Air Quality, Atmosphere & Health (2023) 16:2377–2400
https://doi.org/10.1007/s11869-023-01411-3

Investigation of indoor air pollutants in different environmental settings and their health impact: a case study of Dehradun, India

Abhishek Nandan[1] · Prasenjit Mondal[2] · Sandeep Kumar[1] · Nihal Anwar Siddiqui[2] · Shambhavi Sinha[3] · Sudalai Subramani[4] · Akshi Kunwar Singh[1] · Sivashankar Raja[5] · Chaudhery Mustansar Hussain[6]

Received: 25 April 2022 / Accepted: 3 August 2023 / Published online: 31 August 2023

Abstract

The air we breathe both indoors and in the external environment significantly affects human health and life. The legal systems across the globe, including the United Nations programs, have taken measures to protect the right to clean air as a basic human right. Urbanization and modern lifestyles have changed the dynamics of need and usage of products and allied activities. However, the scope of this study is focused on the investigation of indoor air quality (IAQ). This study is perhaps the first ever attempt to investigate the indoor air pollutant in different environmental setup based on building code specially for nonindustrial indoor environments, i.e., office buildings, public buildings (schools, hospitals, theatres, restaurants), and private dwellings in Dehradun, India. Air pollutants measured in this study include particulate matter (PM10), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO2), volatile organic compounds (VOCs), and formaldehyde (HCHO). In order to identify the exposure level of indoor air pollutants on human health, chronic daily intake has been calculated. In residential building occupancies, the concentration of particulates is higher in indoor air, and the key sources are kitchen activities such as the operation of gas stoves for cooking. In educational buildings, significant pollutants present are CO_2, formaldehyde, and respirable suspended particulate matter (RSPM), predominantly due to characteristic available ventilation systems. Compared to other indoor occupancies, institutional buildings related to health science have significant sources of indoor pollutants generated from biomedical waste, medical equipment, and instruments.

Keywords Indoor air quality · Air pollution · Ventilation · Chronic daily intake

Introduction

Health is wealth is an old age saying that has proven accurate, most recently during the Covid pandemic where we battled to save human lives. There can be no categorical definition of good health, but we would all agree that it would include a holistic positive physical and mental state of mind and body. While most of our focus remains on nutrition, exercise, and immunity, we tend to ignore the importance of an element as basic yet essential for the normal functioning of cells in our body—air (Wang et al. 2022a; Cobbold et al. 2022; Nandan et al. 2021a).

The air we breathe in the external environment and indoor spaces directly affect our health (Vergerio and Becchio 2022; Sadrizadeh et al. 2022; Dong et al. 2022; Choi et al. 2022; Ali et al. 2021). The legal systems across the globe, including the United Nations programs, have taken measures to protect the right to clean air as a basic human right (Mazzarino et al. 2020). In the Indian context, Article 21 of the Constitution reads, "No person shall be deprived of his life or personal liberty except according to the procedure established by law." With changing dynamics of law and society, the ambit of article 21 has widened to include the right to clean environment, air, and health as a fundamental human right extending to natural persons and not just

Highlights

- Indoor air pollutants of various environmental settings were above acceptable limit.
- Institutional and mercantile buildings were observed with higher chronic intake.
- Business building was observed safest in terms of chronic daily intake.
- Residential and business building had highest CO and O_3 concentrations, respectively.
- Proper ventilation and optimization of pollutant sources is required.

Extended author information available on the last page of the article

citizens. Being justifiable against the state for any violation, one can approach the Supreme Court and High Court as of right to Constitutional remedy through Writs under Article 226 and Article 32 of the Constitution. Some critical judicial pronouncements like *Kharak Singh v. State of UP* (AIR 1963 SC 1295), *MC Mehta v. Union of India* (1987 AIR 1086), *Subhash Kumar v. State of Bihar* (AIR 1991 SC 420), *Maneka Gandhi v. Union of India* (AIR 1978 SC 597) serve as important precedents emphasising protection of this right. In addition to some statutes regulating pollution by vehicles, factories, the *Environment (Protection) Act, 1986* serves as the primary law directing the central government to protect and improve environmental quality, control, and reduce pollution from all sources (Vallero and Vallero 2014). The *Air (Prevention and Control of Pollution) Act, 1981* serves as a specific act to control and prevent air pollution in India.

Air, as we understand, both indoor and external environment impacts human health and lives. However, the scope of this study is focused on the investigation of indoor air quality (IAQ). Indoor air quality can be understood as air quality within and around buildings and structures (Mannan and Al-Ghamdi 2022), which along with psychological aspects of natural indoor lighting, acoustics form a part of indoor environmental quality (IEQ) (Du et al. 2022).

Indoor air pollution today is a significant health hazard in developing countries (Yue et al. 2021). Poor indoor air quality has potential health hazards on the occupants due to different kinds of contaminants. The negative impact on health can be acute or chronic. It mainly occurs due to gaseous substances or contaminants in the occupancy primarily generated by anthropogenic activities varying with occupancy classification such as residential, business, and industrial. Sometimes, poor indoor air quality in some occupancy classifications also results from the release of airborne bacteria and gaseous substances.

Additionally, indoor air pollution in modern buildings results from the emission of smoke from fuel combustion and different complex mixture of finishing products containing volatile and semi-volatile compound material. The presence of contaminants and pollutants varies from occupancy to occupancy depending upon its type, nature of usage, geographical position, and material used during construction or operation. While developing building occupancy, indoor air quality is a primary concern for building designers, developers, tenants, and owners. If a proper ventilation rate is not maintained, accumulation of gaseous contaminants and pollutants may exceed its exposure limit and lead to health risks on occupants resulting in respiratory illness, fatigue, nausea, headaches, and allergies.

The National Building Code of India has classified building occupancy into nine groups (Alnuaimi et al. 2022). This occupancy consists of its characteristics according to the nature of work, types of material used, total floor area ratio, and conditions as prescribed by the code (Kumar and Singh 2021). All the classified occupancies generate numbers of indoor air pollutants from different sources (Pal et al. 2022). Since the sources of pollutants are different, the concentration and types of pollutants also vary (Mentese et al. 2020). Few common pollutants can be found in almost every occupancy classification (Nandan et al. 2019), such as CO_2-generally by human respiration, volatile organic compounds-plywood fibers and resins (Nandan et al. 2021b), particulate matters—by dust particles, and raw materials (Nandan et al. 2020a). However, monitoring and controlling these indoor air pollutants within prescribed limits are necessary to ensure no harm is caused to the occupants (Ganesh et al. 2021).

