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Indoor air quality assessment of an existing apartment located in Indian tropical city, Bhubaneswar

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ABSTRACT

Introduction: A proper investigation on indoor pollution level in economical apartments is important, where the provision for ventilation is limited. A series of experiments were conducted in the houses within an existing economical apartment in Bhubaneswar, India to evaluate various pollutant levels.

Materials and methods: Temperature, relative humidity, CO, CO_2, Particulate Matter (PM_{10} and $PM_{2.5}$), Formaldehyde and Total volatile organic compounds in the bedrooms and kitchens are measured by pollution meters. The experiments were conducted with doors and windows closed conditions. The readings were taken on a four consecutive working day in February 2023 at an interval of 3 h (9:00 am to 9:00 pm).

Results: The day wise temperature and humidity variations inside the bedroom and kitchen shows a reverse trend. At the afternoon, the indoor temperature becomes high, while during the night time humidity becomes the highest. The day wise indoor CO_2 and CO variation trend is pretty similar. Both CO_2 and CO concentrations in bedrooms are the highest in the evening. In contrast to that CO_2 and CO concentrations in kitchens becomes maximum during noon time. High particulate matter concentration at outdoor and indoor is observed at the evening time. Higher formaldehyde (HCHO) and Total Volatile Organic Compounds (TVOCs) concentration at the indoor is observed at noon and afternoon time.

Conclusion: The results obtained were compared with the recommended values of World Health Organization (WHO) and National Ambient Air Quality Standards (NAQIS). The results revealed that all measured parameters are at a higher level than the recommended values except the indoor CO_2 concentrations.

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Introduction

Indoor air environment refers to the quality and characteristics of the air inside buildings, homes, and other enclosed spaces where people live, work, or spend time. This includes factors such as temperature, humidity, ventilation, and the presence of pollutants, allergens, and other contaminants in the air. According to the United States Environmental Protection Agency (US EPA) 2006, indoor air pollution levels can be 2 to 5 times higher than outdoor air pollution levels [1]. It is also reported that exposure to indoor air pollution can cause health effects such as headaches, dizziness, and fatigue. According to World Health Organization (WHO), around 4.3 million people die every year due to exposure to indoor air pollution [2]. The largest contributors to indoor air pollution-related deaths are household air pollution from cooking with solid fuels and ambient Particulate Matter (PM) pollution and outdoor air pollution from plant emission, crop burning and vehicle movement etc. [3].

Indoor air pollutants can come from a variety of sources, such as cooking, smoking, cleaning products, and building materials. Common indoor air pollutants are particulate matter, Total Volatile Organic Compounds (TVOCs), formaldehyde, carbon monoxide, and radon [4]. Maintaining good indoor air quality requires proper ventilation, regular cleaning and maintenance of HVAC systems, and minimizing the use of products that release harmful chemicals into the air. Air purifiers and other air-cleaning technologies can also be used to improve indoor air quality. The effects of air pollution on occupant health depend on a variety of factors such as the type and concentration of pollutants, duration of exposure and individual susceptibility. A study was conducted to investigate the relationship between indoor air quality in bedrooms for both naturally ventilated and air-conditioned systems [5]. The study found that naturally ventilated bedrooms have lower levels of CO_2 but have a higher level of particulates as compared to air-conditioned bedrooms. Another study is conducted in a standard class room [6]. From the study, it was observed that through the natural ventilation, CO_2 can be effectively removed. However, still the CO_2 concentration remains at a higher level near the wall region. The presence of volatile organic compounds in the indoor air of residential homes in Ottawa, Canada has been investigated [7]. The results indicated that all targeted TVOCs were present in indoor air at a significant level, but the values were lower than those found in a previous year's study. A comparative study has been made on TVOCs in residential houses in China and Japan in 2006 and 2007 [8]. It was found that the concentrations of indoor TVOCs were significantly higher in China than in Japan, and the TVOCs were higher in indoor environments than outdoors. The study also revealed that the carcinogenic risk exposure was 10 times higher in China compared to Japan. The study conducted in Japan, measured TVOCs in 116 and 66 houses in winter and summer respectively [9]. Most of the cases TVOC levels met Japanese guidelines, but in winter, acetaldehyde levels surpassed the standard value. A study compares the emission characteristics of formaldehyde (HCHO) and TVOC of an eco-friendly material in indoor environments comparing with general materials [10]. It is reported that eco-friendly materials emit lower initial TVOC levels, gradually decreasing over time. On the other hand, general materials take longer to reach acceptable TVOC concentrations. While HCHO emission trend also seems like TVOCs emission pattern.

Impact of particulate matter on human health becomes a great concern across the globe. A relationship between indoor PM_{10} and oxidative damage has been investigated to plasmid DNA in China [11]. The study included houses with smokers and non-smokers for air sampling. From the investigation, it was found that the PM_{10} generated in the living rooms and kitchens of smokers was more toxic and could cause 50% plasmid DNA damage. In contrast, the homes of non-smokers contained less bio-reactive PM_{10}. The investigation concluded that soot and unknown fine particles were responsible for the plasmid DNA damage as well. The presence of fine particulate matter in coronary artery for a long time may increase the risk of genetic modification [12]. It is reported that $PM_{2.5}$ exposure increases the DNA damage probability than PM_{10}. The impact of different cooking fuels on Indoor Air Quality (IAQ) in rural communities of Paraguay has been investigated where mainly the concentration of $PM_{2.5}$ and CO has been recorded [13]. From the investigation, it is found that houses using charcoal and wood for cooking had significantly higher concentrations of $PM_{2.5}$ and CO compared to those using electricity and LPG. These concentrations exceeded the recommended values by the WHO. It is suggested that the choice of cooking fuel has a significant impact on IAQ in low-income rural communities. The IAQ in homes with open combustion sources such as peat, coal, wood, and cooking gas was investigated in Scotland and Ireland [14]. The study assessed the IAQ with no open combustion source with smoker occupants. The analysis revealed that households using gas stoves or solid fuels had satisfactory levels of pollutants within the WHO guideline values. However, households with cigarette smokers had poor IAQ. The impact of various environmental factors on the IAQ of newly built apartments, including construction characteristics, temperature, humidity, and occupation duration has been studied [15]. From the study, it is observed that the levels of pollutants in the apartments were generally within acceptable limits, except for formaldehyde and toluene. The study also recommended evaluating IAQ based on the load ratio of major pollutant sources and observed a reduction in pollutant levels after one year of occupancy. The effect of gas cooking burners on indoor air pollutants, in a dense residential area in California is also studied [16]. From the study, it was found that there was a 165% increase in NO2, 18% increase in CO_2, 25% decrease in formaldehyde, and 4% decrease in $PM_{2.5}$ in the housing with gas cooking burners. It suggests that gas cooking burners may have a significant impact on indoor air quality and should be considered in building design and ventilation strategies. A study was conducted in 55 different schools in Korea to detect indoor air pollutant levels [17]. It was found that the concentration of HCHO (formaldehyde) in the indoor air was significantly higher than the standard value established by the Korean government. Examination of IAQ was done in offices and educational institutes in Delhi, India [18]. The study revealed that occupant density had a significant impact on indoor air pollution. The CO_2 concentrations of office buildings were higher than the ASHRAE baseline, while the measured concentrations of pollutants in educational buildings were lower than those in office buildings. The study also identified ductless air conditioning systems and ineffective air circulation systems as the primary contributors to higher levels of $PM_{2.5}$ in the office buildings. A study is conducted in a school in Chennai, India, where a higher concentrations of Particulate Matters is observed that exceed the National Ambient Air Quality Standards in India [19]. The study suggests that outdoor sources, like traffic emissions are responsible for the high concentrations of PMs, rather than indoor pollution sources. Air quality control national level regulation comparison with various international organizations' standard has been investigated by various authors for Indonesia [20] and India [21]. It has been observed that the national regulatory authority pollutant maximum safe limit is almost closer to the international organizations' standard value. However, a certified limits for many harmful chemical present as indoor pollutants are not included in national regulatory norms of many countries [22]. Japanese guidelines included higher numbers of pollutants in their national regulatory norms as compared to other countries.

