

Diurnal Variation of Ozone Levels in Academic Hostel in Delhi- A Case Study of JNU campus

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Abstract

Urban air pollution has become a serious environmental problem in the last few decades in most of the developing countries including India. Due to widespread industrialization, rapid urbanization and huge growth in the number of motor vehicles have brought about severe deterioration in the urban air quality. Among the various gaseous pollutants, ozone is one of the important pollutants because of its health as well as climatic impacts. This study investigates the levels of ozone concentration at thirteen different hostels in an academic institute, Delhi. The measurements of ozone were carried out in indoor environments by ozone analyzer (Model S-5014 SIR) for 24 hours. Results show that the hourly indoor mean concentrations were observed that the highest concentration during daytime varied from a maximum value of 24.45 ppb at the Godavari hostel (with a mean of 10.74 ppb) to a minimum value of 9.08 ppb at Chandrabhaga hostel (with a mean of 5.51 ppb), whereas lowest concentration varied from a maximum value of 2.05 ppb at Mahi & Mandavi hostel to a minimum value of 0.01ppb at the Periyar hostel. Results

revealed that Godavari, Periyar and Kaveri hostels were associated with the maximum concentration of ozone ≥ 20 ppb (24.45, 21.22 and 20.53 ppb respectively). This might have been due to the higher anthropogenic activities in the area of campus during the daytime. It is pertinent here to mention that these hotels are in close proximity of the main road of the JNU campus which has a high volume of vehicular traffic. In addition, restaurant, and bank housing electronic equipment like Computer, printer, etc. This emission of NO_x and VOCs from automobiles, VOCs from the restaurant and bank activities may be responsible for the formation of ozone in the vicinity of the hostels. The present study reveals that the ozone concentration in the entire indoor environment of the JNU campus lies in the range (2.81 to 4.17 ppb for 24 hours) are well below the permissible limits (100 $\mu\text{g}/\text{m}^3$ for 8 hours) prescribed by CPCB, India. Also the outdoor ozone concentration is found to lie in the range (13.93 ppb to 78. 15 ppb for 8 hours), which well above the standard (100 $\mu\text{g}/\text{m}^3$ for 8 hours) prescribed by CPCB.

Keyword: Indoor ozone, hostels, NO_x, VOCs, CPCB

INTRODUCTION

Ozone is a non persistent gas which is produced in an outdoor environment by a number of processes such as lightning (Godish, 2003) and enters into the indoor environment as a result of transportation and infiltration. Although it occurs in a relatively small amount, it has great importance because of it is proximity to populated areas. This is a matter of health concern in the recent decades where the people are spending about 90% of their lifetime in the indoor environment (Hayes 1991; Sundell, 2004). Besides the outdoor influx, ozone is also produced in the indoor environment (Weschler et al, 1999). Air cleaner devices are one of the sources of indoor ozone (Boeniger et al, 1995). Photocopy machines are also responsible for the formation of indoor ozone (Brown et al, 1999). Beside this, other sources of indoor ozone are formed by ultraviolet sources (for example, in order to sterilize bactericidal UV lamp ozone is frequently used in the hospitals, labs and food industry).

Indoor ozone concentration varies from day to day as well as from one place to another. The half life of ozone is found below 10 minutes in a working office room (Sillman, 1999; Weschler, 2000). Whereas half life of outdoor ozone is 1–2 weeks in summer and 1–2 months in winter, which is formed by reaction between NO_x and VOCs in the presence of sunlight (Jonathan et al, 2005).

In recent decades there has been growing public concern regarding the poor indoor air quality in urban areas which increases risk of adverse health effects (Vaida et al, 2007). The concentration of ozone and aerosols could have adverse effects on human health as well as building materials (Peden, 2001). It is recognized that the effects of ozone on human nostril, throat and eyes are much stronger compared to the other pollutants (Desqueyroux et al, 2000; Moldave et al., 2005). Daily exposure of high level ozone may cause injury to the lungs. There are many studies indicating the impact of indoor environmental chemistry on human health (Weschler, 2006; Wolkoff et al, 1992). Pulmonary damage and asthma attacks are frequent even at very low concentration of ozone (Peden, 2001; Desqueyroux et al., 2002; Mortimer et al., 2002), while the risk of childhood asthma is found to be the highest in the case of O₃ pollution. The sperm count has been known to decline due to effect of ozone pollution. Ozone concentrations at ground levels modulate oxidative DNA damage in circulating lymphocytes of residents of polluted areas. In view of adverse health effects of ozone, WHO (World Health Organization) has prescribed standards of 80 ppb concentration exposure for 1- hour. According to EPA (Environmental Protection Agency), the concentration of ozone standard is designed to protect public health, to a level within the range of 0.60 – 0.07 part per million (ppm) (National Ambient Air Quality Standards, 2008; EPA, 2008). Children and elderly people are more sensitive to ozone and one study also shows that when ozone concentration in air increases by 40 µg/m³, the number of children with respiratory disorders increases by 83% (Gilliland et al., 2001). The disorders reported at different concentrations of ozone have been depicted in table 1.

Table 1. The disorders reported at different concentrations of ozone

Concentration of ozone (in µg/m ³)	Symptom
100	Headache
300	Irritation to eyes
540	Cough
580	Thoracic pain

(Sundel, 2004)

Some investigations show that ozone may react with unsaturated VOCs (particularly citrus or pine oils from cleaners, or from decomposition of the toner powder) to produce a number of relatively reactive compounds (Gallardo et al, 1994). Many studies have investigated the health effects of photocopier toner dust are responsible for siderosilicosis and sarcoidosis-like pulmonary diseases (Armbruster et al, 1996; Vaida et al, 2007). Plant tissue chemistry may be affected by exposure to higher

concentration of ozone as it damages the photosynthetic compounds (chlorophyll and carotenoid) severely and affect the rate of photosynthesis.

STUDY AREA AND METHODOLOGY

General Description of Study Area:

A study was carried out at various locations of hostels in JNU, New Delhi, and the capital city of India. The university campus stressed over a vast tract of natural vegetation covering an area of 1000 acres. This place is far off from the major industrial activity. The traffic density is very low within the campus, but it is surrounded by major roads carrying heavy vehicular traffic.

Delhi is one of the 10 most polluted cities in the world. It is the second largest populous Indian city with a population of about 16 millions with an annual average growth rate of Delhi's population is $\sim 3.8\%$ over a period of five years. During this period the annual average vehicular growth rate had been 5.85% (Economic survey of Delhi, 2011). It lies in the subtropical belt, characterized by semi-arid climate which consists of summer (March-May), monsoon (June-August), post-monsoon (September-November) and winter (December–February). It experiences a maximum temperature of $\sim 45-48^{\circ}\text{C}$ in June during the summer and minimum of $\sim 1-2^{\circ}\text{C}$ in January during winter. It has an average rainfall of 611mm. The air over Delhi is dry during the greater part of the year. Humidity is high in the monsoon season while April and May are the driest month. April to June period witnesses the highest frequency of thunderstorm and dust storms. These storms are generally dry, but some are accompanied by heavy rains. The predominant wind direction in most part of the year is from west to northwest except during monsoon months (July-September) where, it is from south to southeast. The winter months are dominated by calm conditions with low inversion and low mixing height, thereby keeping pollutant level high.

Experimental methodology

Ozone monitoring was carried out at 13 hostels in the Institutional area from January to May 2010 in Jawaharlal Nehru University, Delhi. The measurements of ozone were carried out in indoor environments by ozone analyzer (Model S-5014 SIR, AVD INDUSTRIA, Madrid-Spain). Model S-5014 is an ultraviolet absorption analyzer, specifically designed for the measurement of the ozone in ambient air using sorbent tube automatic thermal desorption that record the mean concentration of ozone at an interval of every 15 minutes. This device works on the principle of a monochromatic UV absorption spectrophotometer specifically for ozone. The detection limit and precision of ozone analyzer is listed in Table 2. The probe of ozone analyzer was

fixed at a height of 1.5 m from the head ground floor. Measurements were carried out for three consecutive days at each hostel.

Table 2 Technical specification of instruments

Technical specification of the ozone analyzer used in study:

Instrument	Lower Detection Limit	Linearity	Precision
Ozone Analyzer	0.6 ppb	$< \pm 1.0\%$	< 1.0 ppb

Characterization of interior materials used in hostel includes ceramic tile floor, painted concrete ceiling, painted concrete wall and aluminum framed glass doors. Some wood desks, chairs and other furniture were also present in the confined room of the hostel. In each hostel, the room dimensions, temperature, humidity, the types of ventilation, the number of entrances are depicted in Table 3. There was proper ventilation in the hostel rooms. The door and window of each hostel was open and closed at random intervals. Typical materials present in hostel rooms include laptop, printer and fan, which were used for different intervals of time.