Several studies have confirmed that the atmospheric pollutants generated by human activities can harm human health (Xu et al. 2022; Silva et al. 2022; Saquib et al. 2021; Li et al. 2020; Jie et al. 2014; Boré et al. 2022; Bao et al. 2022). These pollutants require control and monitoring to prevent health impairment. To control these pollutants, adequate ventilation is essential to dilute them (Ye et al. 2017; Izadyar and Miller 2022). Generally, human activities are carried out under enclosed areas depending on the occupancy type with different sources and types of pollutants (Wolkoff et al. 2021). Thus, a higher ventilation rate would reduce the chances of exceeding exposure limits and reduce the prevalence of the airborne bacterial disease (Paleologos et al. 2021; Louie et al. 2018; Fonseca Gabriel, et al. 2021; Elsaid et al. 2021). A study says that a ventilation rate below 10 l/s has a higher significance on human health due to indoor air pollutants in business occupancies (Nandan et al. 2021b). The ventilation rate of 20–25 l/s does an outstanding job in reducing the concentration of pollutants in the indoor premises (Nandan et al. 2021b).

Indoor air quality can be determined by various methods in which chemical, biological, and physical air pollutant with different composition in different environmental settings (Paleologos et al. 2021; Fonseca Gabriel et al. 2021; Zheng et al. 2022; Stewart et al. 2022; Shendell and Nriagu 2011; Marć 2017; Haines et al. 2020). The indoor environment is dynamic and is influenced by many things such as materials (used in buildings for interior decoration, raw material used in the process), equipment and process, human movement and other activities, re-suspended particulate matter, and inadequate ventilation rate (Zhang et al. 2022; Wang et al. 2022b; Ninyà et al. 2022; Li et al. 2022). From the various pollutants found indoors, certain pollutants are predominantly found in various occupancy and have the most significant health impact, such as nitrogen dioxide, carbon mono oxide, HCHP, VOCs, airborne bacteria, and wood smoke/tobacco smoke (Sivanantham et al. 2021; Kaikiti et al. 2022; Jung et al. 2021; Bralewska et al. 2022; Abdel-Salam 2022). WHO has published literature on IAQ (World Health Organization 2014) and observed its impacts on the human body, such as respiratory issues in children and those exposed at the point of contact, dermal impact, cardiovascular, cancer, and sick building syndrome (Tran et al. 2020; Amoatey et al. 2020).

Occupancy can be used as a dwelling or workplace, the purpose depending upon the need, which varies as discomfort caused to the occupants due to indoor pollutants varies (Raziani and Raziani 2021). It is widely accepted that a building that does not offer natural ventilation is more susceptible to poor indoor air quality (Heracleous and Michael 2019). Logically, air quality in an enclosed environment is mainly based on components and activities. Human beings who occupy the area for the activity are the best judge of its air quality owing to their olfactory sensitivity to irritants and the effect of the chemical compounds (Nandan et al. 2020b).

Globally, people spend more time indoors than outdoors there, and they are exposed to pollutants generated inside the occupancies and the outdoor pollutants that penetrate and contaminate the indoor air (Paleologos et al. 2021; Yang et al. 2019; Pettit et al. 2018; Nair et al. 2022; Goujon-Ginglinger and Mitova 2021; Bhat et al. 2022). It was estimated that the 1.6 million death toll and 3% of the worldwide increase of disease are due to the increased level of particulate matter and gases found indoors generated by solid fuels and biomass (Nandan et al. 2019). This number clearly shows that indoor air quality has a more significant impact than outdoor air ('WHO guidelines for air quality', 1998) (World Health Organization 2014).

Humans are only responsible for creating a comfortable environment for themselves. Their health is foremost; hence, due to any reason their health gets impacted, pollutants are present indoor; it is a matter of concern. ASHRAE guidelines stated that people spend 80–90% in the indoor environment, so building characteristics play a pivotal role in maintaining good indoor air quality (Nandan et al. 2020b). Few studies also state that a poor indoor environment creates significant discomfort for occupants and decreases work performance. Hence, it is established that initial planning building design parameters should be considered for occupant well-being (Sajeev et al. 2022; Abhijith et al. 2022).

Previous observation suggest that reactive organic compounds and their reaction product could adversely impact human health even if exposed to low concentrations (Mousavi et al. 2022; Ma et al. 2022; Liu et al. 2022; Halios et al. 2022; Xue et al. 2022). To be more precise about reaction products, it can also be explained as the indoor environment can be referred to as a reaction vessel where several compounds enter and leave. Some react with the product indoors and create more reactive or irritating substances. Most building finishing products and household products are a source of VOCs during their usage and are referred to as reactive compounds (Nandan et al. 2019).

Research methodology

According to National Building Code, the indoor air was sampled with occupancy classification such as residential, educational, institutional, business, and mercantile. Industrial, storage, and hazardous occupancies fall under industrial environments. Hence, these are excluded from the study (Liu 2021). All the occupancies were situated in the different geographical locations of the area. Institutional and business occupancies were situated along the roadside; hence, the measured concentration is likely influenced by the outside traffic. During indoor air sampling, it was ensured that the same was occupied. All occupancies have natural and mechanical ventilation based on their needs.

The term indoor air usually applies to nonindustrial indoor environments like office buildings, public buildings (schools, hospitals, theatres, restaurants), and private dwellings (Xavier Guardino Solá, no date). Indoor air quality survey was done for residential, educational, institutional, business, and mercantile occupancy for five buildings from each that was sampled for 90 days. The concentration for CO_2 and PM_{10} were measured for an 8-h period during the daytime. The measurement period considered the operation of utilities in the kitchen, pantry, geyser/water heaters, and other types of equipment concerning their occupancy and need of the operation. Similarly, sampling for VOC and formaldehyde was also collected for an 8-h average concentration. Indoor air was sampled by placing the sampling instruments in different points of the indoor occupancy area at 1.5 m of elevation from the ground and 1 m away from the potential source of air pollutants.

Site sampling and meteorological condition

In order to sample the indoor air pollutants, it is necessary to analyze the climatic condition of the area. This study was conducted in Dehradun, the capital of Uttarakhand (India), situated 674 m above sea level. The hilly area leads to natural temperature variations with the elevation difference. The annual average wind speed in Dehradun is 1.7 m/s with maximum wind speed, which goes up to 5 m/s. The pie chart shown in Fig. 1 depicts the month's wind direction during the data. It shows that 32% of the wind direction is in the south-west direction, with the least of 4% in the north and east direction. The average wind speed during the duration was recorded at 0.61 m/s.