From the literature review, it is observed that very few researches have been conducted to evaluate the indoor pollutant concentration in residential buildings situated in tropical cities like Bhubaneswar. In this work, experiments are conducted to evaluate both indoor and outdoor pollutant level throughout a day (9:00 am to

9:30 pm) on four consecutive working days of the fourth week in the month of February 2023. Averaged day wise results are shown as final result. Here, temperature, humidity, CO_2, CO, PM_{10}, $PM_{2.5}$, HCHO and TVOCs concentration are depicted as result.

From the investigation, it is observed that the day-wise temperature and humidity variations inside the bedroom and kitchen exhibit a reverse trend. Just after the noon, the indoor temperature rises significantly, while during the night-time, humidity reaches its peak. The outdoor temperature always a little higher that the indoor temperature but it moves down than the indoor temperature at night. The humidity and temperature variation in kitchen also follows the similar pattern as the bedrooms. Conversely, the day-wise indoor CO_2 and CO variation trends are quite similar. Both CO_2 and CO concentrations in bedrooms are lowest in the morning and night-time, while they peak in the evening. In contrast, CO_2 and CO concentrations in kitchens significantly rises during noon. High particulate matter concentration, both outdoor and indoor, is observed in the evening. A significantly higher concentration of particulate matters is observed at the outdoor as compared to the indoor for the whole day. Similar kind of day-wise PM concentration is observed in kitchens as well. Formaldehyde (HCHO) and TVOCs concentrations indoors are highest at noon and in the afternoon. However, in the kitchen, higher TVOCs are observed in the evening.

The results obtained were compared with the maximum recommended values set by the World Health Organization (WHO) and National Ambient Air Quality Standards (NAQIS). The experiments revealed that the average values of parameters like temperature, relative humidity, carbon monoxide (CO), PM_{10}, $PM_{2.5}$, formaldehyde, and TVOCs are higher than the recommended values proposed by WHO and NAQIS. However, the average value of indoor CO_2 concentrations over a 12-h period falls within the range defined by NAQIS.

Materials and methods

This study was conducted in a selected apartment in Bhubaneswar City, Odisha, India, situated in a hot tropical climate. Due to the rapid urbanisation, people are migrating from different places to Bhubaneswar city for livelihood. According to the 2011 Census, the total number of households in Bhubaneswar was 389,829 and the total population was 881,988. According to a report published by real estate consultancy firm JLL India in 2019, the demand for apartments in Bhubaneswar is growing rapidly and the city has witnessed a significant increase in the number of apartment projects in recent years. The posh area like Patia in Bhubaneswar is becoming overcrowded due to the availability of different kinds of jobs. Hence, several residential projects have been constructed and many are currently under construction. In order to increase the availability of residential house in these areas, many economical apartment buildings are being constructed where the provision for the natural ventilation is compromised. Hence, an economical five-storied apartment situated in Patia is selected for the study. In this apartment, the maximum space is used in construction where the options for natural ventilation are compromised. There are many common walls between houses and very less gaps between the blocks are provided. In this work, the four innermost flats on the middle floor (Third floor) of block-B has been selected for the study those have many common walls and seems to be the less ventilated house. Fig. 1 shows the geographical location of the selected apartment and the satellite image of the building. Fig. 2 illustrates the floor plan of the selected houses (named as house-1, house-2, house-3 and house-4) for experimentation. Fig. 3 shows the detailed plan of one of the house selected for experimentation.

The experiments were conducted on four consecutive days of third week in the month of February 2023. Measurements were conducted in one bedroom and kitchen of the selected houses for 5 times a day in an interval of 3 h. The measurement starts at 9 am and ends at 9:30 pm. In order to achieved the steady state condition, each reading is taken after 5 min with the help of two air quality monitor pollution meters (Smile drive made). One is used for measuring CO and CO_2 and another is for measuring TVOCs, formaldehyde, PM_{10}, $PM_{2.5}$, dry bulb temperature and humidity. Once, the steady state condition achieved, 5 readings are taken at an interval of 5 seconds. The result is obtained by averaging these five consecutive readings. The averaged day wise results are shown as final result. These results are compared with WHO and NAQIS guideline for the further analysis. The readings were taken with room closed condition. Only one person is present inside the room to record the readings. Artificial ventilations are also stopped during the measurement time to avoid any influence of external sources.