Table 3: Physical characteristics of the hostels investigated

Hostel	Measurement time (day)	Laptop/Desktop	Number of Occupant	Ventilation
Sutlej	3	NO	2	One window closed, Two doors closed,
Jhelum	3	NO	2	One window, Two doors opened,
Ganga	3	Desktop (1)	2	One window opened, door closed,
Kaveri	3	Desktop (1)	2	One window closed, Two doors opened,
Periyar	3	Desktop (1)	2	One window opened, Two doors closed,
Godavari	3	Laptop (2)	2	One window opened, Tow doors opened,

Narmada	3	NO	2	One window opened, Two doors closed,
Sabarmati	3	Laptop (1)	2	One window opened, Two doors opened,
Tapti	3	NO	2	One window closed, Two doors closed,
Mahi-Mandvi	3	NO	2	One window closed, Two doors closed,
Chandrabhaga	3	Desktop (1)	2	One window opened, Two doors closed,
Mahanadi	3	Laptop (1)	2	One window, Two doors closed,
Brahmaputra	3	NO	3	One window, One door closed, Air conditioner

RESULTS AND DISCUSSION

The mean concentration and standard deviation of indoor ozone levels measured in various hostels during the day and night are plotted in figures 1 & 2. It may be seen that ozone starts building up in the morning and reaches maximum value around noon and that it gradually declines until the next morning. The pattern observed here is similar to typical variation of ozone levels in the outdoor environment.

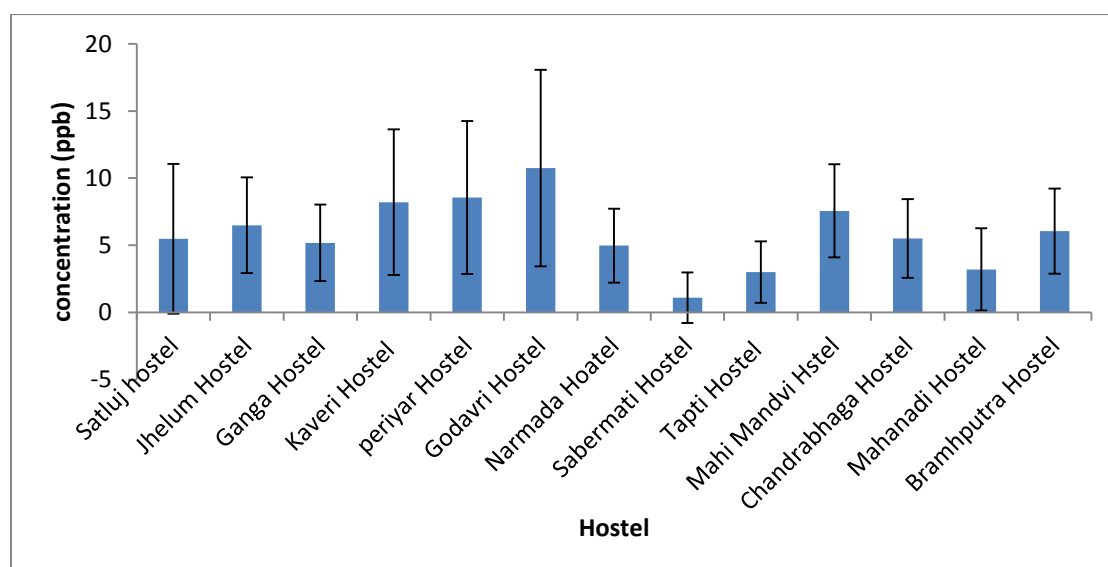


Fig. 1: Mean concentration and standard deviation of indoor ozone concentration in different hostels during daytime.

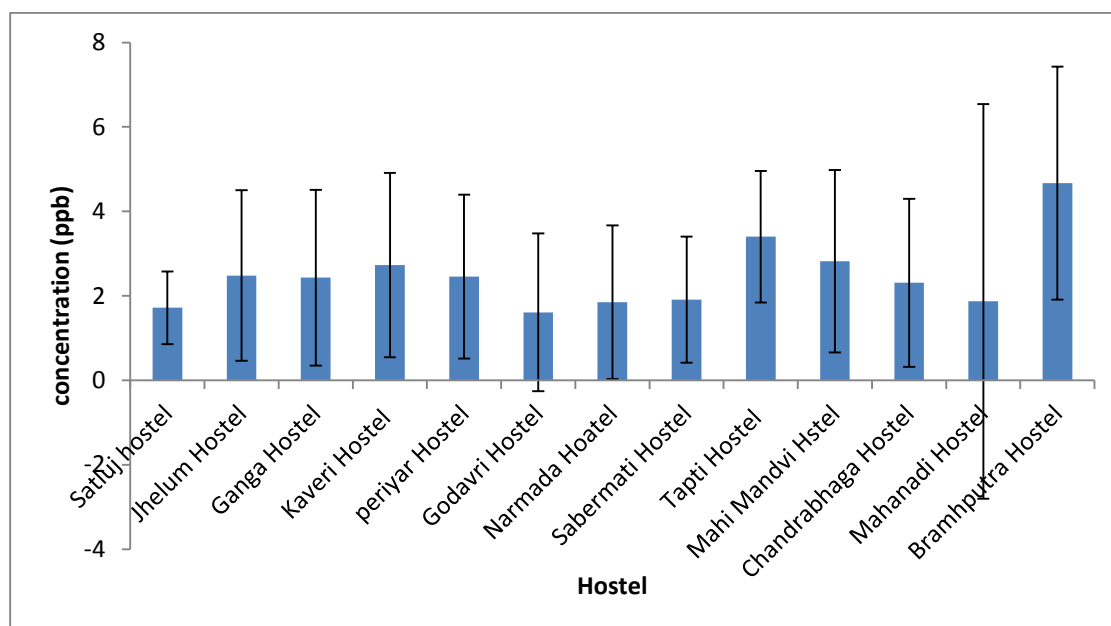


Fig. 2: Mean concentration and standard deviation of indoor ozone concentration during night time

From the Table 4 it is revealed that the concentration of ozone during the daytime is very high as compared to the concentration during nights. This higher concentration in daytime is due to (a) photochemical reactions of NO_x and VOCs in the presence of sun light which enhances the concentration of ozone in outdoor environment (Sillman, 1999; Pitts and Pitts, 2000) (b) Increased number of automobiles which emit NO_x which is a precursor of ozone formation (c) the high influx of ozone through open windows and doors.

The highest concentration during daytime varied from a maximum value of 24.45 ppb at the Godavari hostel (with a mean of 10.74 ppb) to a minimum value of 9.08 ppb at Chandrabhaga hostel (with a mean of 5.51 ppb), whereas lowest concentration varied from a maximum value of 2.05 ppb at Mahi & Mandavi hostel to a minimum value of 0.01ppb at the Periyar hostel. The standard deviation from the mean value is also calculated for all the sites. Maximum standard deviation of 7.32 ppb was found in Godavari hostels while Sabarmati hostel showed minimum standard deviation of 1.89 ppb a similar result was reported by Singh (Singh et al., 2014)

Table 4: The maximum, minimum, mean and standard deviation concentrations of ozone at different Hostel

Hostel	Day					Night				
	mean	S.D.	Max.	Min.	COV	mean	S.D.	Max	Min.	COV
Sutlej	5.48	5.57	18.23	0.91	1.01	1.72	0.86	03.70	0.40	1
Jhelum	6.49	3.57	12.44	0.61	0.55	2.48	2.02	10.91	0.21	0.81
Ganga	5.18	2.85	13.13	0.17	0.55	2.43	2.08	08.60	0.12	0.86
Kaveri	8.2	5.42	20.53	0.41	0.66	2.73	2.18	12.09	0.61	0.80
Periyar	8.55	5.69	21.22	0.01	0.67	2.46	1.94	09.98	0.03	0.79
Godavari	10.74	7.32	24.45	0.57	0.68	1.61	1.87	08.37	0.10	1.16
Narmada	4.97	2.75	09.49	0.19	0.55	1.86	1.82	09.53	0.23	0.98
Sabarmati	1.09	1.89	10.33	0.13	1.73	1.91	1.49	09.46	0.45	0.78
Tapti	2.99	2.79	10.52	0.08	0.77	3.4	1.59	09.82	1.31	0.46
Mahi-Mandvi	7.56	3.47	10.07	2.05	0.46	2.82	2.16	08.76	0.38	0.77
Chandrabhaga	5.51	2.93	09.08	0.70	0.53	2.31	1.99	08.64	0.30	0.86
Mahanadi	3.2	3.07	12.39	0.04	0.96	1.87	4.67	09.24	0.02	2.50
Brahmaputra	6.05	3.17	15.21	0.29	0.52	4.67	2.76	13.05	2.01	0.59

An examination of Table 4 reveals that Godavari, Periyar and Kaveri hostels are associated with the maximum concentration of ozone ≥ 20 ppb (24.45, 21.22 and 20.53 ppb respectively). This might have been due to the higher anthropogenic activities in the area of campus during the daytime. It is pertinent here to mention that these hotels are in close proximity of the main road of the JNU campus which has a high volume of vehicular traffic. In addition, restaurant, and bank housing electronic equipment like Computer, printer, etc. This emission of NO_x and VOCs from automobiles, VOCs from the restaurant and bank activities may be responsible for the formation of ozone in the vicinity of the hostels (Kumar et al, 2104)

Sutlej and Brahmaputra hostels also showed a considerable concentration of ozone (18.23 and 15.2 ppb respectively). The higher concentration in Sutlej hostel might be attributed to its closeness (~50 meters) to KC market (restaurants, photocopy machines, color lab etc.). Although Brahmaputra hostel is quite far away from the

activity of mid campus, but some restaurants in front of the hostel and its closeness to the main bus stand might have been the reason of higher concentration of ozone. All the other hostels, Jhelum, Ganga, Narmada, Sabarmati, Tapti, Mahi & Mandavi, Chandrabhaga and Mahanadi did not show a noticeable variation in ozone concentration.