Dehradun's climate is slightly moderate because it is situated under the foot of the Himalayas. The temperature does not rise much in summer, but it reaches up to freezing point in winter. The average temperature for Jan, Feb, and March is depicted in Fig. 2. It also depicts the relative

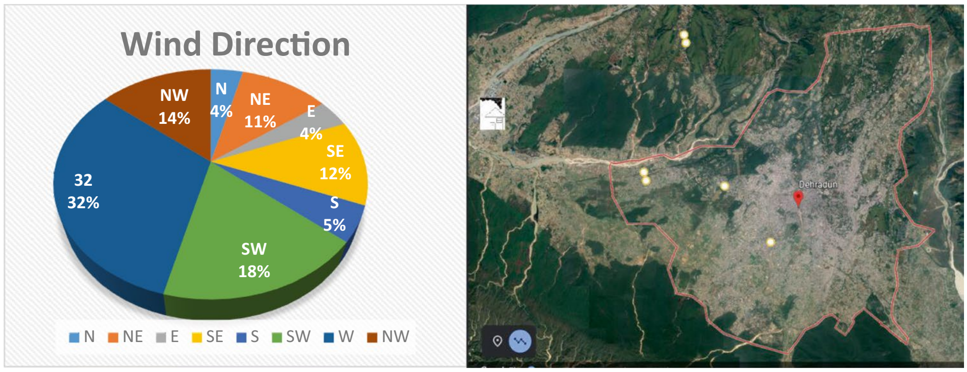

Fig. 1 Wind pattern of selected area for study (Dehradun, India)

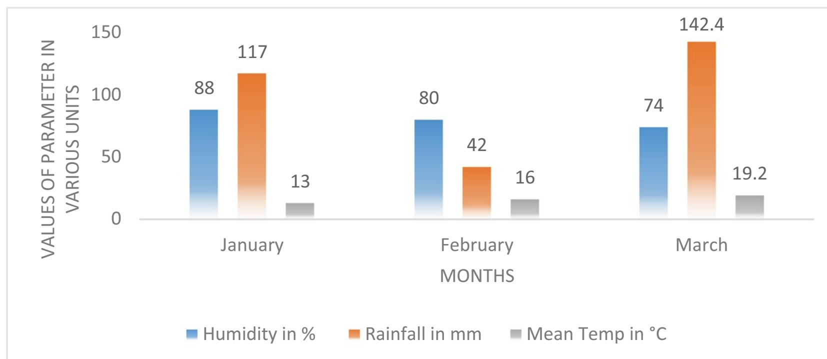

Fig. 2 Weather forecast of study area from Jan to March 20

humidity and the average rainfall during this period. On average, the annual amount of rainfall in the district of Dehradun is 2073.3 mm annually, and the annual temperature is 22.8 °C.

Result and discussion

Group A: residential building

National Building Code of India has classified residential building as group A, and it has six subdivisions depending on the characteristics and nature of usage. Generally, these occupancies are provided with sleeping accommodation with or without cooking or dining facilities for the occupants.

Several studies have shown that particulate concentration is higher indoors than outdoor air, and one of the sources is kitchen activities, e.g., use of gas stove for cooking and tobacco smoking (Huang et al. 2022). General characteristics of the monitored occupancy are given in Table 1 where different home has been considered for study in different environmental setup.

In the present study, commercial area, traffic flow, and population density have been considered to consider different home to determine precise pollutant type at different environmental setup. It was observed that housekeeping activities, re-suspended indoor particulate matter deposited on domestic floors and furniture, also contribute to the concentration. The sources of VOC in residential occupancies are leather sofas, old laundry, fiber and resins, and furnishing on the wall. Aromatic VOCs such as benzene and toluene depend on consumer products. The operation of gas stove and unvented gas heaters could have led to emission of high level of formaldehyde in kitchen and living room. Usage of water heater and solid fuel also produces carbon mono oxide in the indoor environment, which was also observed (Fig. 3).

Particulate matter

The line chart shown in Fig. 3A illustrates the concentration of recorded PM_{10} for all five residential occupancies. Table 1 describes the general characteristics of each occupancy, where the number of occupants and number of smokers vary. In the case of particulate matter, smokers have a more significant influence on concentration. The PM_{10}-recorded concentration has been compared with the standard of "American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE), which comprises three classes to the ranking of indoor air quality. The concentration of particulate matter was found more in the kitchen area comparatively living rooms and bedrooms. The average indoor concentration of PM_{10} with or without smokers were observed as 123 μg/m^3 and 70.13 μg/m^3, respectively. In addition to measuring pollutant concentration, tobacco smoke and outdoor air have a more significant impact.

Table 1 General description of the sampled indoor occupancy

Indoor occupancy	District condition	Age of the occupancy in year	Indoor finishing material	Type of ventilation	No. of occupants	Type of cooking appliances used	No. of smokers
Home A	Mixed commercial area, high traffic flow, medium population density	8	Plastering wall, marble floor	Natural ventilation with ceiling fan	7	Natural gas and electric induction	3
Home B	Mixed residential area with number of private dwellings, medium traffic flow	6	Plastering wall with wood furnishing, tile floor	Natural ventilation and exhaust fan	5	LPG gas	1
Home C	Mixed residential area low traffic flow, high population and vehicle density	7	Plastering wall, vinyl floor	Mechanical ventilation	5	LPG gas	2
Home D	Mixed residential area with number of private dwellings, medium traffic flow	10	Plastering wall with wood furnishing, tile floor	Mechanical ventilation	3	LPG gas and electric mug	0
Home E	Mixed commercial area, medium traffic flow	11	Plastering wall, marble floor	Mechanical ventilation	4	Natural gas	1

Home A recorded the highest concentration of 352 μg/m^3 due to its district condition (highly dense with most minor ventilation available) and higher number of tobacco smoke. Except for Home D, all other four occupancies exceeded the ASHRAE standard of 100 μg/m^3. Home D has less number of the occupant as well as there are no smokers present in it. In some cases, predominant indoor cleaning activities such as vacuuming and sweeping contribute highly to indoor air pollution.

Carbon dioxide

The primary sources of carbon dioxide in residential buildings are respiration, kitchen operation, tobacco smoke, and outside air. The CO_2 concentration varied according to the space and number of occupant smokers. The average concentration of CO_2 in all the five occupancies was recorded at 682 ppm. Similarly, PM_{10} except for Home A did not exceed the HKIAQO Level II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999) concentration of 1000 ppm (Fig. 3B). In addition to this, CO_2 concentrations were found to be slightly more near the kitchen area comparatively living area. Home A recorded the highest concentration of 1260 ppm, and Home D recorded the least amount of concertation of 180 ppm.

