Case Study Paper

Indoor and Built Environment

Indoor Built Environ 2013;22;4:710–718

Accepted: April 16, 2012

Air Pollution in Micro-Environments: A Case Study of India Habitat Centre Enclosed Vehicular Parking, New Delhi

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Key Words
Indoor air pollution · Hazardous pollutants · Enclosed parking garages · Construction period · Micro-environment · Deteriorates

Abstract
Indoor air pollution deteriorates the quality of air present in the household or enclosed areas. The polluted air present contains hazardous pollutants like carbon monoxide (CO), nitrogen oxides, volatile organic compounds and particulate matter which could be respired easily. When inhaled, these pollutants can cause negative health impacts leading to various pulmonary and cardiac problems and in extreme conditions to mortality. Enclosed parking garages are one of the major sources for indoor air pollution. The reason for buildup of combustion pollutants is a lack of proper ventilation system in enclosed parking areas. Therefore, proper planning is required during construction design rather than post-construction addition of this necessary facility. In this study, the micro-environment of India Habitat Centre (IHC) parking area and their pollutants concentrations was examined; the pollutants concentrations were compared with ambient air concentrations. The pollutants found were in higher concentrations than the ambient; e.g., CO level ranged from 12 ppm to a maximum level of 164 ppm, exceeding the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and WHO guidelines; similarly $PM_{2.5}$ concentration averaged more than 100 $\mu g \cdot m^{-3}$ with a maximum concentration of 234 $\mu g \cdot m^{-3}$ and NO_2 concentration were 25 to 56 $\mu g \cdot m^{-3}$, thereby leading to indoor air pollution and main sufferers are the guards and employees of IHC. Mitigation measures have been suggested for ameliorating the problem.

Introduction

Technological advances have changed the way we consider our lives, raised our comfort levels and has brought about improved development in all the fields, be it agriculture, industry or transportation, but it has also

DOI: 10.1177/1420326X12448489
Accessible online at http://ibe.sagepub.com
Figures 1–3 and 6–9 appear in colour online

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affected the air we breathe, water we drink and the land we live on. Unlike water pollution, air pollution is a global problem and the local aspect at micro-level is usually ignored. For instance, people spent majority of their time indoors as statistics on the American people's way of living show that they spend 87% of their time indoors, 8% outdoors and 5% in transportation (by car, bus, train or plane) [1]. In Europe, similar tendencies are observed: 90% indoors, 6% outdoors and 4% in transportation [2]. As a consequence, indoor air quality has a preponderant role in evaluating the people's exposure to air pollutants.

In India, the situation is worse as women and children have overwhelming exposure to indoor air pollution [3]. This happens as traditional biomass fuels account for 80% of India's rural domestic energy consumption [4]. When these fuels burn in simple cook stoves during meal preparation, air inside home gets heavily polluted with smoke containing carbon monoxide (CO), oxides of nitrogen and sulfur dioxide, aldehydes, dioxins, polycyclic aromatic hydrocarbons and respirable suspended particulate matter [5]. The resulting human exposure exceeds recommended WHO level by factors of 10, 20 [6] or more. Acute poverty forces poor people to die as medical facilities are beyond their reach in most parts of India. Like poverty and unemployment, pollution is an evil for the entire human civilization. Indeed, poverty, infectious diseases and environmental degradation are the true "Axis of Evil". Poor people works in the poor environment leading to various health hazards [7]. So in a country like India, poverty breeds pollution and pollution breeds poverty.

Indoor air pollution can be traced to prehistoric times when humans first moved to temperate climates and it became necessary to construct shelters and use fire inside them for cooking, warmth and light. Fire led to exposure to high levels of pollution, as evidenced by the soot found in prehistoric caves. Approximately half the world's population and up to 90% of rural households in developing countries still rely on unprocessed biomass fuels in the form of wood, dung and crop residues. These are typically burnt indoors in open fires or poorly functioning stoves. As a result, there are high levels of air pollution, to which especially those women responsible for cooking and their young children are most commonly exposed. In developed countries, modernization has been accompanied by a shift from biomass fuels to more sophisticated fuels which are available; still households often continue to use simple biomass fuels. The proportion of global energy derived from biomass fell from 50% in 1900 to around 13% in 2000 [8]. However, there is still evidence of increasing use of biomass fuels among the poor. Poverty is one of the main barriers to the adoption of cleaner fuels. The slow pace of development in many countries suggests that biomass fuels will continue to be used by the poor for many decades. Notwithstanding the significance of exposure to indoor air pollution and the increased risk of acute respiratory infections in childhood, chronic obstructive pulmonary disease and lung cancer, the health effects have been somewhat neglected by the research community, donors and policy-makers.