Though, during the night time, more or less a similar concentration of ozone was observed in all the hostels but the highest concentration ranged from a maximum value of 13.05 ppb (with a mean of 4.67ppb) at the Brahmaputra hostel to a minimum value of 3.7 ppb (with a mean of 1.72 ppb) at Sutlej hostel, while the lowest concentration varied from a value of 1.31 ppb at Tapti hostel to a value of 0.02 ppb at Mahanadi hostel (Fig 3). The standard deviation during night time was found to be highest for Mahanadi with a value of 4.67 and lowest for Sutlej hostel with a value of 0.86. The ozone levels in indoor hostels are plotted for every hostel (supplementary Fig. 1 to 24).

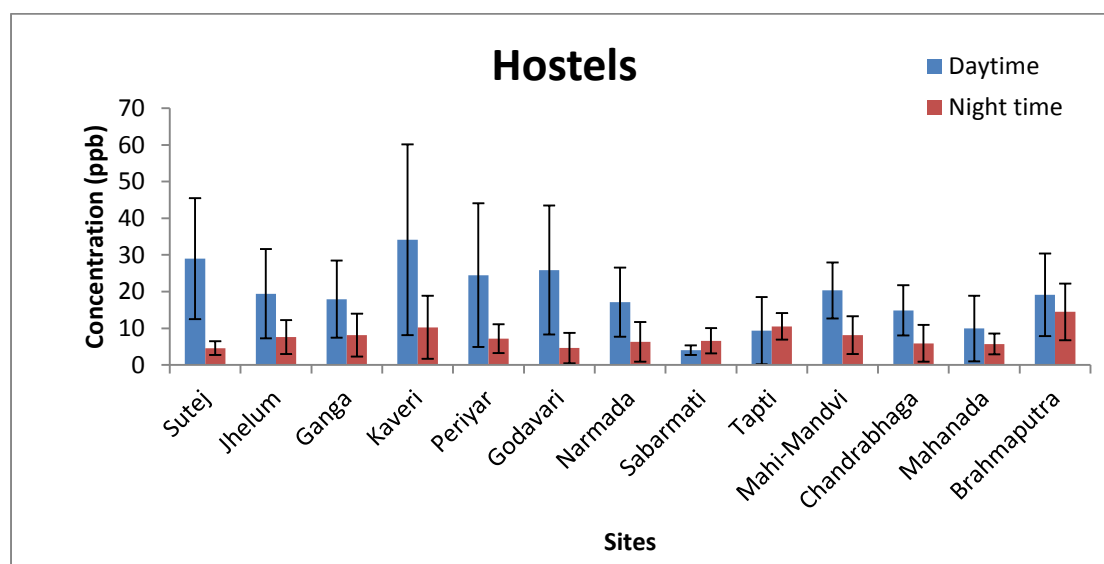


Fig. 3: Mean indoor ozone concentration in different hostels during daytime and night time

Though, during the night time, more or less a similar concentration of ozone is observed in all the hostels but the highest concentration ranged from a maximum value of 13.05 ppb (with a mean of 4.67ppb) at the Brahmaputra hostel to a minimum value of 3.7 ppb (with a mean of 1.72 ppb) at Sutlej hostel, while the lowest concentration varied from a value of 1.31 ppb at Tapti hostel to a value of 0.02 ppb at Mahanadi hostel. The standard deviation during night time is found to be highest for Mahanadi with a value of 4.67 and lowest for Sutlej hostel with a value of 0.86.

Photochemical activity results in in-situ production of ground level ozone from morning till afternoon. The concentration of ozone decreases with the decrease in solar radiation. Ozone being a highly reactive species has a very important role in atmospheric chemistry. Once produced, ozone is rapidly consumed primarily by NO_x and VOCs. However, due to the greater rate of production of ozone from its precursor gases during daytime, build-up of ozone is observed till afternoon. During nighttime, absence of ultra violet light (UV light) forbids ozone production; thereby the effective removal processes of ozone from the atmosphere get enhanced. Thus a diurnal variation of ozone levels observed a maximum concentration around noon or early afternoon (Lal et al., 2000) with the values gradually decreasing as afternoon to till night.

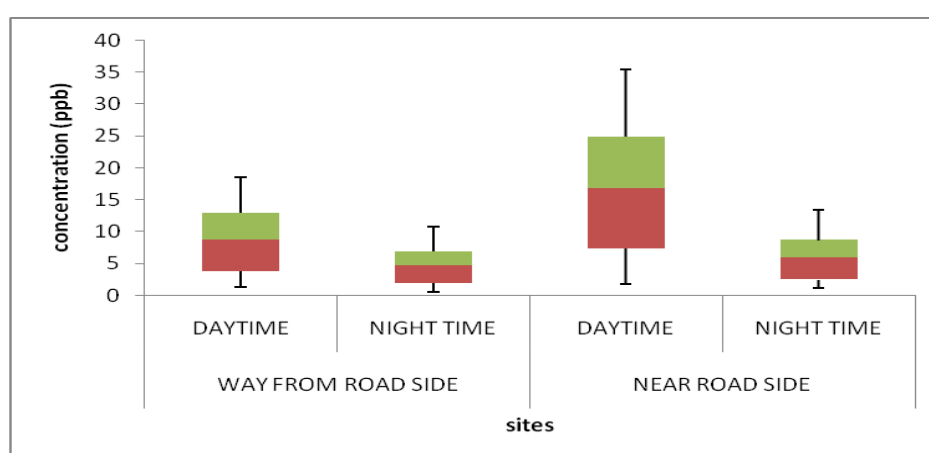


Fig. 4: Maximum and minimum indoor ozone concentration in all hostels during daytime and night time

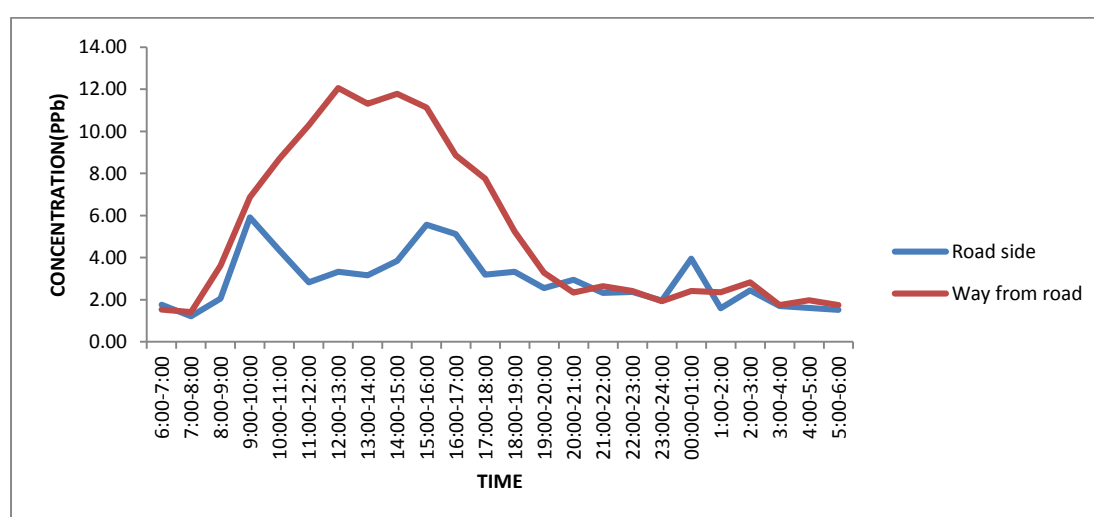


Fig. 5: Maximum indoor ozone concentration in all hostels during daytime

In the box plots reveals that the ozone concentration is observed higher near the road side during the daytime (≥ 25 ppb) and night time (≥ 10 ppb) as compare to way from road side during the daytime (≥ 10 ppb) and night time (≥ 5 ppb) (Fig 4). This higher concentration in daytime near road side due to the transport activates which might be responsible for photochemical reactions of NO_x and VOCs in the presence of sun light which enhances the concentration of ozone in outdoor environment (Seinfeld, 1998; Sillman, 1999; Pitts and Pitts, 2000). The emissions of NO_x from number of automobiles which are a precursor of ozone formation during the daytime which might be responsible the high influx of ozone through open windows and doors (Fig 5). The meteorological parameters play an important role both during day time as well as night time. They are responsible for the formation, transport as well as dispersion of ozone and other precursors. Temporal variation of ozone can also be directly influenced by the variation of local meteorological parameters such as solar radiation, temperature, wind speed and wind direction. At night, no ozone is formed due to the absence of photochemical activity. It was observed that high concentration of ozone appears in situations with high pressure. It is known that high-pressure conditions suppress the turbulence and ozone remains trapped under a stable nocturnal boundary layer near the surface. Bulk Richardson Number is another surface layer scaling factor which determines the stability of the atmosphere (Ghosh et al, 2013)