Carbon monoxide

The sources of CO are from the combustion process used for cooking and heating since 65% of the study that has been conducted widely falls under the winter period. The graph shown in Fig. 3C clearly depicts the increase in concentration during winter and started to decrease as the temperature increases. Because of that, it gave rise to the concentration of CO due to the usage of room heaters. During sampling, windows and other sources of opening were closed. CO can also be induced in the indoor environment by infiltration of the outdoor air. Nowadays, various cooking and heating appliances are used in residential occupancies, out of which any faulty and poorly maintained equipment can also be the source. All the occupancies exceeded the ASHRAE Class B and C of 9 ppm, mainly during winter. Later, as the atmospheric temperature starts to increase, the concentration started to fall. The mean concentration of all the five occupancies was 8.90 ppm, slightly less than the ASHRAE Class B and C standard value, but it exceeded the Class A value of 2 ppm.

Ozone

Since the sources of ozone are primarily outdoor air, other air purifiers regularly used instruments such as electrostatic precipitator, and negative ion generator was not used

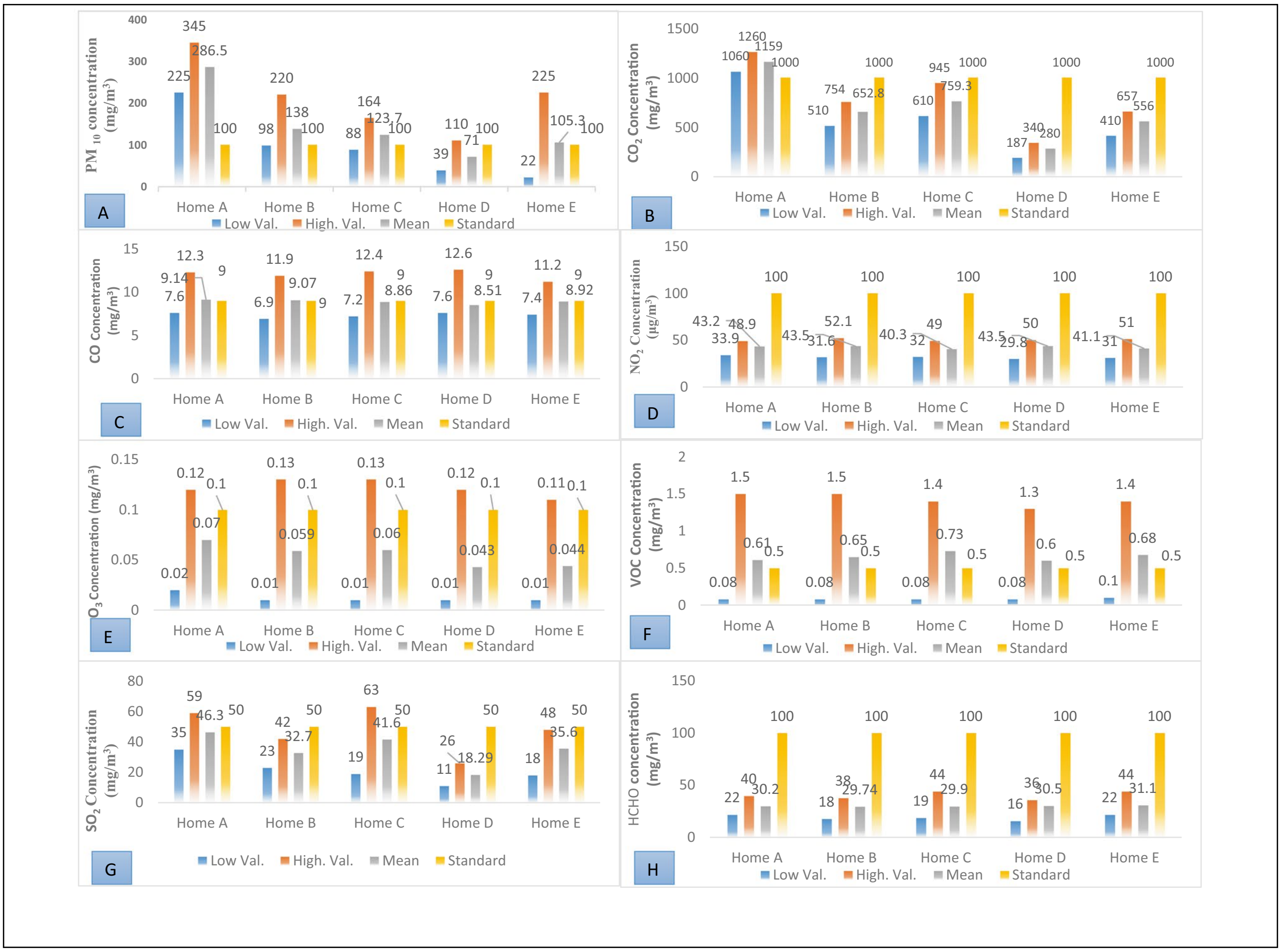

Fig. 3 Concentration of different types of **A**–**H** indoor air pollutant in different residential occupancies

in residential building. Hence, it is evident that the indoor ozone level could vary according to the outdoor level. The line chart shown in Fig. 3E depicts the level of concentration that fluctuates as the outdoor level increases or decreases. The mean ozone concentration is 0.055 ppm, far behind the OSHA standard value of 0.1 ppm. The lowest concentration level was 0.01 ppm, and the highest recorded concentration level was 0.13 ppm. The day the highest concentration was recorded, the outdoor temperature was 38.5 °C which greatly influenced the indoor concentration level.

Sulfur dioxide

The sources of sulfur dioxide in residential occupancies are tobacco smoke, vehicle exhaust (space for parking the vehicle inside the occupancy), and improperly vented gas appliances. Wood and coal stoves are also sources, but LPG or natural gas are now being used for cooking purposes. These are the sources that contribute to the indoors, but the concentrations are highly affected by the outdoor sources such as vehicle emission and smoke from industrial chimneys. Figure 3G illustrates the variation recorded of indoor SO_2 level. Only a few instances did Home A and Home C exceed the ASHRAE standard level of 50 µg/m^3. The mean concentration was recorded for all the five occupancies that were 35 µg/m^3. The highest and lowest level of mean SO_2 was recorded in Home A and Home D, and the concentration was 46 µg/m^3 and 18 µg/m^3. The reason behind the increased level of SO_2 in Home A is that there was the parking of two-wheelers inside the space.