Though indoor air pollution in rural households is a matter of concern, air pollution in other micro-environments is still out of focus. CO levels were measured up to 120 ppm in an underground parking garage in the United Kingdom on busy days as vehicles queued to leave the parking facility [9]. The buildup of emission pollutants in the kiosk areas can be aggravated depending on their location. Pay kiosks located on a gradient were observed to have higher CO concentrations, and cars were found to generate up to 50% more CO on up-gradients than on down-gradients [10]. CO concentrations were recorded up to 450 ppm within the exit ramps of a 13-level underground parking garage in the United Kingdom [9]. These high CO concentrations were measured during a traffic congestion that forced the leaving vehicles to fill the ramps all the way down to the lowest parking level with exit times of 25–30 min. Poor traffic flow patterns within a parking facility can lead to high CO concentration buildup. In this investigation of a parking facility serving a shopping centre in the United Kingdom, CO levels up to 120 ppm were recorded at an internal traffic junction [9]. At this junction, there are several conflicting traffic flows that can contribute to traffic congestion within the parking garage.

In a country like India, the process of urbanization is expanding, and multistorey buildings for offices and commercial purposes are now a symbol of the urbanization process today. The enclosed basement parking is a built-in component of these buildings and commercial centres. Since it is very difficult to have post-construction air pollution control measures in the enclosed basement parking areas, care has to be taken at the planning stage to incorporate air pollution control components like proper ventilation system, etc. [11].

The problems associated with inadequate ventilation system design include the following:

1. Short-circuiting of the ventilation airflow, due in most cases to the placement of the exhaust vents in the proximity of the supply vents [12].

2. Reliance on air infiltration (i.e., non-mechanical ventilation) to supply fresh air to a large section of the parking garages (typically near ramps) for a parking facility in Los Angeles, California [13].
3. Obstruction of free airflow within the garage due to the existence of structural elements or parked vehicles for a two-level parking garage in Hartford, Connecticut [13].
4. Placement of outdoor air intake near pollutant source such as traffic fumes, restaurant exhausts or exhaust vents of the parking garage itself. It was found that the fresh air intake for the parking area of a Canadian public library is located at the street level on a busy downtown area [14]. This fresh air intake location leads to high CO concentrations in both the garage and the library.

Combustion pollutants generated in an enclosed parking garage may disperse into occupied spaces adjoining the garage, such as offices, shopping centres or hotels. A number of studies have reported the problem of buildup of emission contaminants in spaces attached to parking garages. An investigation in a seven-storey office building with one-storey basement and a two-and-one-half-storey underground parking garage revealed that the upper floor offices had higher CO concentrations during some periods in winter and autumn, since CO was transported from the garage through elevator shafts and stairwells in the absence of stack effects [15]. Similar findings were reported for a newly constructed office building in Portland, Oregon [15]. High levels of hydrocarbons were found inside the office space. These hydrocarbons originated from the basement loading deck and the parking garage levels and travelled through stairwells and elevator shafts, especially during the cold months when the stack effect is significant. Motor emissions can penetrate into occupied spaces through a variety of paths. For instance, an unblocked opening in the concrete structure had provided a direct path for CO from a parking garage ramp to adjoining offices, subjecting occupants of the offices to very high levels of CO and subsequent health problems [16].

Hence the present study will be informative for the engineers and policy makers, for which the IHC parking areas were studied. Here, fine particulate matter ($PM_{2.5}$), fine fraction in the ambient Respirable Suspended Particulate Matter (RSPM), the CO level and NO_x concentrations in parking areas were monitored and then compared all parameters with the ambient air concentrations.