Table 5: A comparison of indoor ozone concentrations in different countries

S.No.	Country	Location	Ozone concentration (ppb/ $\mu\text{g}/\text{m}^3$)
1	Sweden ^a	Room	1-9 $\mu\text{g}/\text{m}^3$
2	Lithuania(Vilnius) ^b	Room	200 $\mu\text{g}/\text{m}^3$
3	Denmark ^c	Room	≤ 1.0 to 150 ppb
4	J.N.U. , New Delhi, India	Room	16.30 ppb

a. Y-H. Mi (2006)

b. Bycenkiene et. al. (2009)

c. Hansen et. al. (1986)

The result shows the maximum concentration of ozone in Denmark followed by Lithuania. The present study reveals that the ozone concentration in the indoor

environment (of JNU campus is well below the permissible limits prescribed by CPCB, India.

CONCLUSION

In the present study, indoor and outdoor ozone concentrations were measured at different locations of hostels within J.N.U. campus. Among the hostels, during daytime, Godavari has the highest mean ozone concentration in the indoor environment and Sabarmati has the lowest mean ozone concentration. During night time, Brahmaputra hostel showed the maximum ozone concentration followed by Tapti hostel and lowest concentration was observed at Godavari hostel. In terms of coefficient of variation (COV) Sabarmati hostel has the maximum value during daytime, whereas, in the night Godavari has the maximum value. At Sutlej hostel COV values (~ 1.0) were found to be similar during the day as well as in the night. The relative high value of COVs of these sites pointed towards the better dispersion of ozone concentration in comparison to other sites.

The present study reveals that the ozone concentration in the entire indoor environment of the JNU campus lies in the range (2.81 to 4.17 ppb for 24 hours) are well below the permissible limits ($100 \mu\text{g}/\text{m}^3$ for 8 hours) prescribed by CPCB, India. Also the outdoor ozone concentration is found to lie in the range (13.93 ppb to 78.15 ppb for 8 hours), which well above the standard ($100 \mu\text{g}/\text{m}^3$ for 8 hours) prescribed by CPCB.

Thus, as far as surface ozone levels are concerned, the indoor environments on the university Campus are safer, but outdoor ozone levels are certainly a cause of concern. In the order to device measures to limit the surface ozone levels, it is imperative that monitoring of NO_x and VOCs can be suggested and implemented on the University campus.

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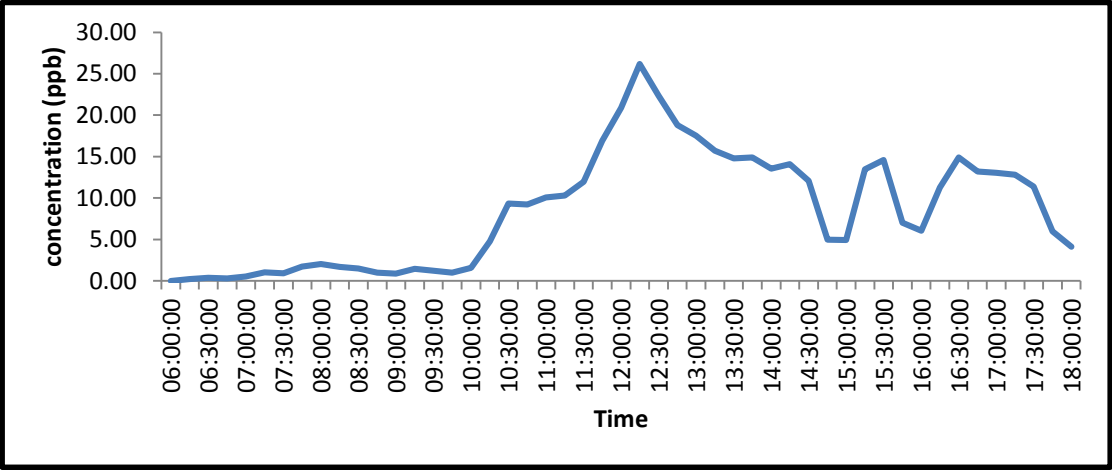
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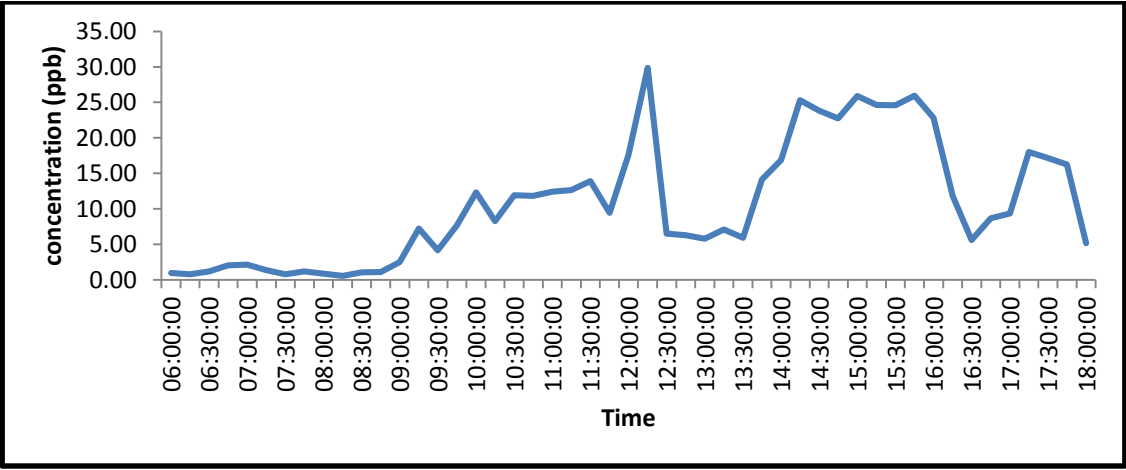
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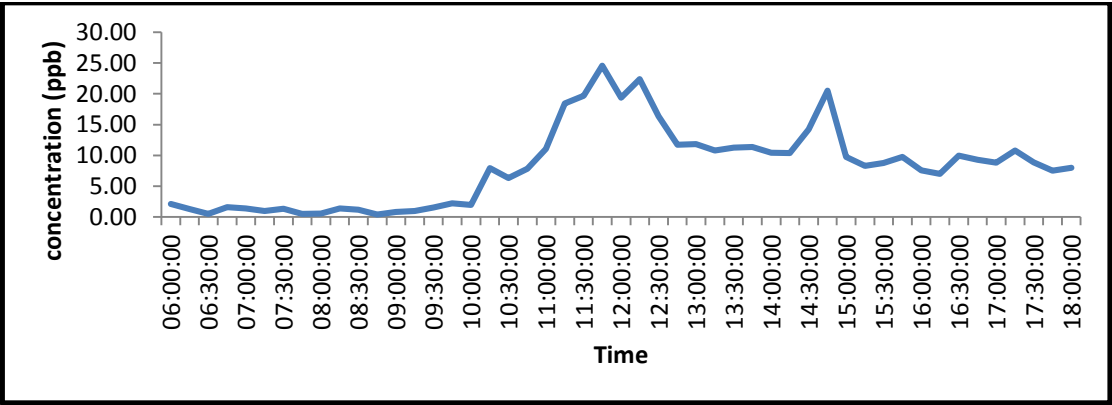
SUPPLEMENTARY