Nitrogen dioxide

The primary source of indoor nitrogen dioxide is LPG or natural gases used for cooking and heating appliances. During sampling, the concentration was found to be more during the cooking period than during non-cooking periods. As we can see from the line chart shown in Fig. 3D, there is an increase in NO_2 concentration during January and February because the air exchange rate during winter is usually reduced since the NO_2 concentration is far below the ASHRAE permissible limit, i.e., 100 µg/m^3. The measured mean concentration of NO_2 for all the five occupancies is 42 µg/m^3. The highest measured NO_2 concentration was 54.1 µg/m^3, and the lowest was 30 µg/m^3. According to WHO, having a gas stove indoors is equivalent to an increased concentration of 28 µg/m^3 compared to homes using electric stoves. The exposure to the occupants is likely too high where gas stoves are being used for cooking purposes rather than electric induction.

Volatile organic compounds

The sources of volatile organic compounds in residential buildings are due to various products that are most tobacco smoke, liquefied petroleum gas, and natural gas used for cooking that has more impact. The concentration exceeds at most the occasion due to LPG and laminates used in wooden furniture and finishing products such as lacquer, and paint is also one of the primary sources. Occupancies, which were recently painted, have recorded variation in the concentration. Figure 3F depicts the concentration variation of all the five occupancies, and the measured mean concentration of VOC was 0.65 ppm which exceeds the value of 0.5 ppm of Leeds standard (Fig. 3F).

Formaldehyde

In residential buildings, various products are the sources of it, such as cork products (flooring materials), wood-based products used for finishing (fiberboard and plywood), cleaning and caring products, disinfectants, and cosmetics (Salthammer et al. 2010). The formaldehyde concentration in all the five occupancies was uniform, and there was not much variation. The average concentration of formaldehyde measured was 30.38 µg/m^{3}which is behind the HKIAQO standard of 100 µg/m^3 as shown in Fig. 3H. There was a slight variation in sampling where wooden products were used for household purposes, and carpeting was used on the floor. The measured HCHO ranged from 22 µg/m^3 to 40 µg/m^3 in all the occupancies. A summary of all the indoor air pollutants collected has been tabulated in Table 2.

Group B: educational building occupancy

It is the second category that NBC classifies as Group B, and it has two subdivisions that are classified on the basis of number of occupants. This occupancy is mainly for schools and colleges where training, educational, and other recreational activities are carried in the premises.

Sampling was conducted in the Dehradun region of five educational institutions. The educational institutes included schools and colleges as well. The sample has been collected in classrooms with a sitting arrangement of 75, 46,

Table 2 Descriptive statistics of sampled concentration of residential indoor air pollutant

Parameters	Home A			Home B			Home C			Home D			Home E			Average mean of all 5 occupancies	AQG (air quality guideline)
	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean		
PM_{10} in mg/m^3	225	345	287	98	220	138	88	164	124	39	110	71	22	225	105	144.9	100[a]
CO_2 in ppm	1060	1260	1159	510	754	652.8	610	945	759	187	340	280	410	657	556	681.42	1000[b]
CO in ppm	7.6	12.3	9.14	6.9	11.9	9.07	7.2	12.4	8.86	7.6	12.6	8.51	7.4	11.2	8.92	8.9	9[a]
Ozone in ppm	0.02	0.12	0.07	0.01	0.13	0.059	0.01	0.13	0.06	0.01	0.12	0.04	0	0.11	0.04	0.05	0.1[c]
SO_2 in µg/m^3	35	59	46.3	23	42	32.7	19	63	41.6	11	26	18.29	18	48	35.6	34.8	40[a]
NO_2 in µg/m^3	33.9	48.9	43.2	31.6	52.1	43.5	32	49	40.3	29.8	50	43.5	31	51	41.1	42.32	40[a]
VOC in ppm	0.08	1.5	0.61	0.08	1.5	0.65	0.08	1.4	0.73	0.08	1.3	0.6	0.1	1.4	0.68		0.5[d]
Formaldehyde in µg/m^3	22	40	30.2	22	40	29.74	22	40	29.9	22	40	30.5	22	40	31.1	30.2	100[b]

[a]"American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE) (Taylor 1999)

[b]Hong Kong Indoor Air Quality Objective Level I and II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999)

[c]"Occupational Safety and Health Administration" (OSHA) Permissible Exposure Limit (Administration, O. S. and Health, Tide 29, n.d.)

[d]Leeds standard

64, 58, and 39 occupants, respectively, as shown in Table 3. The general characteristics of classrooms are as detailed in Table 3. Pollutant concentration in classrooms were analyzed and compared with the relevant standard.

Each classroom has two windows and two means of access and egress. None of the classrooms has an air conditioning system. For ventilation purposes, classroom one, classroom three, classroom 4, and classroom five have entirely relied on natural ventilation and ceiling fan, whereas in classroom three, an exhaust fan was installed. Mainly, the pollutants present in these indoor occupancies are CO_2, formaldehyde, and respirable suspended particulate matter. The source of CO_2 pollutants is from the respiration activity of occupants and the outside air, and for formaldehyde, it is generally due to plywood resins and fiberboard used in the classroom for decorative purposes. These pollutants can harm students' health and result in impaired concentration or memory, which directly or indirectly affects learning. An increase in concentration may cause neurologic effects and may lead to diseases such as asthma or allergies, which may increase absenteeism in the class.

Particulate matter

The primary sources of particulate matter in educational buildings are outside air and activities, such as construction activity or vehicle emissions. The figure shows the indoor PM_{10} levels of all the five classrooms measured across the Dehradun area. The lowest, highest, and mean value of measured concentration is depicted in the chart w.r.t ASHRAE Class B standard. The mean value for all five classrooms exceeded the standard limit. The measured concentration of particulate matter ranged from 30 to 270 mg/m^3 across all five classrooms as shown in Fig. 4A. Highest level of pollutant concentration was detected in classroom A due to highest number of occupant, and the sampling that was done during classroom was occupied at the fullest which also lead to the resuspension of the particulate matter during the sampling. Classroom E detected the lowest level of mean concentration of 105 mg/m^3 because of its district condition and fewer number occupant (Fromme et al. 2007).

Carbon dioxide

In educational building, the main source of carbon dioxide is outside air and respiration of the occupant. The figure shows the CO_2 concentration variation in all five classrooms w.r.t the source and occupancy. Classroom A and B's mean concentration exceeded the given HKIAQO (Hong Kong Indoor Air Quality Objective) Level II Standard of 1000 ppm, whereas classrooms C, D, and E complied with the standard. The CO_2 concentration in all the five classrooms ranged from 400 to 2150 ppm. An increase in CO_2 concentration was caused due to insufficient fresh air supply indoors.