Study Methodology

Study Design

India Habitat Centre (IHC) known as Cultural centre of the capital city of India is situated near Lodhi road 3 km away from the historic India gate. It houses many government as well as private offices dealing with habitat-related issues along with world class convention centre. It is a well-known place for the city's intellectuals. To cater the motor-vehicle parking needs, IHC has its own basement parking spaces called P1 and P2. These parking areas have three entrance and exit points (Gate no. 1, 2 and 3; Figure 1). Only Gate no. 2 allows two wheelers along with four wheelers. On average, about 2,500 to 3,000 vehicles park in the parking area daily. It has been observed that most of the vehicles are parked in P1, while few prefer to park their vehicles in P2. The parking area is well guarded by private security guards at the entrance as well as inside the parking area. The drivers and security guards spent maximum number of their duty hours in these car parks. Air quality monitoring was done in both the parking areas (P1 and P2). To compare the level of pollution, data was also collected from ambient air. The chosen sampling site was near the entrance of The Energy and Resources Institute (TERI) at P1 and P2, where guards used to sit. Since the duty hours of TERI guards are confined up to 8 p.m., the monitoring was done only for 8 h for security reasons. The parameters monitored were $PM_{2.5}$, CO, oxides of nitrogen as NO_2. Sampling was carried out during months of June–July, 2008 on alternate days. Sampling equipment was kept at a height of approximately 1.5 m in order for the sampling to occur in the breathing zone of a seated person.

Materials and Methods

Particulate Matter

Samples were collected using SKC pumps and BGI cyclones fitted with 37-mm glass fibre filter (0.8 microns). Pumps were calibrated prior to the sampling at a rate of 1.5 L/min using rotameter. Electronic microbalance (Least count 1 µg) was used for gravimetric analysis. All filter papers were kept in the desiccator for at least 24 h before sampling. One filter paper was also kept for blank correction. The filter paper was kept in a specially designed cassette after taking initial weight and then flow was adjusted to 1.5 L/min. After a specified time of 8 h, the flow was observed and then the pump switched off. The filter paper assembly was removed from the pump and kept in a desiccator. After 24 h, the final weight of the filter

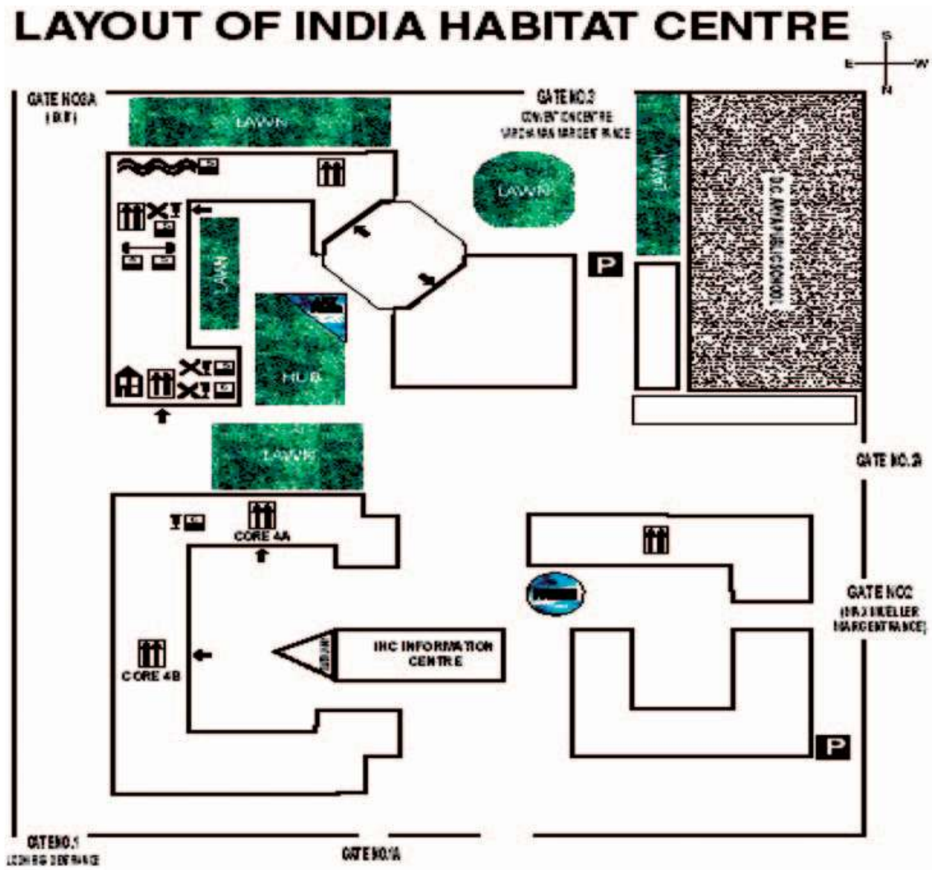

Fig. 1. Layout of India Habitat Centre, Lodhi Road, New Delhi.

paper was measured and the analysis was done by Gravimetric technique.