Fig. 1. Geographical location and satellite view of the selected apartment

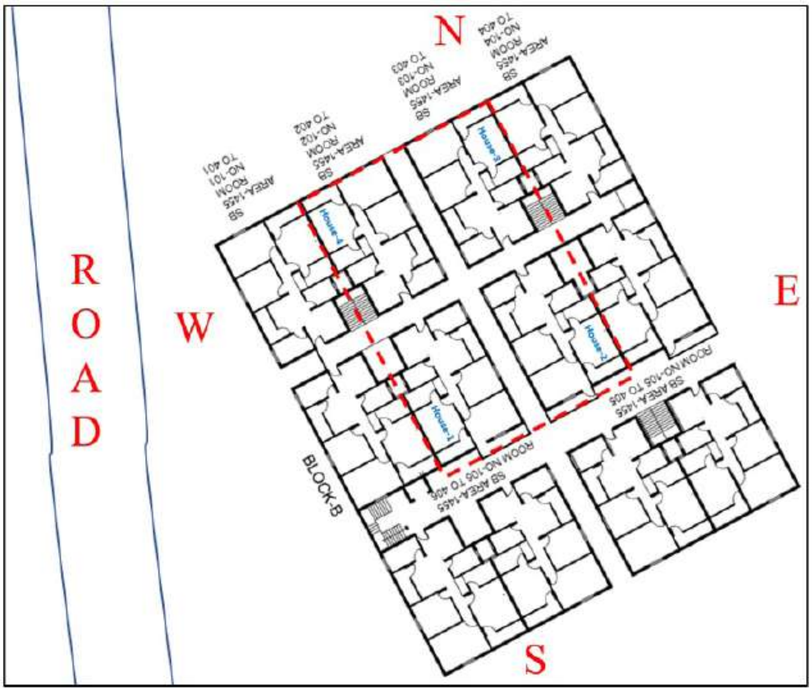

Fig. 2. House layout of 3rd floor (block-B) of the selected apartment

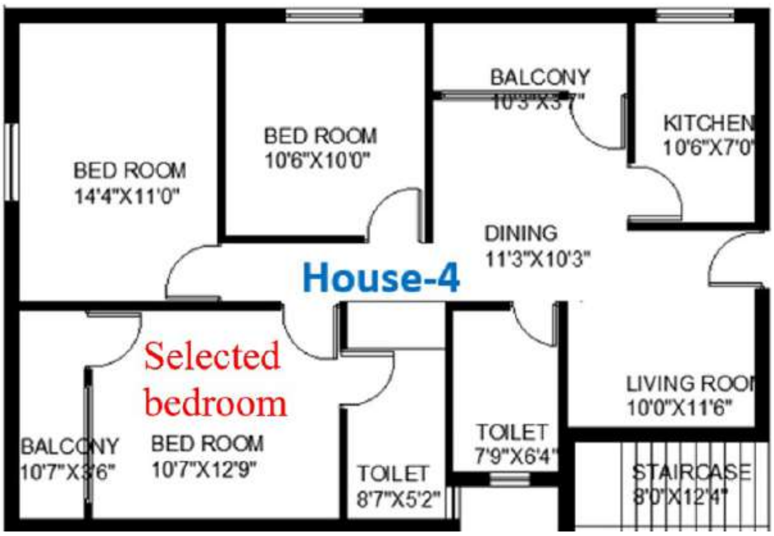

Fig. 3. Detailed layout of sample house-4

Fig. 4. Sample photographs of bedrooms and kitchen during the measurements with the help of air quality monitor

Fig. 4 shows some photographs taken during experimentation in bedrooms and kitchen. For reading, the apparatus were tried to keep in the central position of the bedrooms and kept near the cooking stoves at the kitchens.

Results and discussion

Fig. 5 shows the temperature of the selected bedrooms for the four innermost houses along with the outdoor temperature variation at 9:00-9:30 am, 12:00-12:30 pm, 3:00-3:30 pm, 6:00-6:30 pm and 9:00-9:30 pm. In the same figure, the relative humidity of the selected bedrooms for the four innermost houses along with the outdoor relative humidity variation at 9:00-9:30 am, 12:00-12:30 pm, 3:00-3:30 pm, 6:00-6:30 pm and 9:00-9:30 pm has also been depicted.

From the figure, it is observed that during morning time (9:00 am), indoor temperature is at the lowest level. Similarly, during the night (9:00 pm), the outdoor temperature is at the lowest level. In the morning time, the outdoor temperature is a little higher than the indoor temperature. Both indoor and outdoor temperature increases with progress in time up to 3:00 pm then both indoor and outdoor temperature decreases. During the afternoon period, there is almost no difference between the indoor and outdoor temperatures. During the evening (6:00 pm) and night-time (9:00 pm), the indoor temperature is relatively higher than the outdoor temperature. During the day time, solar radiation makes the building surface heated up and part of the heat is stored in the building materials due to its better thermal conductivity and specific heat. The rate of thermal radiation from the houses becomes slower than the rate of thermal radiation from the outdoor surfaces during the night because the building materials store a higher amount of heat as compared to outdoor surfaces.

From the comparison of the indoor temperature of bedrooms of individual house, it is observed that house-1 & 2 has a lower temperature than house-3 & 4 during the morning time. From Fig. 2, it can be visualized that house-1 & 2 are the most interior flats. It does not have any exposure to direct sunlight. On the other hand, house-3 & 4 have at least one side wall which has no restriction to the exposure of sun rays. Though during the morning time, this wall does not have direct exposure to the sunlight due to its directional position but the reflective sunlight probably is responsible for the heating. Therefore, during the morning time, the indoor temperature of the bedrooms of the house & 4 is at a higher level than house-1 & 2. On the other hand, during the evening and night, the temperature of bedrooms of house-1 & 2 is higher than house-3 & 4 because house-1 & 2 does not have any wall that is exposed to ambient directly. These houses are separated through a narrow corridor from their neighbouring houses. Hence, the stored energy could not be radiated out properly.

From Fig. 5, it is also revealed that the relative humidity variation is almost inversely proportional to the temperature of the house. During the morning time (9:00 pm), both the indoor and outdoor humidity is high but it is the highest during the night-time (9:00 pm). It is obvious that as the temperature of air decreases, its density increases or its specific volume decreases. As a result, the capacity to absorb more amount of moisture decreases. Hence, during night-time, the air moisture holding capacity moves towards the saturation state. Therefore, with a decrease in air temperature, the relative humidity of air increases.

It is observed from figure 5 that the indoor relative humidity is always higher than the outdoor relative humidity. It is due to the addition of moisture from the human body and other accessories present in the bedrooms. House-1& 2 show relatively a higher value of relative humidity as compared to the house-2 & 3's relative humidity. It happens because one wall that has windows and a balcony is exposed to open space and the outdoor humidity affects it significantly.

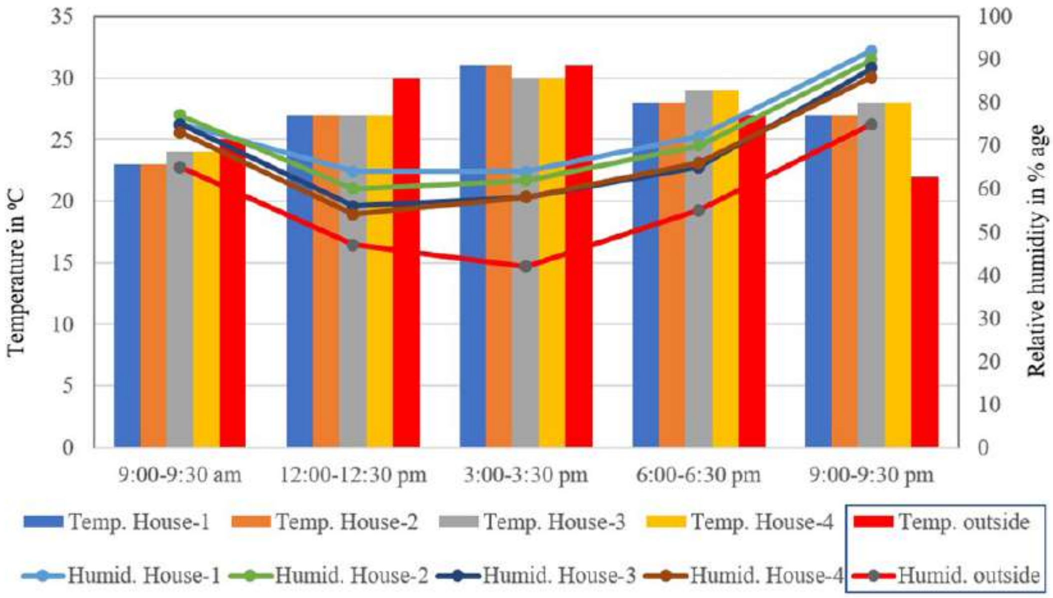

Fig. 5. Average temperature and relative humidity at bedrooms of the four interior-most flats and at the outdoor from 9:00 am to 9:30 pm.