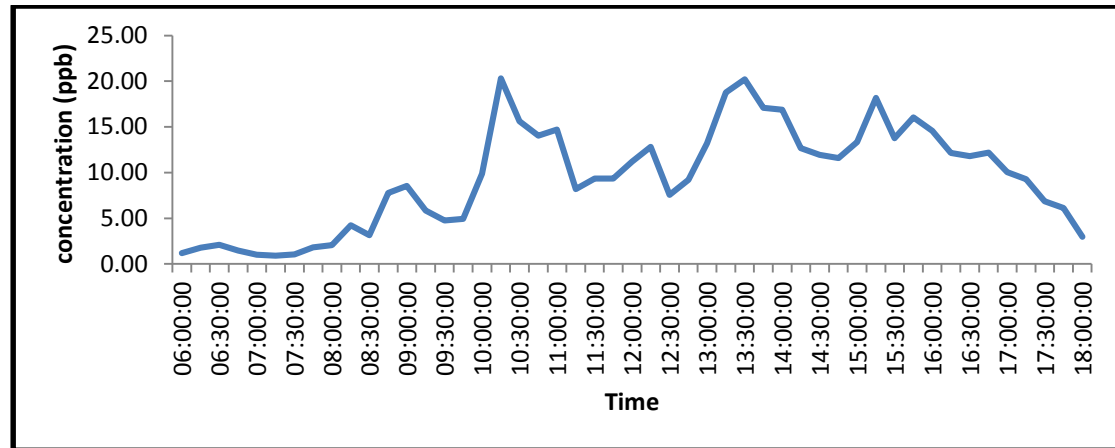
SFig 1: Indoor ozone concentration in Godavari hostel during daytime.



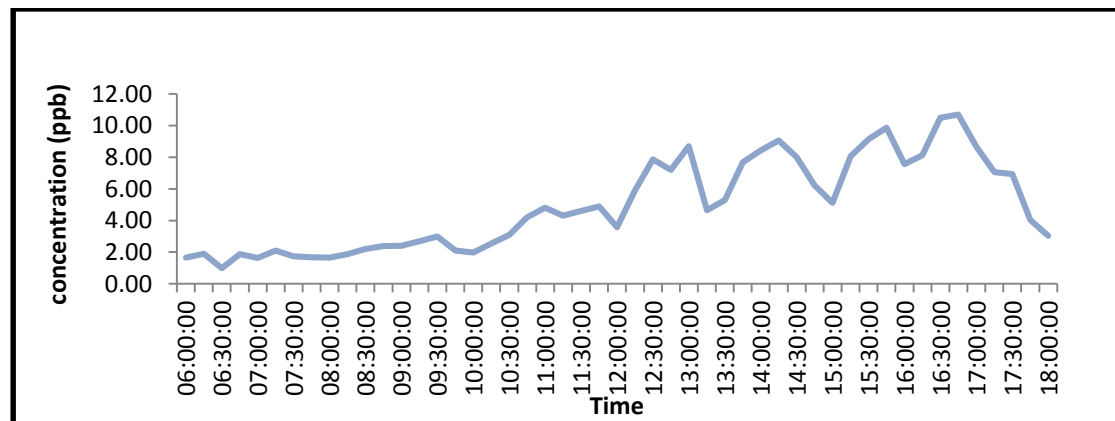
SFig 2: Indoor ozone concentration in Periyar hostel during daytime.



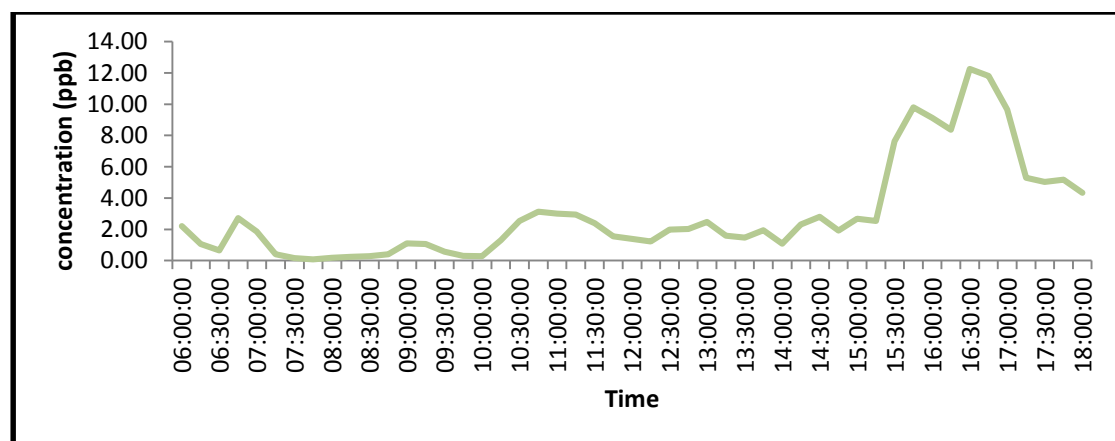
SFig 3: Indoor ozone concentration in Kavari hostel during daytime.



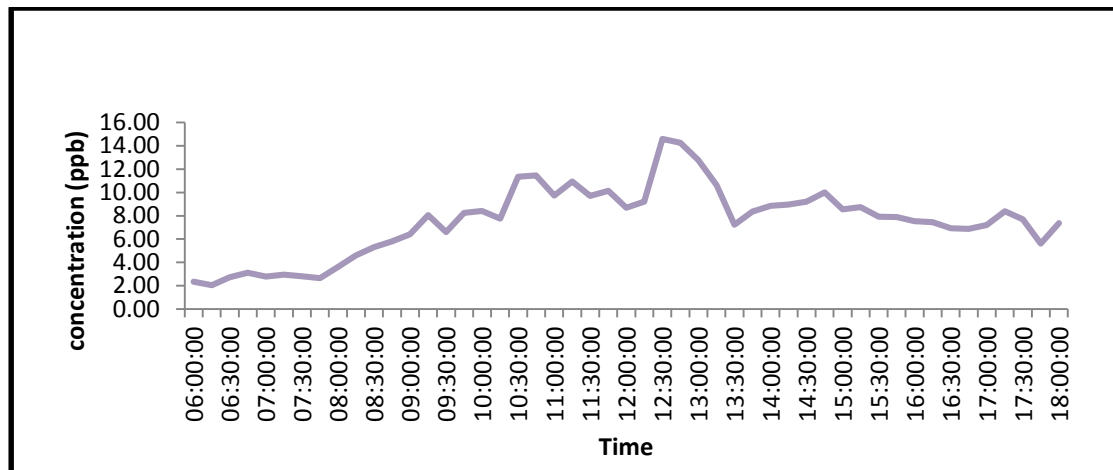
SFig 4: Indoor ozone concentration in Sutej hostel during daytime.



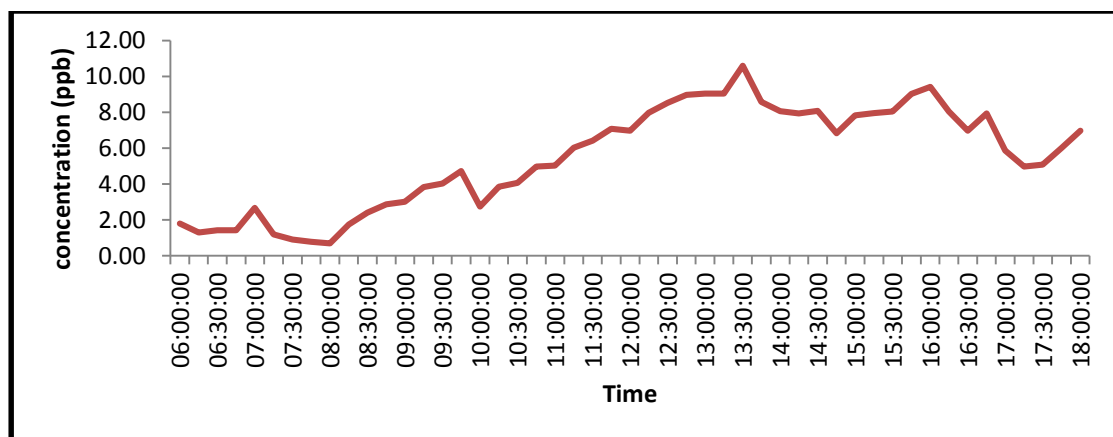
SFig. 5: Ozone concentration in Narmada Hostel during daytime.