Figure 4C shows the variation of measured CO_2 of 90 days; here in the chart, classroom B is equipped with a mechanical exhaust fan and classroom E, which wholly relied on natural ventilation. The chart shows that the air change hour in classroom E is better than that in classroom B. The concentration of CO_2 was lowest when the class was not occupied. As soon as the classroom starts occupied, the concentration of CO_2 starts increasing. Similarly, variation was also noticed during lunch breaks or when the classroom was partially occupied. According to ASHRAE, it is mandatory to maintain 15 cfm/p of ventilation rate to maintain good indoor air quality.

Carbon monoxide

In educational buildings, the only source of carbon monoxide is from the outside air. Hence, the concentration level is far below the ASHRAE Class B of 9 ppm. The carbon monoxide concentration in all five classrooms ranged from 0.6 to 3.2 ppm as shown in Fig. 4E. There was a slight increase in concentration detected in classroom A due to the presence of a nearby food court. The detected mean concertation was 1.8 ppm.

Table 3 General description of the sampled educational indoor occupancy

Indoor occupancy	Age of the occupancy, in year	Indoor finishing material	Type of ventilation	Area of the occupancy in m^2	No. of occupants	Means of access and egress
Classroom A	8	Plastering wall with partially wood furnishing	Natural ventilation	90	75	02
Classroom B	6	Plastering wall	Natural ventilation and exhaust fan	60	64	02
Classroom C	4	Plastering wall, tile floor	Natural ventilation	45	46	02
Classroom D	2	Plastering wall with cement painted	Natural ventilation	60	58	02
Classroom E	5	Plastering wall	Natural ventilation	60	39	02

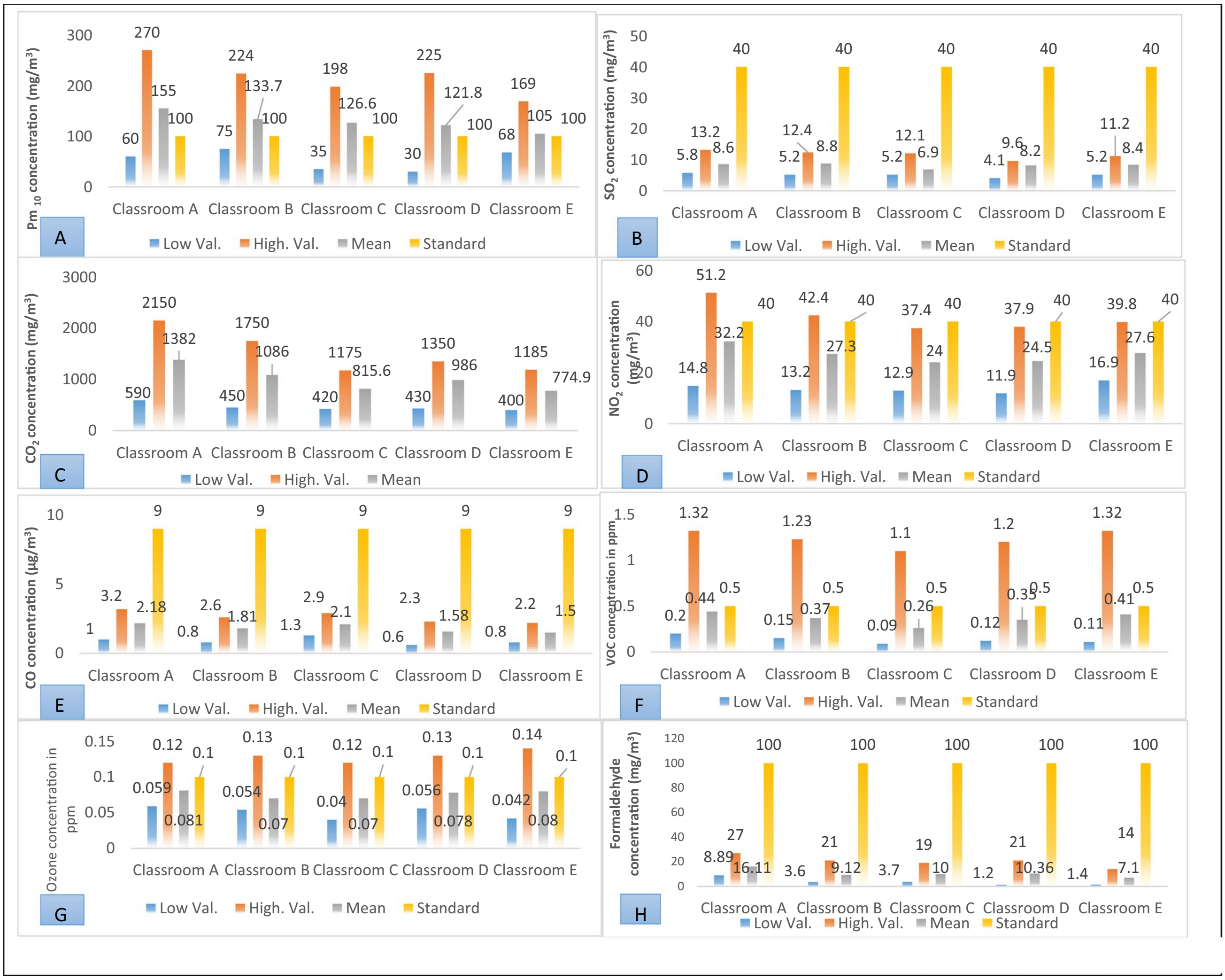

Fig. 4 Concentration of different types of **A**–**H** indoor air pollutant in different educational occupancy

Ozone

Figure 4G contrasts the indoor concentration variation across all five classrooms w.r.t OSHA standard value of 0.1 ppm. The mean concentration of detected ozone level was 0.07, which is below the permissible limit. An increase in ozone concentration was detected as the increase in hot weather. The primary source of ozone is that it is formed by a photochemical reaction in the presence of sunlight and precursor pollutants (NOx and VOCs). Hence, it was likely to observe a controlled ozone concentration level in educational buildings.

Sulfur dioxide

In general, motor vehicle emissions and industrial emissions are the predominant sources of sulfur dioxide. Figure 4B shows the measured variation of SO_2 in educational institutes. The range of measured concertation was sampled from 5.2 to 13.2 μg/m^3.