Fig. 5 shows the temperature of the selected bedrooms for the four innermost houses along with the outdoor temperature variation at 9:00-9:30 am, 12:00-12:30 pm, 3:00-3:30 pm, 6:00-6:30 pm and 9:00-9:30 pm. In the same figure, the relative humidity of the selected bedrooms for the four innermost houses along with the outdoor relative humidity variation at 9:00-9:30 am, 12:00-12:30 pm, 3:00-3:30 pm, 6:00-6:30 pm and 9:00-9:30 pm has also been depicted.

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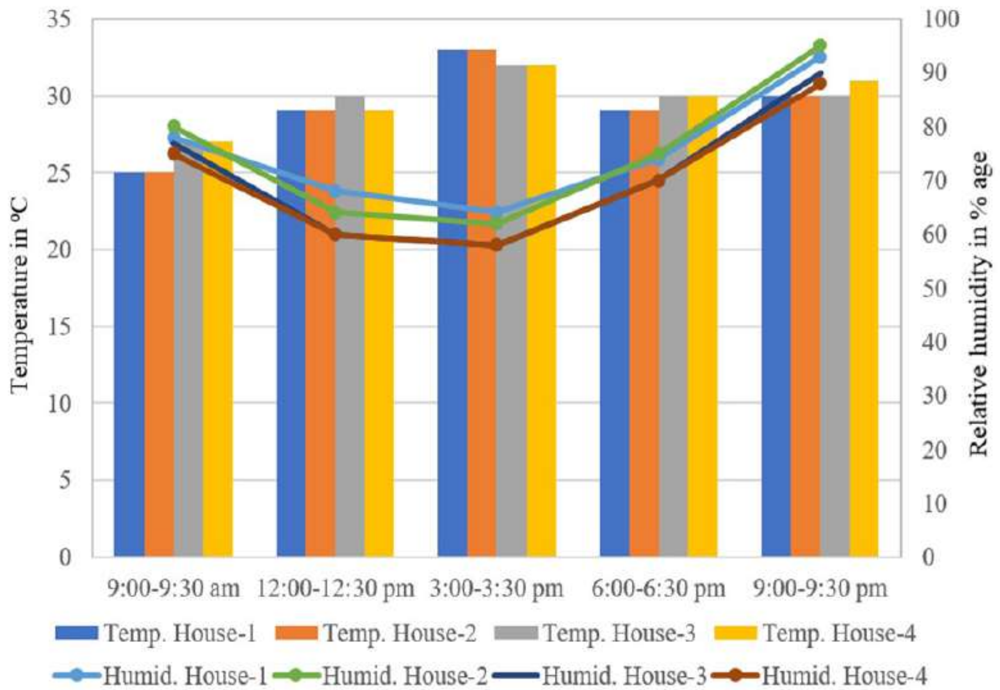

Fig. 6. Average temperature and relative humidity at kitchens of the four interior-most flats from 9:00 am to 9:30 pm

Fig. 6 shows the temperature and relative humidity of kitchens for houses 1 to 4 for the duration of 9:00 am to 9:00 pm at an interval of 3 h. By comparing figure 6 with figure 5, it is observed that both the temperature and humidity variation patterns along with the progress in time are similar. However, 1oC to 3oC temperature rise is observed in the kitchen as compared to bedrooms. Similarly, 2% to 5% relative humidity rise in the kitchen is observed as compared to bedrooms. It happens due to the cooking activities during the morning, noon and evening time. It is obvious that during cooking heat energy is liberated and diffused to nearby atmosphere. At the same time, the steam formed and H_2O vapour as a combustion product during the cooking enhances the humidity of the nearby atmosphere. Both the temperature and humidity level set in the houses are beyond the range set by NAQIS and WHO. The studies by Goldstein et al. say that high temperatures can cause blood vessels to constrict, leading to elevated blood pressure, which can be particularly problematic for individuals with heart conditions [23]. High temperatures and humidity levels can lead to excessive sweating and fluid loss, increasing the risk of dehydration. Dehydration can result in fatigue, confusion, and heat-related illnesses. Drinker has suggested that excessive heat can impair cognitive function and decision-making abilities [24].

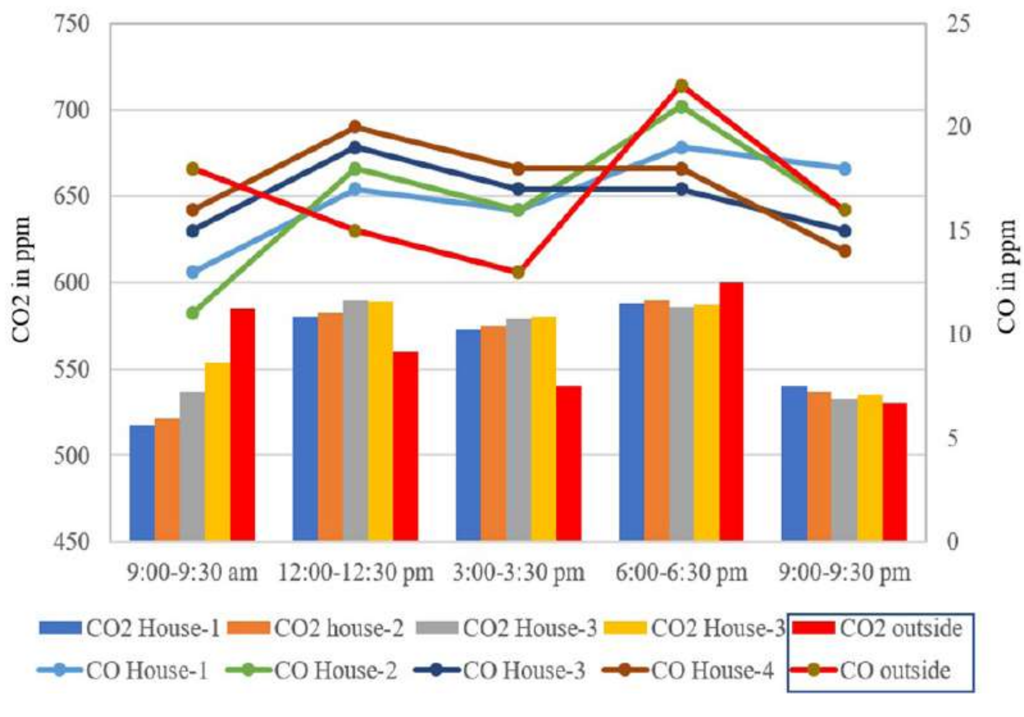

Fig. 7. Average CO_2 and CO concentration in ppm in bedrooms of the four interior-most flats and at the outdoor from 9:00 am to 9:30 pm

Fig. 7 shows the CO_2 concentration in bedrooms for the four innermost houses along with the outdoor CO_2 concentration variation at 9:00-9:30 am, 12:00-12:30 pm, 3:00-3:30 pm, 6:00-6:30 pm and 9:00-9:30 pm. In the same figure, the average CO concentration in bedrooms for the four innermost houses along with the outdoor CO concentration variation at 9:00-9:30 am, 12:00-12:30 pm, 3:00-3:30 pm, 6:00-6:30 pm and 9:00-9:30 pm has also been depicted.