CO

A passive sampler called Dräger was used, which can record CO per second up to 15-min intervals with a least count of 1 ppm. It can record from 0 to 2000 ppm. Care must be taken to clear the data logger before use. The device was kept at a height of 1.5 m for a specific period. The Sensor was kept exposed without any obstruction. A portable electrochemical cell-based monitor (Pac III, Dräger) was used for CO monitoring. All the instruments were checked and calibrated before every experiment. A span gas of 1,000 ppm was used to calibrate the monitors. The data recorded in computer was viewed in a graphical as well as tabular form.

Estimation of NO_2

Jacob and Hochheiser method [17] was used and NO_2 was collected by bubbling air through a sodium hydroxide–sodium arsenite solution to form a stable solution of sodium nitrite. The nitrite ion produced during sampling was reacted with phosphoric acid, sulphanilamide and EDTA to form an azo dye, the absorbance of which was measured at 540 nm on a spectrophotometer. The concentration was estimated using a standard graph made with known concentration of NO_2. Monitoring of NO_2 was carried out for 8 h.

Results

Comparison of $PM_{2.5}$ in Different Micro-Environments

The $PM_{2.5}$ concentration in different microenvironments, i.e. P1, P2 and ambient, are shown in graphical form below. From the graph it has been observed that the 8-h average $PM_{2.5}$ concentration at P1 was always found to be higher than that at P2. This may be due to more vehicle movement at P1 and proximity to the ambient environment (background concentration) (A manual count of moving vehicles for peak hours was conducted in P1 and P2 and it was found that movement in P1 (4/min) was more than that of P2 (1/min), since vehicles move to P2 parking area through P1).

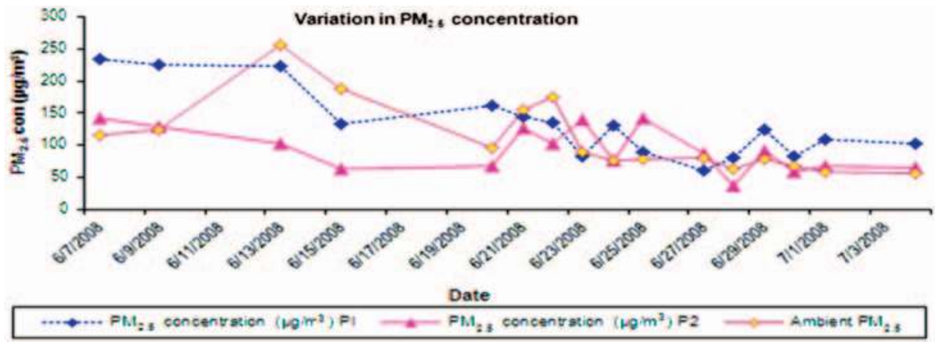

Fig. 2. $PM_{2.5}$ concentration at P1 and P2 and its ambient concentration.

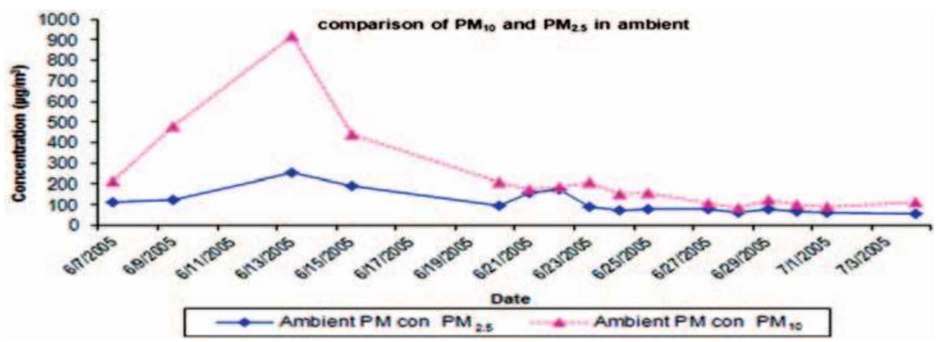

Fig. 3. Comparison of ambient PM_{10} and $PM_{2.5}$ concentration.