Nitrogen dioxide

In 2010, WHO guidelines for indoor air quality for selected pollutants defined the toxicology effect of NO_2 and also derived maximum exposure limit, i.e., 200 μg/m^3 for 1-h average and 40 μg/m^3 for annual average. ASHRAE has also provided threshold values for indoor air quality parameters in which there are two classes for NO_2 Class A and Class B, 40 μg/m^3 and 80 μg/m^3, respectively. However, only classroom A exceeded the annual average at few instance; otherwise, the mean value is under prescribed standard limit. Figure 4D shows the NO_2 variation in all five classrooms. The NO_2 concentration ranged from 11.9 to 51.2 μg/m^3 across all five classrooms. There is no primary source of NO_2 indoors; the concentration we measure is penetrated by outdoor sources and causes the elevated indoor level. Hence, the district condition of educational institutes plays a pivotal role in managing indoor air quality. For example, the range of concentration measured for classroom A is 14.8 to 51.2 μg/m^3, whose district condition is a mixed urban area with high traffic flow, whereas, for classroom D, the measured concentration range is from 11.9 to 37.8 μg/m^3, which is situated in a rural area with significantly less traffic flow. The chart shows that the concentration in educational institutes situated in diverse urban areas has a broader range than the educational buildings in rural districts.

Volatile organic compound

Figure 4F shows the lowest, highest, and mean concentration value of volatile organic compounds in all five classrooms and the variation between the concentration measured in the classroom. The measured concentration of VOC ranged from 0.09 to 1.32 ppm across all the classrooms sampled. The mean concertation ranged from 0.26 to 0.44 ppm, below the standard permissible limit of Leeds of 0.5 ppm. There was an elevated level of VOC detected in classroom A because of poor ventilation, which causes the polluted outdoor air to infiltrate into the indoor.

Formaldehyde

Formaldehyde in educational building ranged from 1.2 to 27 μg/m^3, which were below the HKIAQO standard level of 100 μg/m^3. Figure 4H shows the concentration variation of formaldehyde in all the five classrooms. There was not much of an apparent source in the classroom; hence, the concentration levels were deficient. Some of the evidence sources in a few classrooms were sitting arrangements which are made up of plywood and coated with aldehyde resins. In the classroom, fiberwood was also used for the decorative purpose of the classroom, which can be a potential source; a summary of all the educational indoor air pollutants collected has been tabulated in Table 4.Environmental Protection

Group C: institutional building occupancy

The institutional building has a very complex environmental condition, including various kinds of pollutants. Hence, it is necessary to study indoor air quality and ensure its healthful condition for patients and healthcare workers.

The sample has been collected for five hospitals across Dehradun city, which included civil hospitals and multi-speciality facilities that are tabulated in Table 5. To sample, the pollutant at a different location was designated, according to the point of source of the pollutant. The frequent location was the hospital's main entrance, laboratory, outpatient department, emergency ward, and kitchen unit. Indoor air

Table 4 Descriptive statistics of sampled concentration of educational indoor air pollutant

Parameters	Classroom A			Classroom B			Classroom C			Classroom D			Classroom E			Average mean of all 5 occupancies	AQG (air quality guideline)
	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean		
PM_{10} in mg/m^3	60	270	155	75	224	133.7	35	198	126.6	30	225	121.8	68	169	105	128.42	100[a]
CO_2 in ppm	590	2150	1382	450	1750	1086	420	1175	815.6	430	1350	986	400	1185	774.9	1008.9	1000[b]
CO in ppm	1	3.2	2.18	0.8	2.6	1.81	1.3	2.9	2.1	0.6	2.3	1.58	0.8	2.2	1.5	1.83	9[a]
Ozone in ppm	0.059	0.12	0.081	0.054	0.13	0.07	0.04	0.12	0.07	0.056	0.13	0.078	0.042	0.14	0.08	0.07	0.1[c]
SO_2 in μg/m^3	5.2	13.2	8.6	5.6	12.4	8.8	5.2	12.1	6.9	5.5	9.6	8.2	5.2	11.2	8.4	8.18	40[a]
NO_2 in μg/m^3	14.8	51.2	32.2	13.2	42.4	27.3	12.9	37.4	24	11.9	37.9	24.5	16.9	39.8	27.6	27.12	40[a]
VOC in ppm	0.2	1.32	0.44	0.15	1.23	0.37	0.09	1.1	0.26	0.12	1.2	0.35	0.11	1.32	0.41	0.36	0.5[d]
Formaldehyde in μg/m^3	8.89	27	16.11	3.6	21	9.12	3.7	19	10	1.2	21	10.36	1.4	14	7.1	10.58	100[b]

[a]"American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE) (Taylor 1999)

[b]Hong Kong Indoor Air Quality Objective Level I and II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999)

[c]"Occupational Safety and Health Administration" (OSHA) Permissible Exposure Limit (Administration, O. S. and Health, Tide 29, n.d.)

[d]Leeds standard

Table 5 General description of the sampled hospital indoor occupancy

Indoor occupancy	District condition	Type of hospital	Area of the hospital	Type of ventilation	Age of the occupancy in year
Hospital A	Commercial area, high traffic flow, medium population density	Civil	2215	Natural ventilation with exhaust fan	8
Hospital B	Mixed commercial area, medium traffic flow	Multi-specialty	4452	Centralised AC	6
Hospital C	Mixed commercial area medium traffic flow, high population and vehicle density	Civil	1635	Natural ventilation with exhaust fan	7
Hospital D	Mixed commercial area, medium traffic flow	Multi-specialty	3569	Centralised AC	10
Hospital E	Mixed commercial area, low traffic flow	Multi-specialty	4125	Mechanical ventilation with AC	11

was sampled by placing the sampling instruments in different points of the indoor occupancy area at 1.5 m of elevation from the ground and 1 m away from the potential source of air pollutants. Since most of the assessed hospital district condition was commercial, there was also a potential source for indoor pollutants outdoor air and nearby traffic flow.

The indoor air of hospital buildings contains various sources for these pollutants that need to be contained to decrease the indoor environment's pollutant concentration. Hospital is one of those public places where gatherings of people with different health conditions; hence, it is essential to avoid any secondary source of a contaminant that causes additional impairment to the patient or the occupant. Compared to other indoor occupancies, the institutional building has loads of sources for these pollutants generated from biomedical waste, medical equipment, and instruments.

Particulate matter

Figure 5A represents the variation of PM_{10} in institutional buildings. The characterisation of PM_{10} concentration was primarily dependent on the district condition and the occupant activity, which is one of the primary sources that causes particulate matter's resuspension in the environment by walking through it via its shoes, clothes, and ground to the air. There are a few primary sources of particulate matter in hospital buildings, such as the main entrance, outpatient department, and kitchen unit. The measured range of particulate matter across the five sample hospitals was 45 to 324 μg/m^3. The mean concentration for the sampled occupancy varied between 92 and 236 μg/m^3. Hospital A recorded the highest concentration level due to its district condition and penetration of outdoor air into it. All the sampled hospitals exceeded the ASHRAE Class B standard permissible level for PM_{10}. Low levels of PM_{10} were detected in Hospital C due to the better ventilation system compared to other sampled hospitals.