The Fig. 7 reveals that the outdoor CO_2 and CO levels are too high in morning time 9:00 O'clock. It decreases continuously at day time and during evening (6:00 pm), it is at its peak. Outdoor CO_2 and CO mainly depends on the vehicle pollution. According to the map presented in figure 2, the apartment is nearer to a busy road. As a result, vehicle movement from homes to offices, schools etc., around 9:00 am causes a rapid rise in outdoor CO_2 and CO concentration. Further, the nearby industries add on some pollutants like CO_2 and CO. Similarly, office returning vehicles at the evening causes a very high concentration of CO_2 and CO to the ambient air. In contrast to it, the indoor CO_2 and CO concentration rise or fall follows a different trend. Though at morning time (9:00 am), the outdoor CO_2 and CO concentration is at a very higher level, the indoor CO_2 and CO concentration is at its lowest level. This is probably due to the lagging in ambient pollutant diffusion towards the indoor ambience. During the progress in time, the CO_2 and CO concentration trend of indoor is almost follow the outdoor trend. However, the occupant contribution towards the increase in CO_2 and CO pollutant also add on its concentration.

It is observed that two innermost flats (house-1 & 2) has the lowest level of CO_2 and CO as compared to the house- 3& 4 at the morning time. It may because of the ambient pollutant diffusion delay or the airflow direction away from the house towards the road. However, as the house-3 & 4 have an open wall, the ambient pollutant affects much to the house-3 & 4 as compared to house-1 & 2.

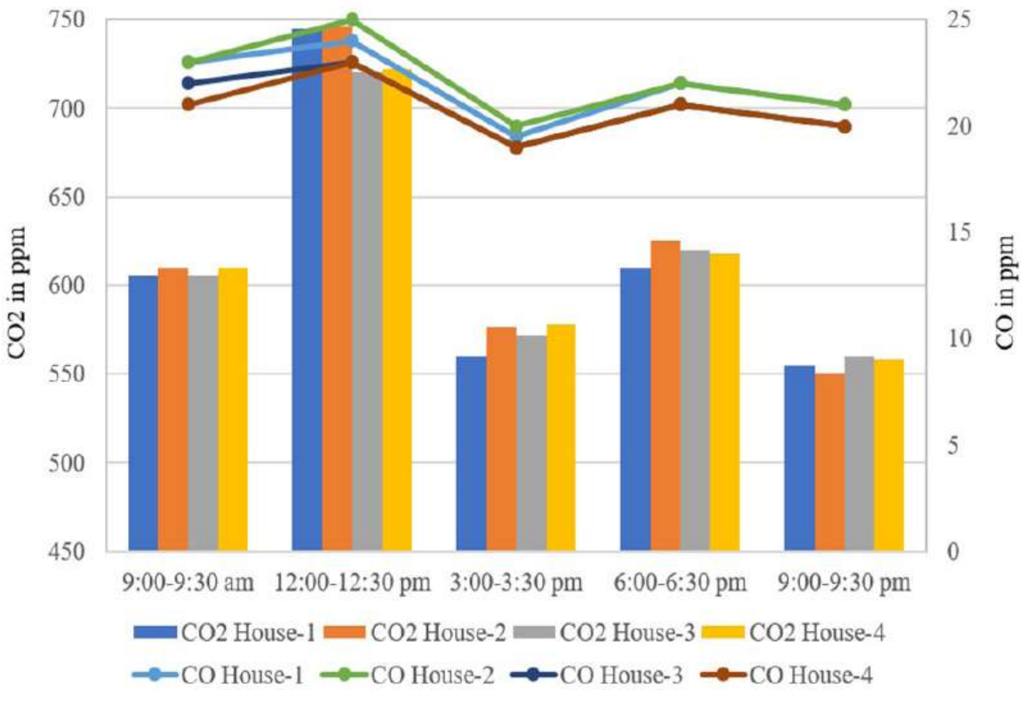

Fig. 8. Average CO_2 and CO concentration in ppm in kitchens of the four interior-most flats from 9:00 am to 9:30 pm

Fig. 8 shows the CO_2 and CO concentration throughout the day from 9:00 am to 9:30 pm in kitchens of all four innermost houses. It is observed that the CO_2 and CO concentration variation in kitchens are follow the similar pattern. From this figure, it is observed that unlike bedroom's CO_2 and CO concentration, the concentration of these pollutants are a little higher level in kitchens at morning time (9:00 am). It happens probably due to the addition of CO_2 and CO from gas stoves flame during cooking. Generally, in morning hour, breakfast is prepared in India. By comparing figure 6 with figure 5, it is noticed that around 70-80 ppm increase in CO_2 in kitchens as compared to bedrooms. 12 noon becomes the period when CO_2 and CO level is at its peak. Obviously this is the time for lunch preparation in most of the house hold kitchens in India. As a result, a huge addition of CO_2 and CO to the nearby ambient enhances their concentration. Similarly at 6:00 pm cooking stove product gases add the pollutant levels in the kitchen. Therefore, this time also shows a higher level of pollutants. At night, concentration of both gases are almost at the same level in bedrooms and kitchen due to no cooking activities is performed in this time.

According to Stewart, when CO levels exceed the recommended standards, individuals can experience carbon monoxide poisoning [25]. Symptoms may include headaches, dizziness, nausea, confusion, and, in severe cases, unconsciousness and death. Prolonged exposure can have lasting neurological effects.

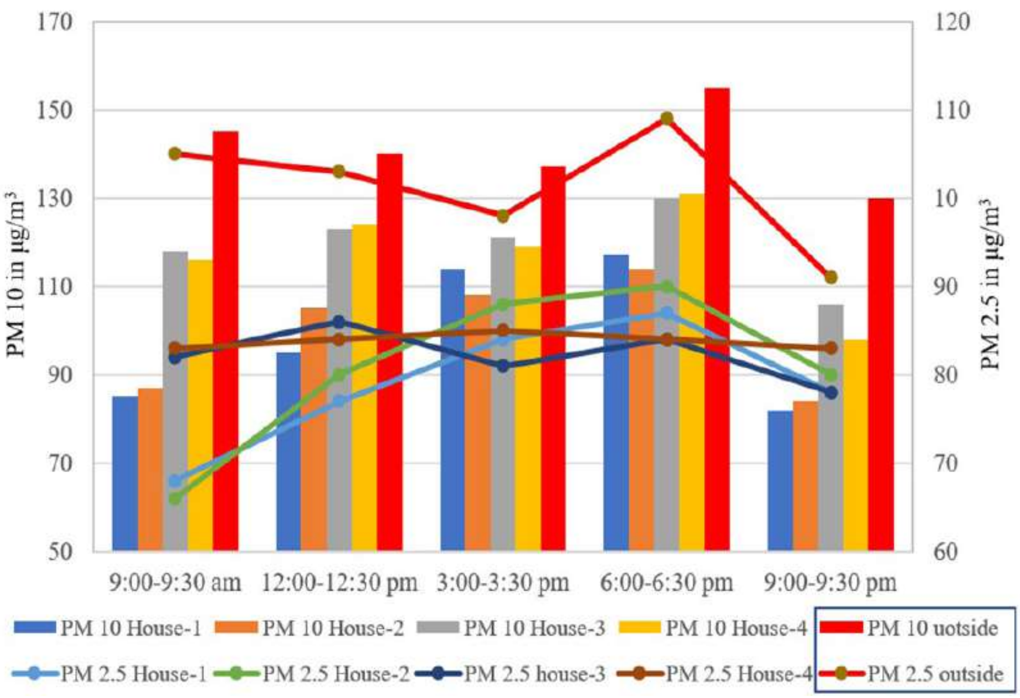

Fig. 9. Average values of PM_{10} and $PM_{2.5}$ in µg/m³ in bedrooms of the four interior-most flats and at the outdoor from 9:00 am to 9:30 pm