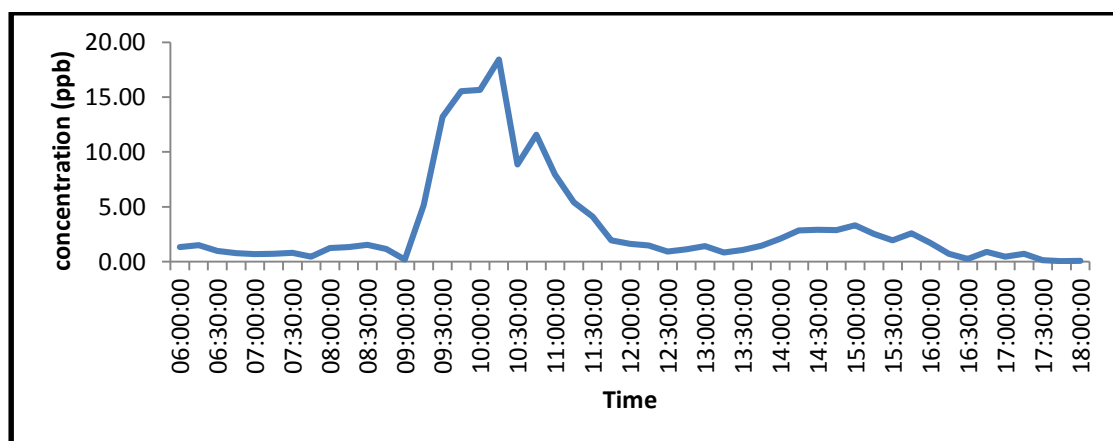
SFig 6: Indoor ozone concentration in Tapti hostel during daytime.



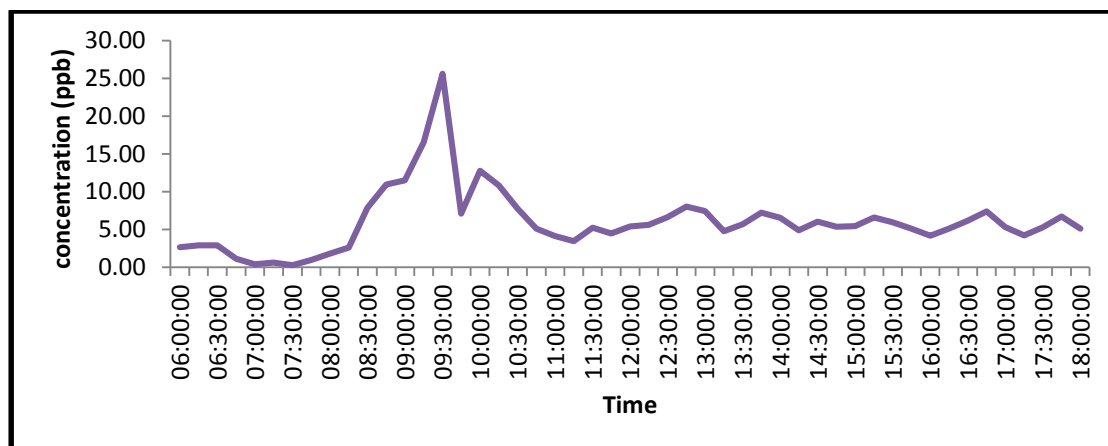
SFig. 7: Indoor ozone concentration in Mahi & Mandovi hostel during daytime.



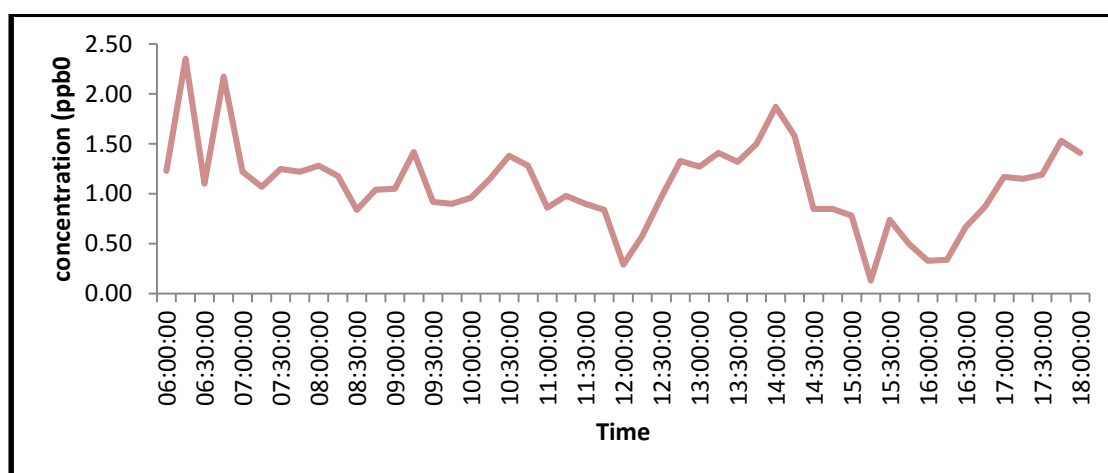
SFig. 8: Indoor ozone concentration in Chandrabhaga hostel during daytime.



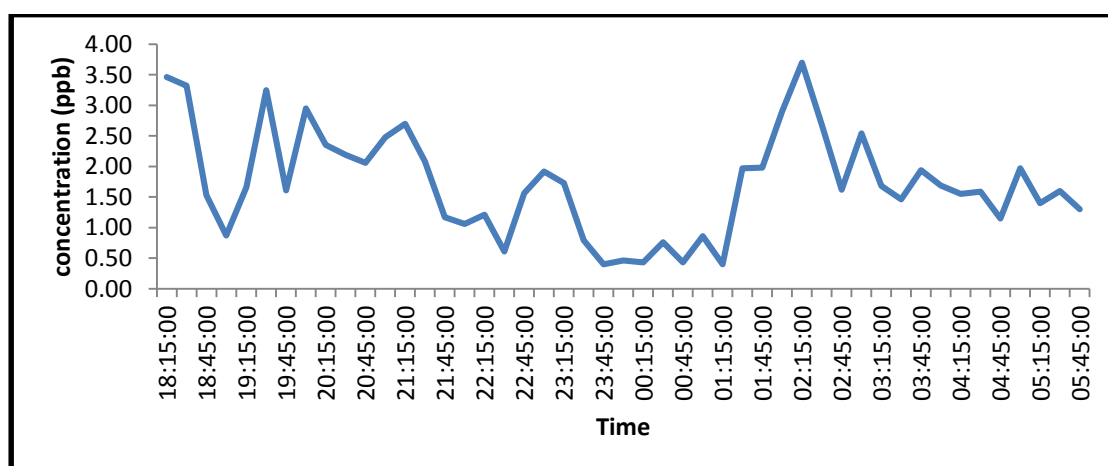
SFig. 9: Indoor ozone concentration in Mahanadi hostel during daytime.



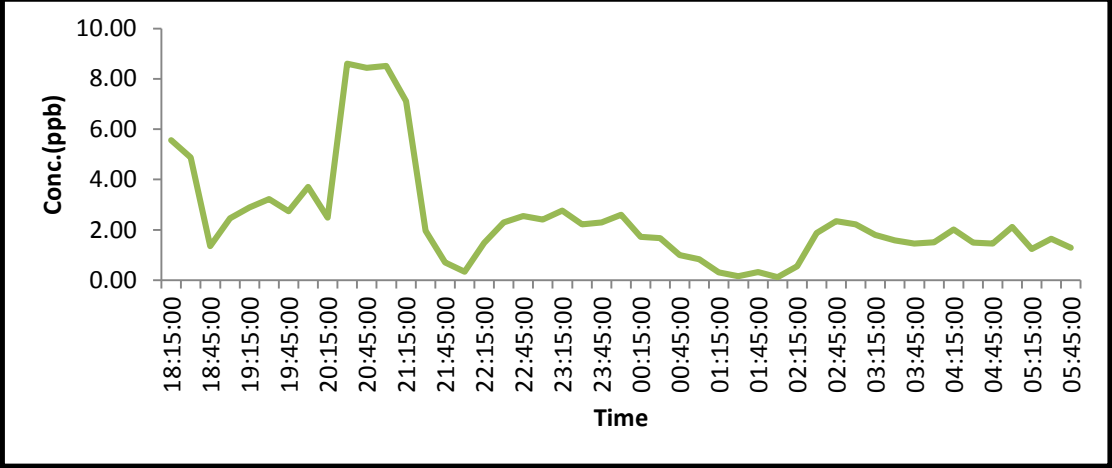
SFig. 10: Indoor ozone concentration in Brahmaputra hostel during daytime.



