteen, cooking occurs during 12:00–01:00 pm only

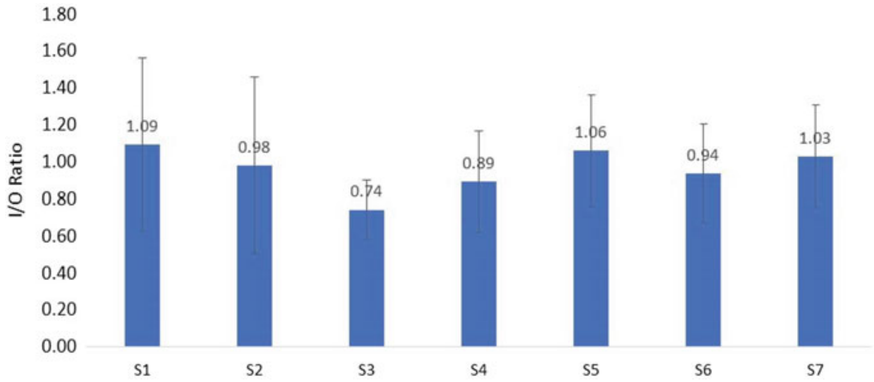

Fig. 2 I/O ratio of different indoor spaces of the building

(one hour) along with tea making during the whole day. During night time and on weekends; the activities are negligible in the office building. Considering these variables, further diurnal data analysis was performed to see the variations in the pollution level. Figure 3 shows the diurnal profile of $PM_{2.5}$ during weekdays and weekend period for each sensor.

The variations are observed in $PM_{2.5}$ values during the weekday compared to weekends in all indoor sensors which directly reflects the influence of activities. The pattern in the reception area (S5) is more or less similar on weekdays and weekends which might be due to influence from the outside area as this area is connected with stairs as well as open window, however, the concentration was higher during the weekends compared to weekdays which fully depends on the outside activities as reflected in the roof sensor (S8) and CAAQMS.

Earlier in 2018, a similar kind of study was conducted, wherein $PM_{2.5}$ monitoring was carried out for three days during August 23–25. The monitoring results indicate that average and standard deviation values of $PM_{2.5}$ were found to be 32 ± 5 $\mu g/m^3$ in Admin room, 33 ± 4 $\mu g/m^3$, in staff room and 57 ± 9 $\mu g/m^3$ in canteen (Mishra et al., 2018). It is inferred that $PM_{2.5}$ concentration were found less in the renovated building which might be due to an efficient ventilation system. The building indoor spaces are renovated with modern furniture and small cabins are replaced with large open spaces. Proper spaces are created to keep the files, old reports etc. The pantry/canteen area are kept separate.

Further, $PM_{2.5}$ monitoring is being carried out during the post-monsoon season from 3^{rd}–10^{th} November 2022 at the terrace (S8) and indoor in the staff room (S6). The average concentration and standard deviation of $PM_{2.5}$ were found to be 194 ± 118 $\mu g/m^3$ by S8 (Outdoor Environment) and 163 ± 84 $\mu g/m^3$ by S6 (Indoor environment). The average I/O ratio of the hourly average $PM_{2.5}$ concentration was found to be 0.99 which is comparatively higher from the monsoon period i.e., 0.94. This change might be due to poor ventilation in the Indoor environment during November due to non-operation of the air conditioning system. Further, the average and standard deviation concentrations of $PM_{2.5}$ at CAAQMS, Pusa were found to be 192 ± 111 $\mu g/m^3$ which is matching with S8 data.