Fig. 9 presented the PM_{10} and $PM_{2.5}$ variation both at indoor (bedrooms) and outdoor in the four innermost flats from 9:00 am to 9:30 pm at the interval of 3 h. It is observed that both PM_{10} and $PM_{2.5}$ is at a higher level at outdoor as compared to indoor (bedrooms) regardless of time of measurement. At outdoor, it is very high due to the movement of vehicles nearby road as it is the office going time. It decreases with progress in time and becomes maximum around 6:00 pm as it is the office returning time. At night (9:00 pm), it is at its lowest level. Indoor PM_{10} variation trend is also pretty similar to the outdoor PM_{10} variation. However, house-1 & 2, the most interior flats shows the lowest level of PM_{10} throughout the day because these flats has the lowest exposure to the ambient. In contrast to the PM_{10} variation, $PM_{2.5}$ concentration varies at a different manner particularly in house-1 & 2. $PM_{2.5}$ is at its lowest level during morning time in house-1 & 2 and it increases continuously up to 6:00 pm. $PM_{2.5}$ is the very small in size and lighter in weight, probably that is why it takes a longer time to float and also takes a longer time to settle down. As a result, it shows a continuous increasing trend in indoor. However, at the night, $PM_{2.5}$ gets sufficient time to settle down. Therefore, $PM_{2.5}$ is its lowest level at 9:00 pm.

From Fig. 10. It is observed that the variation of PM_{10} and $PM_{2.5}$ in kitchens with time is very much similar to their variation in bedrooms. However, some where the concentration is a bit higher and some where it is a bit lower as compared to bedrooms.

The value found in all the houses are higher than the recommended value provided by WHO and NAQIS. Increased levels of PM_{10} and $PM_{2.5}$ are associated with various health problems, including respiratory and cardiovascular diseases, such as asthma, bronchitis, lung cancer, and heart attacks [26].

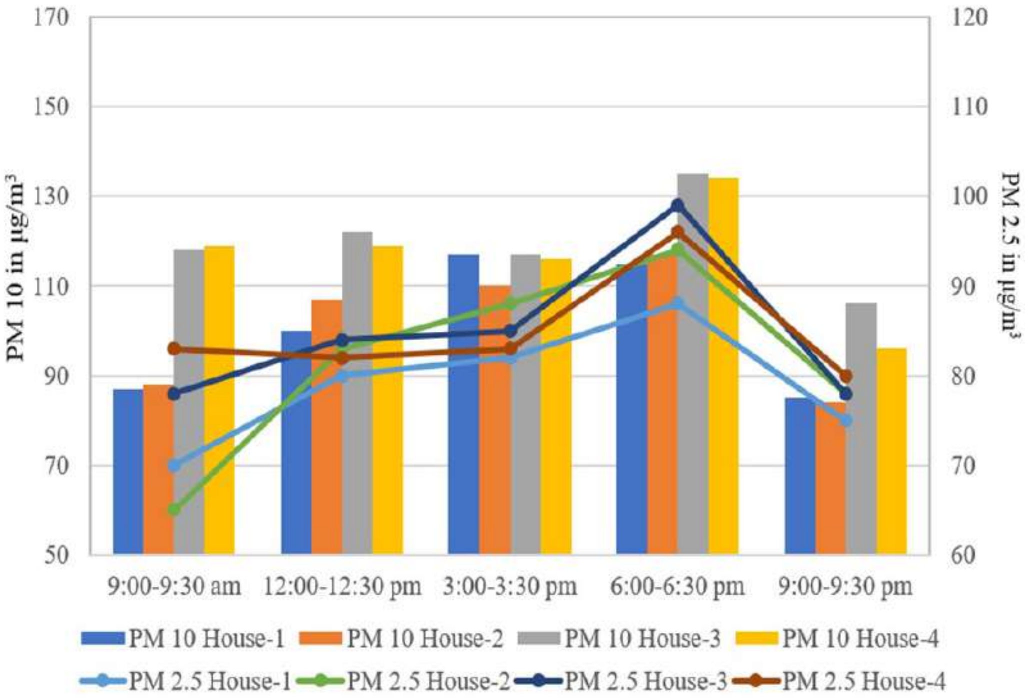

Fig. 10. Average values of PM_{10} and $PM_{2.5}$ in µg/m^3 in kitchens of the four interior-most flats from 9:00 am to 9:30 pm

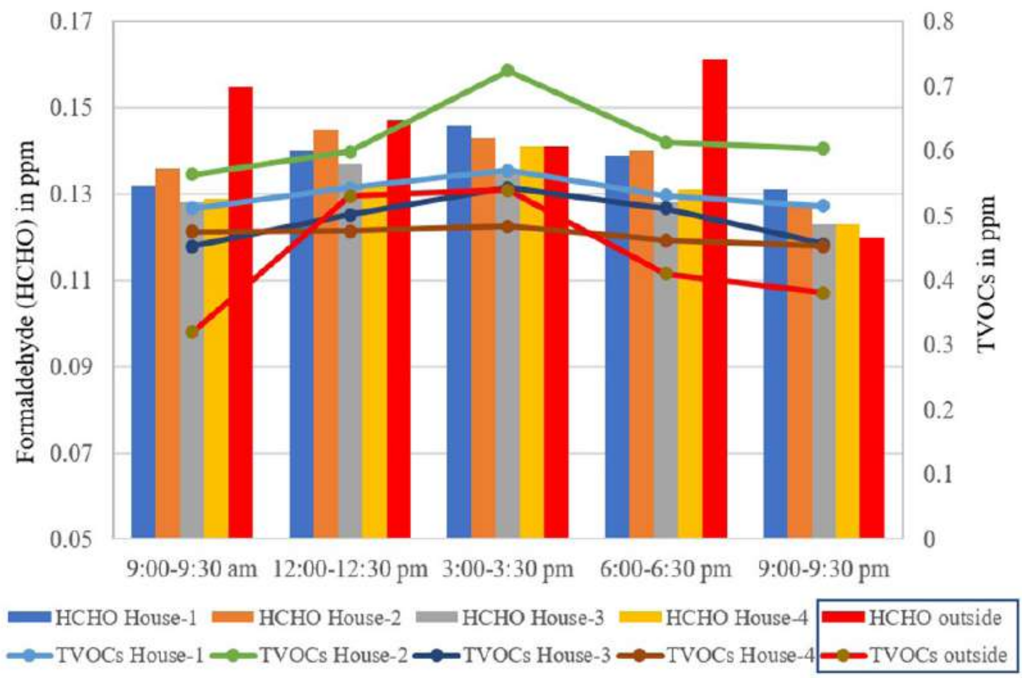

Fig. 11. Average values of HCHO (Formaldehyde) and TVOCs (Total volatile organic compounds) in ppm in bedrooms of the four interior-most flats and at the outdoor from 9:00 am to 9:30 pm