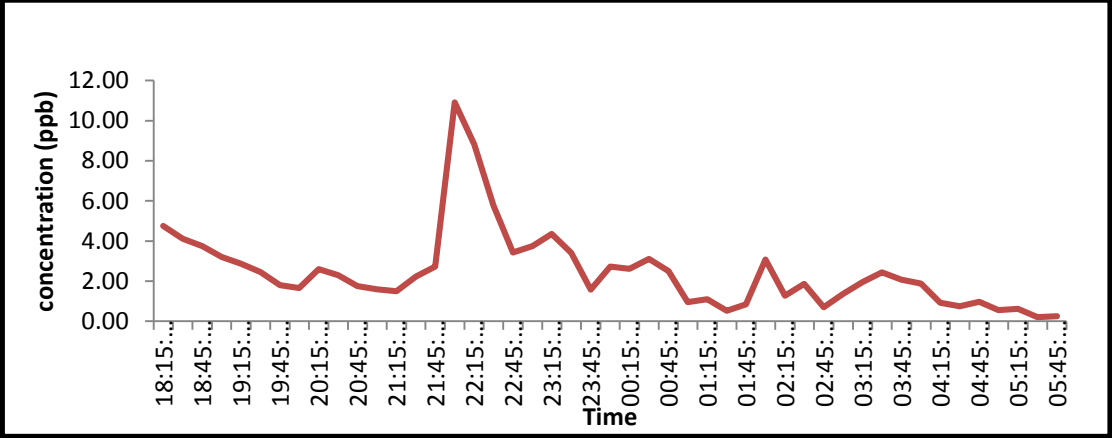
SFig. 11: Indoor ozone concentration in Sabarmati hostel during daytime



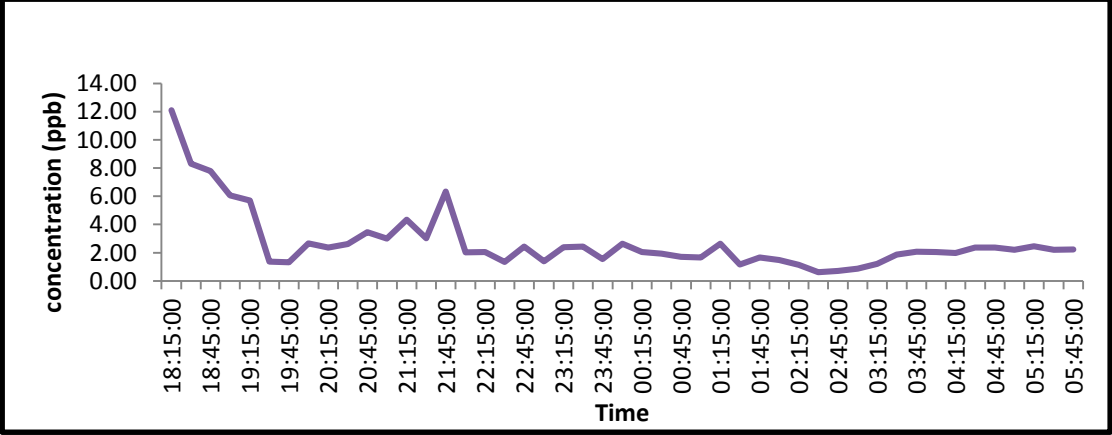
SFig. 12: Indoor ozone concentration in Sutlej hostel during night time.



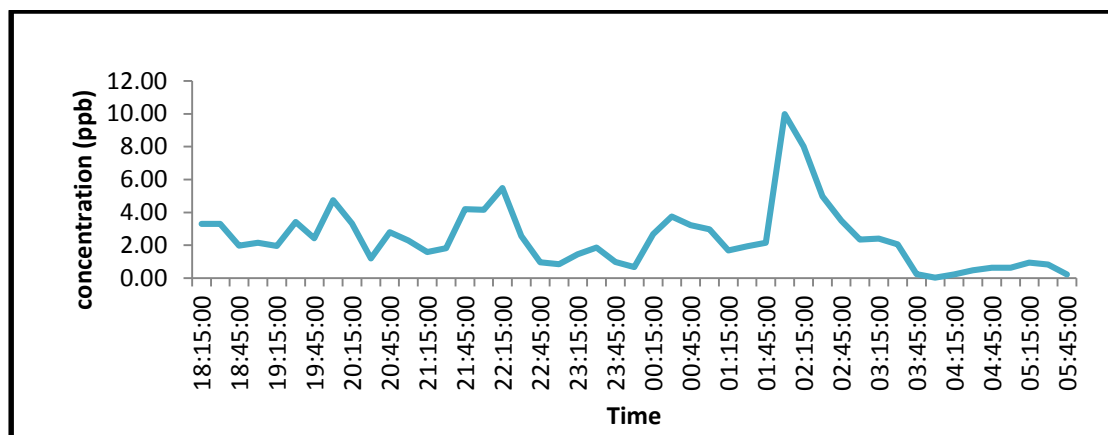
SFig 13: Indoor ozone concentration at Ganga Hostel during night time



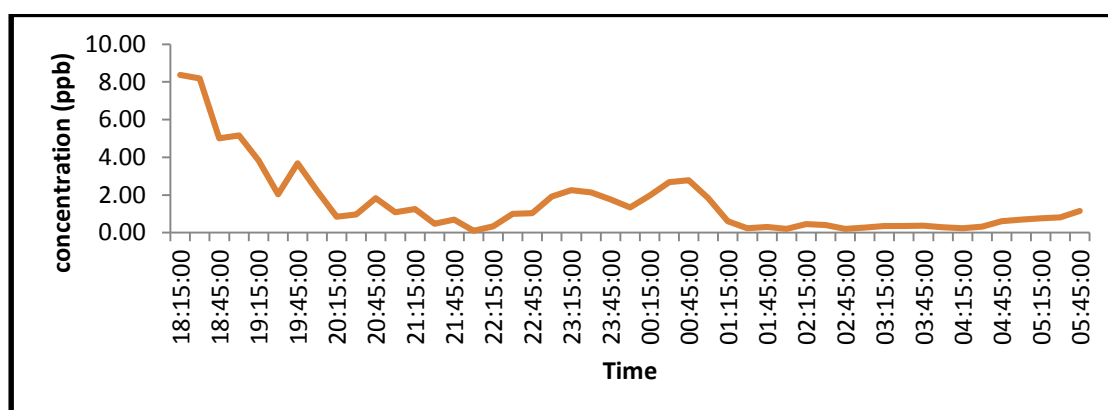
SFig 14: Indoor ozone concentration in Jhelum hostel during night time.



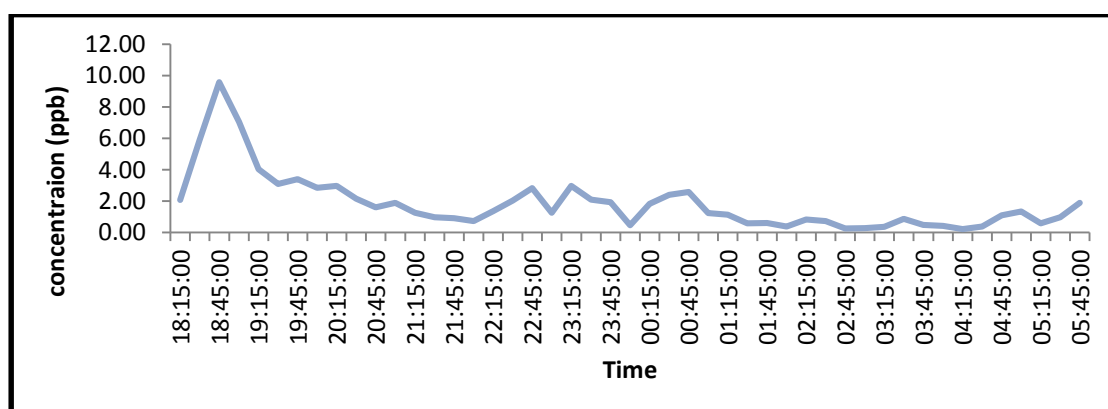
SFig. 15: Indoor ozone concentration in Kaveri hostel during night time.



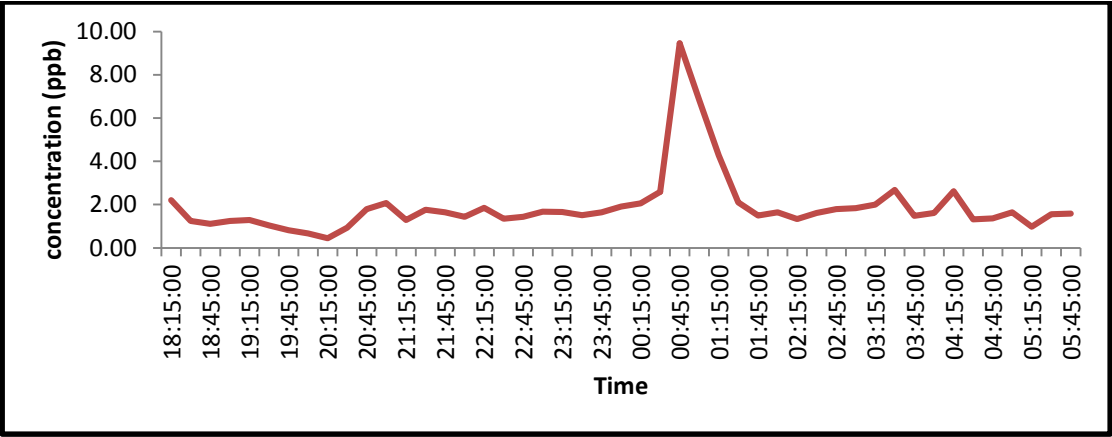
SFig. 16: Indoor ozone concentration in Periyar hostel during night time.