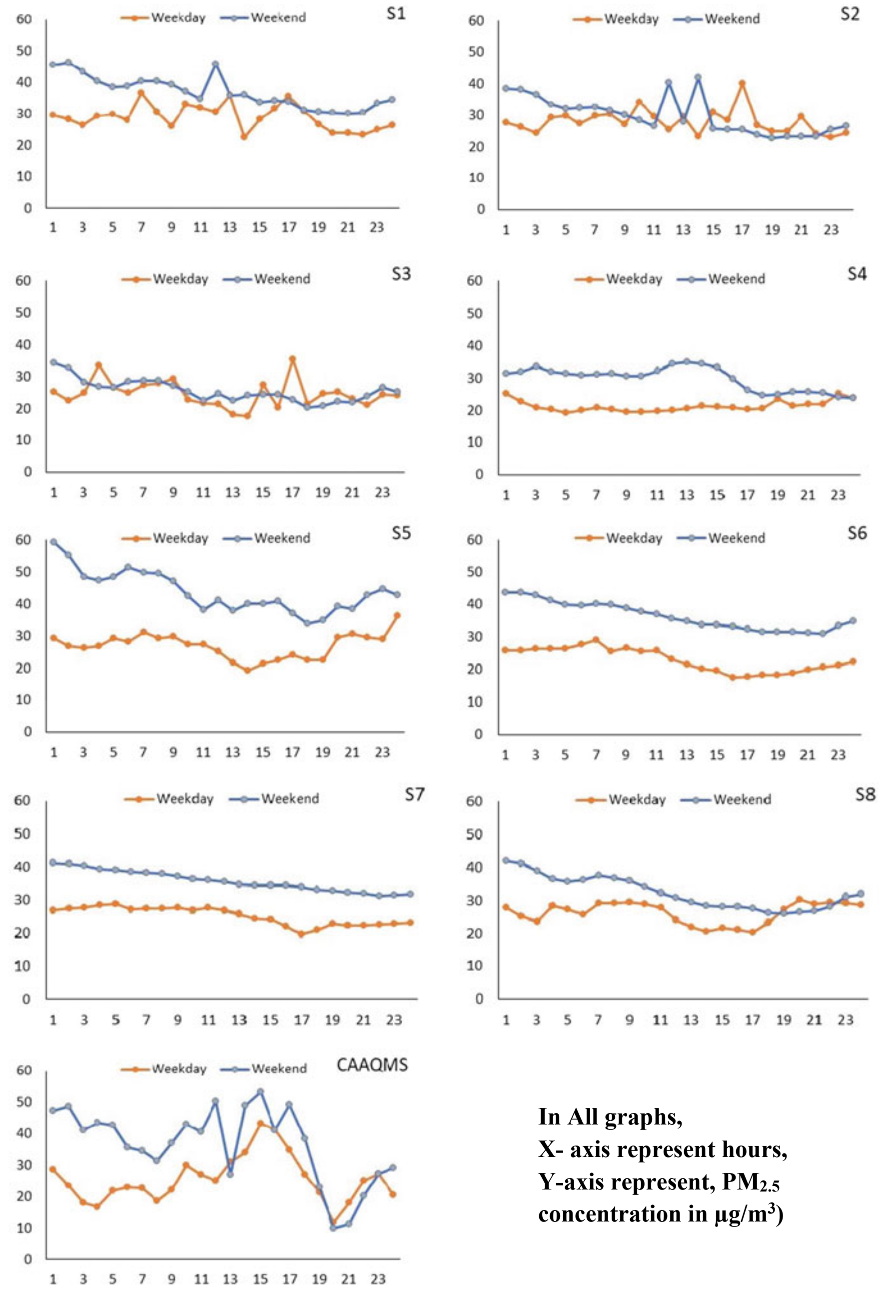

Fig. 3 Diurnal Profile of $PM_{2.5}$ during weekday and weekend in indoor and outdoor environment

4 Conclusion

Indoor air quality is a major concern as people spend most of their time indoor either in homes or workplace. The indoor air quality can be influenced through a number of factors including infiltration from outside air which again vary in mechanical and naturally ventilated buildings. Now a days, most of the offices are mechanical ventilated buildings. The present study also analysed the fine particulate matter concentration in different rooms of one office building along with canteen and outside area and correlated with activities based on one week data of September 2022.

The $PM_{2.5}$ concentrations were found higher in the canteen area compared to other office rooms. However, the $PM_{2.5}$ concentration was found higher at the reception area which might be due to continuous movement of staff/visitors compared to other indoor spaces. The average $PM_{2.5}$ concentration measured by the sensor at the Roof of the building and CAAQMS at Pusa campus are well matched. The $PM_{2.5}$ concentration in few indoor spaces was found to be slightly more than the outdoor environment. These indoor spaces are canteen, reception and office room at ground floor whereas other the air conditioned office room has low indoor $PM_{2.5}$ than outdoor. The diurnal profile of $PM_{2.5}$ concentration shows high variations during weekdays compared to weekends which reflect the influence of office activities.

The study gives some preliminary analysis of fine particulate matter in a newly renovated and painted building whereas other gaseous pollutant might also be studied, especially, VOCs. The painted walls and adhesives from new furniture may emit various types of VOCs. Additionally, the cooking emission in the canteen should be studied in detail with comprehensive monitoring using robust air quality sensors for particulate as well as gaseous pollutants and emission rate should be calculated from this monitored data. The sensor monitored $PM_{2.5}$ matched with the CAAQMS data, however, detailed monitoring covering all seasons could improve the understanding of the performance of the sensors and their application in indoor as well as outdoor spaces.

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