Formaldehyde and the total volatile components concentration at 9:00 am to 9:30 pm in bedrooms and kitchens

Fig. 11 depicts the formaldehyde (HCHO) and TVOCs concentration in the bedrooms of the four inner most flats. HCHO is mainly a by-product of hydrocarbon combustion and also house building material emits some HCHO when it exposed to heat. A higher level of HCHO concentration has been observed during 9:00 am and 6:00 pm because in this office going and returning time, a large number of vehicles probably emits a huge amount of HCHO. In the night (9:00 pm), the outdoor HCHO concentration comes down to its minimum level. In contrast to that, the indoor HCHO concentration during noon becomes maximum. Probably it happens because the chemically painted hot wall contributes some HCHO to the indoor air. Moreover, the cooking stove emitted HCHO might have contributed a little to the indoor air.

From Fig. 11, it is also observed that the indoor TVOCs is higher than the outdoor TVOCs regardless of time. Volatile compounds are generally formed from the hydrocarbons even exposed to a moderate temperature. The reason for higher concentration of TVOCs at indoor ambience is the petroleum based distempers applied on walls and furniture. As the temperature of house increases, the rate of emission of TVOCs increases. As a result, the TVOCs increases at day time. However, the source of outdoor TVOCs are tar coal roads and petroleum based vehicle fuel. More interestingly, house-2 shows relatively a higher concentration of TVOCs. During investigation, it is found that that house is painted just a year back whether the wall painting of other houses are six years of old. As a result, a higher concentration of TVOCs has been observed in house-2 irrespective of time.

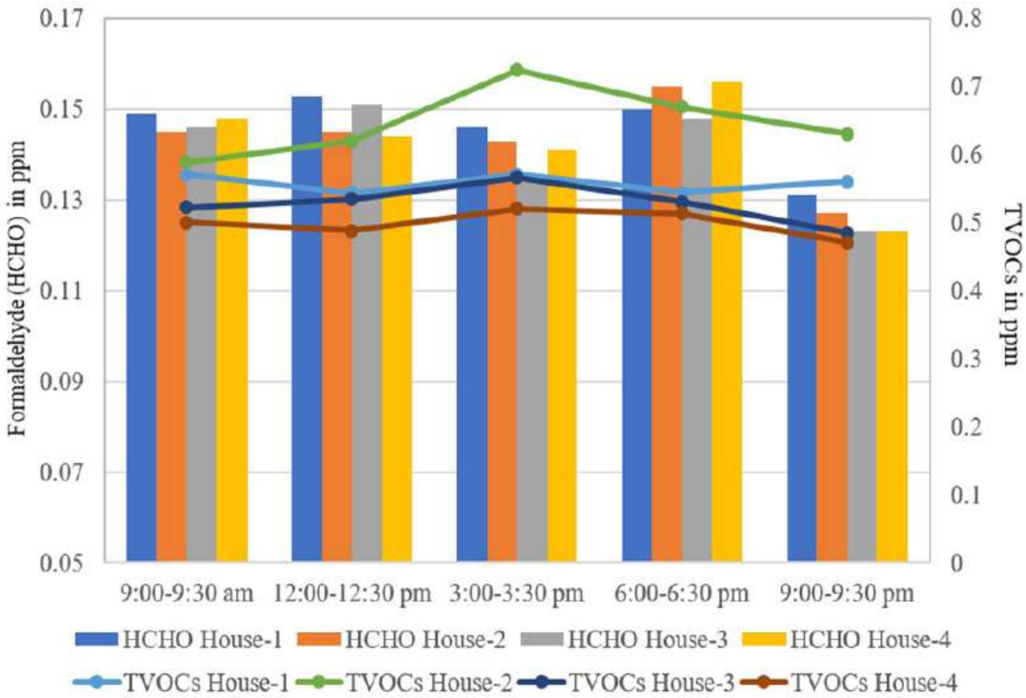

Fig. 12. Average values of HCHO (Formaldehyde) and TVOCs (Total volatile organic compounds) in ppm in kitchens of the four interior-most flats from 9:00 am to 9:00 pm

Fig. 12 shows the concentration of HCHO and TVOCs in kitchen with progress in time. From the figure, it is observed that both of the pollutants are relatively at higher level in kitchen as compared to bedrooms. The combustion by-products from the gas stove increases the level of HCHO in kitchen. With rise in temperature in kitchen, the TVOCs emission becomes increases from the walls and other hydrocarbon accessories present in kitchen. It is also observed that during the cooking time, their value is higher.

These compounds can persist for an extended period, contributing to elevated concentrations in the indoor environment. A research have shown that formaldehyde and TVOCs are commonly released from various building materials, including paints, adhesives, and furnishings. The emissions can be influenced by factors such as ventilation, temperature, and the age of the materials [27]. Additionally, the study have highlighted the importance of adequate ventilation and proper selection of low-emitting materials to mitigate indoor air pollution and maintain a healthier living environment.

Indoor temperature, humidity and pollutant levels comparison with WHO and NAQIS recommended value

The maximum recommended value of various pollutants, comfort temperature and humidity levels in indoor environments proposed by WHO and NAQIS is presented in Table-1. Table 2 shows whether the indoor air pollutant level is within the WHO and NAQIS recommended value or exceeds the maximum limit.

Table 1. Standards and guidelines set by WHO [28] and NAQIS [29]

PARAMETERS	WHO	NAQIS
Carbon monoxide (CO)	CO should not exceed 10 milligrams per cubic meter (mg/m^3) or 8.45 ppm on average over 8 h.	0.88- 1.76 ppm (parts per million) for an 8-h exposure or 1-2 mg/m^3
Carbon dioxide (CO_2)	CO_2 concentrations should not exceed 1,000 ppm (parts per million) for occupied spaces.	Not mentioned
Particulate Matter (PM_{10})	PM_{10} should not exceed 50 micrograms per cubic meter ($\mu g/m^3$) on average over 24 h	51-100 $\mu g/m^3$ (24-h average)
Particulate Matter ($PM_{2.5}$)	$PM_{2.5}$ should not exceed 25 $\mu g/m^3$ on average over 24 h.	31-60 $\mu g/m^3$ (24-h average)
Formaldehyde (HCOC)	Formaldehyde should not exceed 0.1 parts per million (ppm) on average over 30 minutes.	Not mentioned
Total volatile organic compounds (TVOCs)	Has not set a specific guideline for indoor air quality	The maximum limit is 0.5 mg/m^3 on exposure of 8 h.
Temperature	temperatures between 18°C and 24°C (64°F to 75°F) for thermal comfort and health.	Not Mentioned
Humidity	relative humidity range is between 30% and 60%	Not mentioned