Most of the cases the $PM_{2.5}$ concentrations at P1 and P2 were higher than the ambient $PM_{2.5}$ concentration.

It was observed that the contribution of $PM_{2.5}$ in the ambient RSPM ranges from 65–90%. The PM_{10} and $PM_{2.5}$ concentrations in the ambient location were found to follow the same trend.

The PM_{10} concentrations in P1 and P2 micro-environment were not measured, due to resource constraints. Much of the measurements were on $PM_{2.5}$. The monitored data of $PM_{2.5}$ and PM_{10} in P1 and P2 as compared to the ambient over the study period are shown in Figures 2 and 3.

Carbon Monoxide

CO levels were found to be nearly the same for both the parking areas, with P1 concentration little higher than P2. The maximum CO concentration was 164 ppm in the parking areas. The average CO concentration at P1 was found to be 7 ppm while that at P2 was 6 ppm. At P1, the 8-h average CO concentration exceeded the WHO guideline value of 10 ppm twice, and nearly was thrice close to the WHO guideline value, while the exceedance was observed twice at P2. The maximum concentration at P1 during the entire monitoring period varied between 19 ppm and 42 ppm and the minimum concentration fluctuated between 0 ppm and 7 ppm with the average varied between 5 ppm and 12 ppm. The corresponding concentrations at P2 were 10 ppm to 164 ppm (maximum), 0 ppm to 5 ppm (minimum) and 2 to 10 ppm (average). The data are shown in Figures 4–6.

Nitrogen Dioxide

In comparison to ambient air concentration, very high concentrations of NO_2 were observed for both the parking areas. The trend of NO_2 concentration at P1 is higher than P2 and concentration of P2 is higher than that of ambient air at IHC site. Although the NO_2 level at P1 is higher, it follows the same trend as the ambient one that clearly reflects the effect of background concentration on the parking place. Unlike the ambient one, the range of variation of NO_2 at P2 was less and at P1, the variation was significant. The temperature effects on NO_2 level was distinct, as indicated by a drop of temperature due to rain, the NO_2 level illustrated a decreasing trend. The maximum 8-h average concentration of NO_2 at P1, P2 and ambient were 56, 42 and 37 $\mu g/m^3$, respectively, while the 8-h-average minimum concentration of NO_2 at these locations were 35, 27 and 19 $\mu g{\cdot}m^{-3}$, respectively. On average, the average concentrations throughout the monitoring period at P1, P2 and ambient were found to

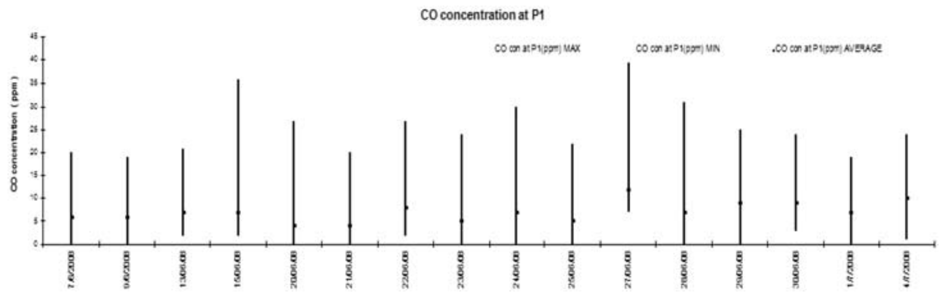

Fig. 4. Carbon monoxide (CO) concentration at P1.

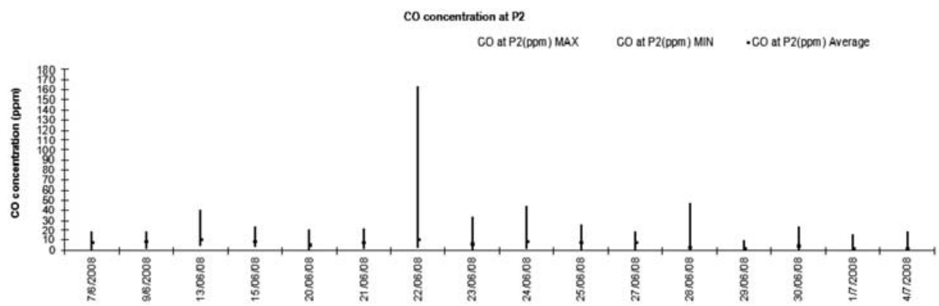

Fig. 5. Carbon monoxide (CO) concentration at P2.