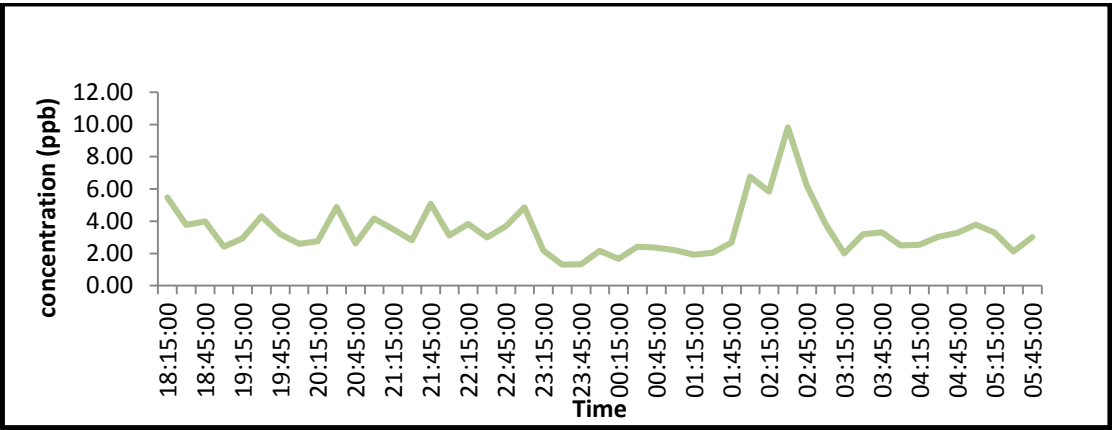
SFig. 17: Indoor ozone concentration in Godavari hostel during night time



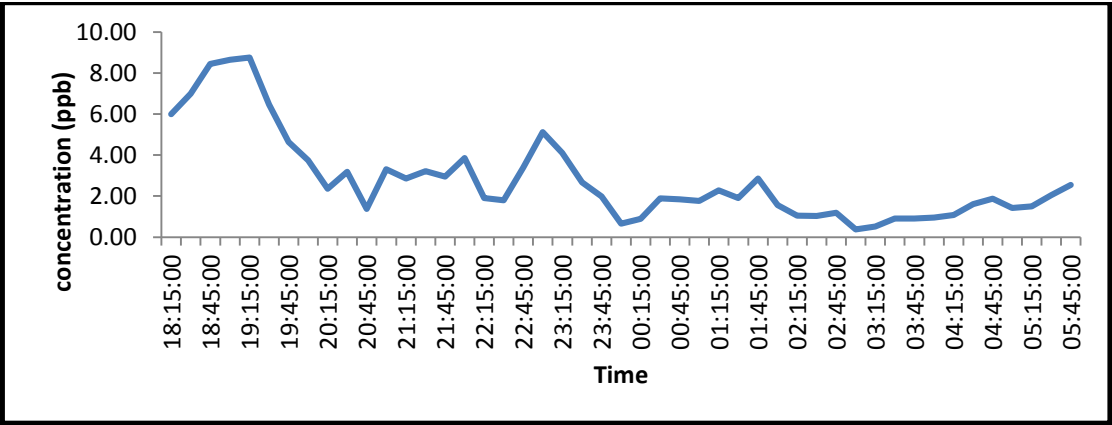
SFig. 18: Indoor ozone concentration in Narmada hostel during night time.



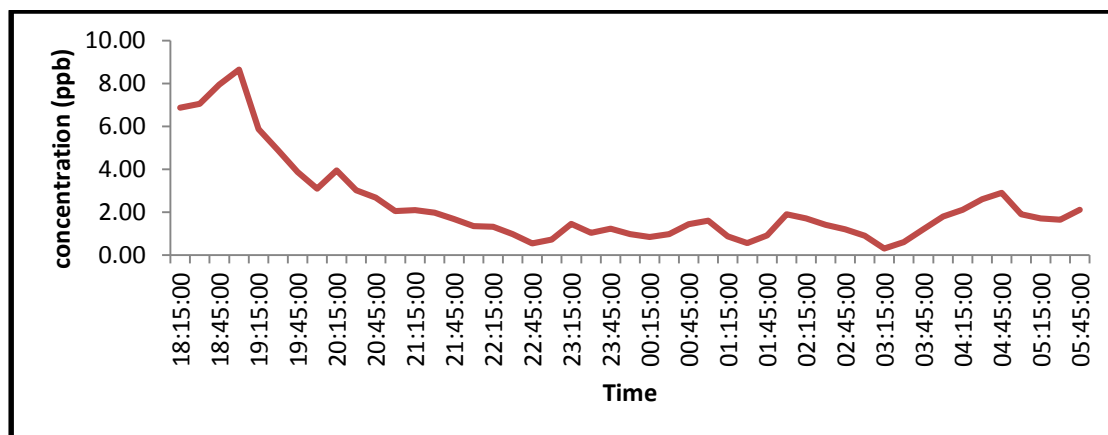
SFig. 19: Indoor ozone concentration in Sabarmati Hostel during night time



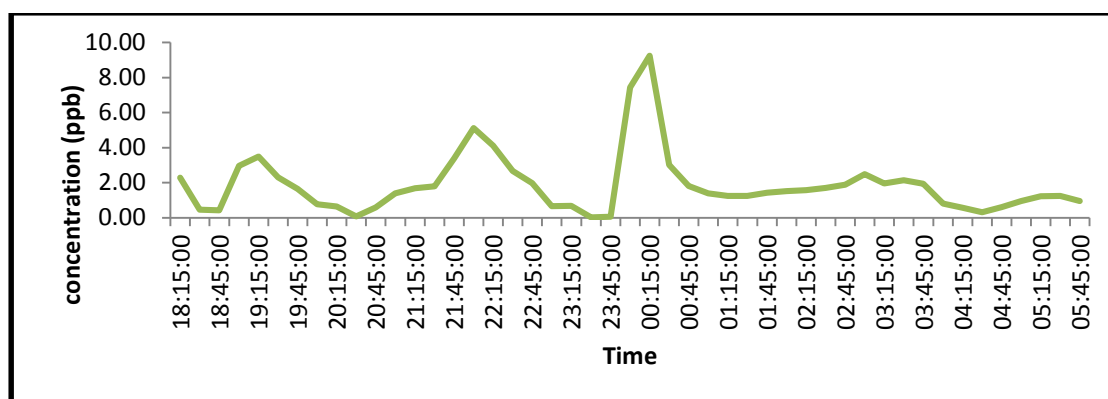
SFig. 20: Indoor ozone concentration in Tapti Hostel during night time.



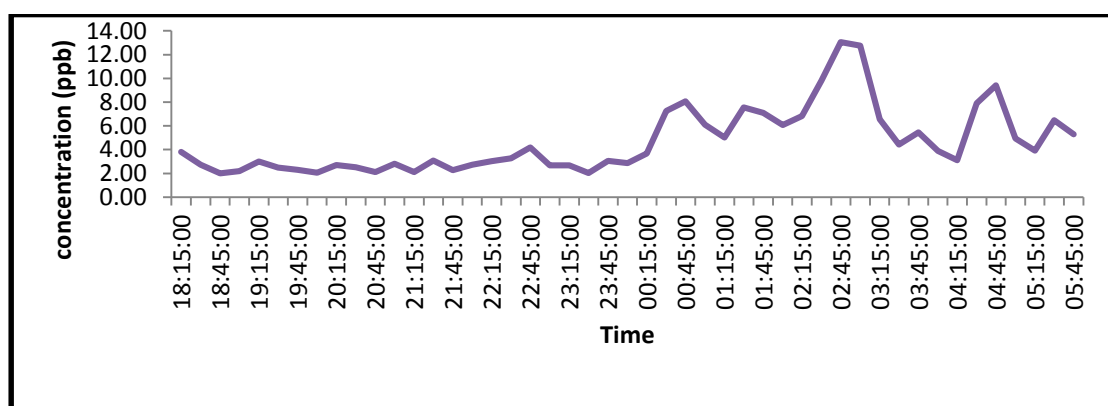
SFig. 21: Indoor ozone concentration in Mahi & Mandavi Hostel during night time.



SFig. 22: Indoor ozone concentration in Chandrabhaga Hostel during night time.



SFig. 23: Indoor ozone concentration in Mahanadi Hostel during night time.



SFig. 24: Indoor ozone concentration in Brahmaputra Hostel during night time.