Table 2. Interpretation of data for Indoor Environmental Parameters

Parameter	Range or Measurement	Comfort Range (WHO)	WHO/NAQIS Recommended Limit
Indoor Temperature (°C)	23 °C - 33°C	18°C - 24°C	Exceeds WHO
Relative Humidity (%)	54%-95%	30% - 60%	Exceeds WHO/NAQIS Limit
Carbon Dioxide (CO2) (ppm)	517 -746 ppm	< 1000 ppm	Within WHO limit.
Carbon Monoxide (CO) (ppm)	11 -25 ppm	0.88 - 1.76 ppm	Exceeds WHO/NAQIS Limit
Particulate Matter (PM10) ($\mu g/m^3$)	82 - 135 $\mu g/m^3$	< 50 $\mu g/m^3$	Exceeds WHO/NAQIS Limit
Particulate Matter (PM2.5) ($\mu g/m^3$)	65 -99 $\mu g/m^3$	< 25 $\mu g/m^3$	Exceeds WHO/NAQIS Limit
Formaldehyde (ppm)	0.123 - 0.155 ppm	< 0.1 ppm	Exceeds WHO Limit
Total volatile organic compounds (TVOCs) (mg/m^3)	0.47 - 0.724 mg/m^3	< 0.5 mg/m^3	Exceeds NAQIS Limit

The data highlights concerning indoor environmental conditions in the apartment building with potential health implications. The indoor temperature (23°C - 33°C) and relative humidity (54%-95%) exceed the comfort range recommended by the World Health Organization (WHO), which could lead to discomfort and health issues such as heat stress and mould growth. While carbon dioxide (CO_2) levels (517 ppm -746 ppm) remain within WHO-recommended limits, indicating acceptable air quality in this regard, carbon monoxide (CO) concentrations (11 ppm -25 ppm) significantly surpass both WHO and NAQIS guidelines, posing a serious health risk. Additionally, elevated levels of particulate matter (PM_{10} and $PM_{2.5}$) and formaldehyde exceeding WHO and/or NAQIS standards indicate potential respiratory and cardiovascular health risks. On a positive note, TVOCs are within the safe limit recommended by NAQIS. In conclusion, addressing the elevated levels of CO, PM_{10}, $PM_{2.5}$, and formaldehyde is crucial to improving indoor air quality and mitigating potential health impacts on occupants. The indoor environment in the apartment building does not meet the WHO recommendations for temperature, relative humidity, CO levels, PM_{10}, $PM_{2.5}$, and formaldehyde. However, only the CO_2 levels are within acceptable limits as per relevant standards. Addressing the elevated levels of CO, PM_{10}, $PM_{2.5}$, and formaldehyde is essential to improve indoor air quality and occupants' health and comfort.

Conclusion

An investigation was conducted in a compact apartment building situated in the northern region of the tropical Indian city, Bhubaneswar. Specifically, attention was given to a poorly ventilated building. For this study, four interior flats, designated as house-1, 2, 3, and 4, located on the third floor were chosen to assess air quality. Notably, house-2 and 3 were positioned as the innermost flats among the selected four. Various parameters such as temperature, relative humidity, levels of Carbon dioxide (CO_2), Carbon monoxide (CO), Particulate Matter (PM_{10} and $PM_{2.5}$), Formaldehyde, and Total Volatile Organic Compounds (TVOCs) were measured within the bedrooms and kitchens of these flats. Pollution meters manufactured by SMILEDRIVE were utilized for data collection. The experiments were conducted under conditions where doors and windows remained closed, and artificial ventilation systems were not activated. Data collection took place over four consecutive working days in February 2023, with readings recorded at 3-h intervals from 9:00 am to 9:00 pm each day. Additionally, the outdoor air conditions were also monitored.

From the investigation, it is observed that the day-wise temperature and humidity variations inside the bedroom and kitchen exhibit a reverse trend. During morning to noon, the outdoor temperature is higher than the indoor temperature. Just after the noon, the indoor temperature rises significantly and slowly comes down with progress in time, while during the night-time, humidity reaches its peak. Insignificance variation between the results of the flat no. 1, 2 and 3, 4. The humidity and temperature variation in kitchen also follows the similar pattern as the bedrooms. Conversely, the day-wise indoor CO_2 and CO variation trends are quite similar. However, their variation pattern at the outdoor is not similar as the indoor variation trend. Both CO_2 and CO concentrations in bedrooms are lowest in the morning and night-time, while they peak in the evening. In contrast, CO_2 and CO concentrations in kitchens significantly rises during noon due to additional cooking activities. Higher particulate matter concentration, both outdoor and indoor, is observed in the evening. A significantly higher concentration of particulate matters is observed at the outdoor as compared to the indoor for the entire day. Similar kind of day-wise PM concentration is observed in kitchens as well. Here, the house position significantly influences the particulate matter concentration. The flats which are less exposure to ambient has lower Pm concentration. Formaldehyde (HCHO) and Total Volatile Organic Compounds (TVOCs) concentrations indoors are highest at noon and in the afternoon whereas, in the evening time HCHO becomes the highest at the outdoor. However, in the kitchen, higher TVOCs are observed in the evening.

The indoor environment within the apartment building exhibits a mixed picture in terms of air quality and its potential impact on occupants' health and comfort. While indoor temperature and relative humidity surpass the comfort level recommended by the World Health Organization (WHO), potentially causing discomfort and health concerns, carbon dioxide (CO_2) levels are within the WHO-recommended limit signifying acceptable air quality in this aspect. However, carbon monoxide (CO) levels significantly exceed both WHO and National Air Quality Information System (NAQIS) guidelines posing a notable health concern. Furthermore, particulate matter (PM_{10}) and $PM_{2.5}$ concentrations exceed WHO standards, potentially impacting respiratory health. Formaldehyde levels and TVOCs level also surpass the WHO recommended limit. To enhance indoor air quality and safeguard occupants' well-being, it is imperative to address the elevated levels of CO, PM_{10}, $PM_{2.5}$, TVOCs and formaldehyde while maintaining CO_2 levels within acceptable limits by providing proper ventilation to the apartment.

From the study it is observed that indoor CO, CO_2, HCHO prime sources are cooking stove product gas and vehicle emission. Therefore, to minimize the concentration, proper chimney in kitchen should be used and the rooms should have cross ventilation provision. TVOCs main source are the wall paints and other organic chemical materials present in the room. Moreover, volatile hydrocarbon emitted from the vehicle is also a source of TVOCs. With increase in temperature the amount of emission increases. Hence, the house wall should be less exposure to sun and it is advised to open the window for a longer time so that the TVOCs and other pollutants moves out properly. It is observed that outdoor PM concertation is higher than indoor PM concentration. Particularly it becomes high during the frequent movement of vehicles on the nearby road. Therefore, it is advised to close the door windows during office going and returning time to minimize the indoor PM concentration.

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Competing interests

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Ethical considerations

“Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc.) have been completely observed by the authors.

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