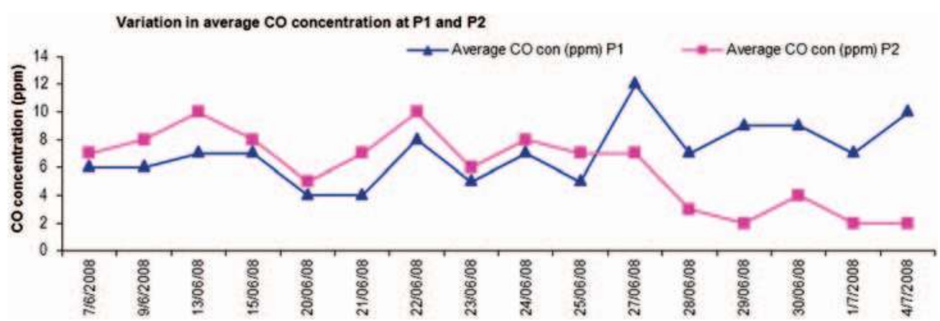

Fig. 6. Variation in average Carbon monoxide (CO) concentrations at P1 and P2.

be 46, 36 and 27 $\mu g \cdot m^{-3}$, respectively. The data are shown in Figures 7–9.

Discussion

For key pollutants such as particulate matter (PM), there are no established thresholds of exposure below which population health impacts are absent [18]. Recent evidence showed that air pollution could lead to inflammatory processes that would mediate a variety of diseases, which suggests an expanding range of health impacts related to air pollution exposure [18]. The American Heart Association (AHA) concluded that exposure to particulate matter (PM) air pollution could contribute to cardiovascular morbidity and mortality [19]); which could be significant not only for the IHC TERI guards but also the drivers who usually stay in the drivers' lounge present in the car park, where a lot of drivers spend their time. A reduction in life expectancy can be attributed directly to exposure to $PM_{2.5}$ [20], which was found in high concentrations in our study. Moreover, it has been observed that exposure to nitrogen oxides can cause respiratory diseases and aggravate pre-existing conditions [21].

The results and the reported scientific literature clearly show a need to develop some kind of ventilation systems within the parking lots so as to prevent further damage to

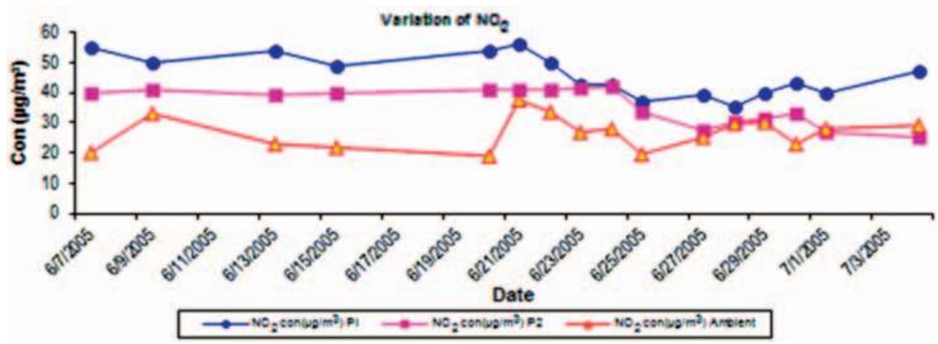

Fig. 7. Variation of NO_2 at P1, P2 and its ambient concentration.

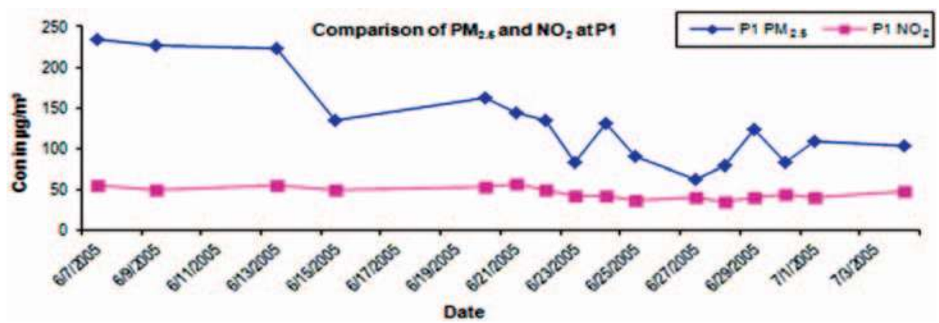

Fig. 8. Comparison of $PM_{2.5}$ and NO_2 at P1.

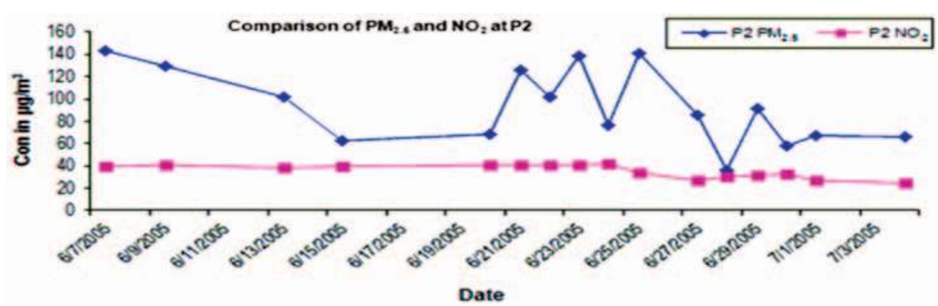

Fig. 9. Comparison of $PM_{2.5}$ and NO_2 at P2.

the health of the people who occupy the building for significant durations of the day, e.g. the security guards and the drivers. This raises the need to also perform an exposure assessment exercise on the vulnerable people. In the absence of indoor air quality standards in India, there has been no monitoring exercise performed. This study underscores the need to monitor such spaces regularly and also to include further parameters such as volatile organic compounds and formaldehyde.

There may also be a possibility of these pollutants penetrating into the main building due to design defects and through joints and cracks within the building, which could lead to sustained exposure of employees in the buildings above the parking lots to the air pollutants. As the health effects due to sustained exposure are known, there should be requirements to study the air quality inside these buildings and check for any correlation with the high pollution levels inside the parking lots.

The study was conducted in the summer and monsoon seasons. With the onset of monsoon, the pollution level dropped significantly. On the rainy days due to wash-out effect, the $PM_{2.5}$ clearly showed decreasing trend. Similar trend was also significant in case of NO_2. But in case of CO, the trend was not significant. CO level in all parking places were very high, many times exceeding the WHO/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) guidelines.

Conclusions and Suggestions

Enclosed basement parking areas are likely to be features of urbanization in future. Since post-construction measures of controlling air pollution in those parking areas is very difficult, sometimes technically and economically unsustainable, consideration regarding the need to reduce impact of air pollution has to be taken during planning and construction stage. Hence, engineers and planners need to be aware of the pollution aspects in parking areas. It was observed that the air pollution levels in IHC parking are much higher than ambient pollution levels. The TERI guards and drivers who spend significant amounts of time in those parking areas would be prone to exposure to these air pollutants. Knowing the impacts of PM on health and mortality, there is an urgent requirement to develop some kind of ventilation system for the parking lots. There is also a need to check air quality within the main buildings as well to check for potential leakages.

Though the study was confined to a short span of time, it can be a building block for future detailed analysis. Based on this study, the following suggestions are made:

- Monitoring has to be done throughout the year preferably in all seasons (summer, winter and monsoon),
- Monitoring should be done at various critical points such as entrance and exit points and in areas where people visit frequently for getting the clear picture of the pollutant levels, as well as the office buildings to check for any upward movement trends.
- More parameters (i.e. CO_2, volatile organic compounds (VOCs), total hydrocarbons (THC), PM_{10} etc.) should be included for a detailed study,
- Monitoring should be done for 24 h so that we can compare results with the existing standards,
- Types and frequency of vehicular movements should be studied properly,
- Exposure assessment studies should be conducted.

Acknowledgement

The authors are thankful to Dr. R Uma for her immense guidance and support, without her work the present study would not have been successful. We are thankful to all The Energy and Resources Institute (TERI) employees and laboratory in-charges who helped in monitoring the various pollutants at parking sites, which constituted a major portion of the study. We would also like to thank the management of India Habitat Centre (IHC), Lodhi Road, for all the help they have provided.

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