Carbon dioxide

Figure 5C shows the variation of carbon dioxide in observed institutional buildings. Carbon dioxide in hospital buildings mostly depends on the number of the occupant, mechanical movement within the closed space, and penetration of outside air. The average concentration was detected between 890 and 1227 ppm across five assessed hospital buildings. Hospital D detected the highest level of CO_2 concentration of 1980 ppm. It is also because the hospital has excess gatherings of people compared to other institutional occupancies. Except for Hospital A, all other hospitals exceeded the HKIAQO Level II standard permissible limit of 1000 ppm.

Carbon monoxide

Carbon monoxide is derived as so-called combustion gas, which means it occurs due to incomplete combustion. This generally occurs from vehicle exhaust fumes from parking vehicles entering the indoor and contributing to higher concentration. These higher levels of CO mainly were detected where there is direct access to the outside air. During sampling of hospitals, the concentration levels of CO detected were varied from location to location. Figure 5E shows the sampled hospital's low, high, and mean values. The sampled concentration of CO ranged between 1.1 and 5.2 ppm, and the average concentration ranged between 2.8 and 3.42 ppm across all the five observed hospitals. The detected concentration level for CO was far below the ASHRAE Class B standard permissible value.

Ozone

The nature of ozone is that it is generally found in substantial concentration near the source, and it does not accumulate as such in the indoor environment. In institutional buildings, various medical equipment utilizes UV (ultraviolet) or

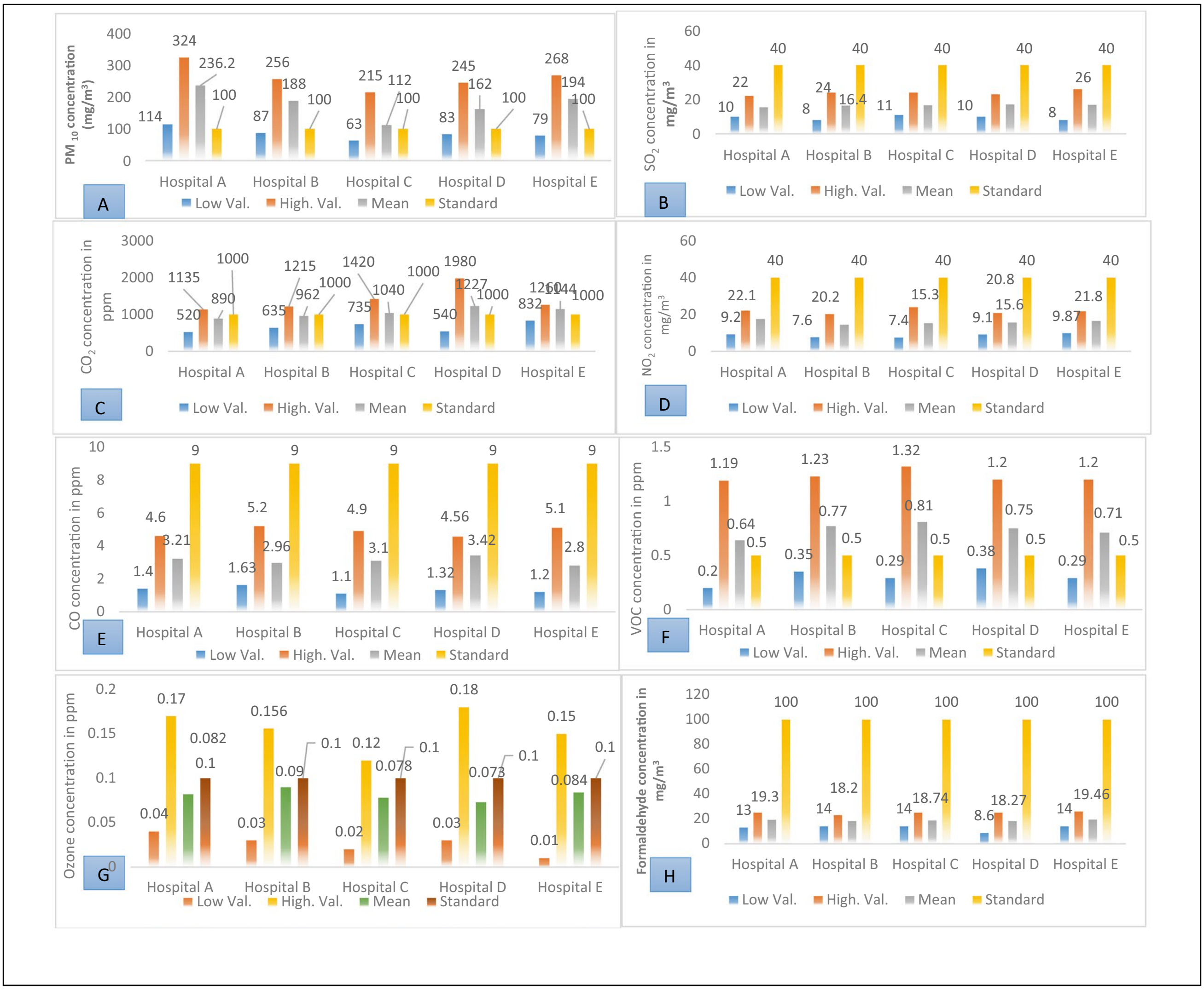

Fig. 5 Concentration of different types of **A**–**H** indoor air pollutant in different institutional building occupancy

causes ionization in air, which produces ozone in the indoor environment. Ozone is highly reactive, and it is evident that various pollutants are present indoors, so if it is inhaled, it may cause severe damage to the lungs and irritation to the respiratory tract. Figure 5G shows the detected concentration of ozone in hospital buildings. The ozone concentration ranged from 0.01 to 0.18 ppm, and the average value was 0.087, which was below the standard value of OSHA permissible exposure limit. A higher ozone concentration level was detected in the laboratory and intensive care unit (ICU), where medical equipment was present.

Sulfur dioxide

Figure 5B shows the measured concertation of SO_2 with its lowest, highest, and mean value. The measured range of SO_2 varied between 8 and 26 μg/m^3, and the mean concentration among the five hospitals were 15.42 to 17.03 μg/m^3 since the measured concentration was substantially lower than the Class B and Class A of ASHRAE standard value of 80 μg/m^3 and 40 μg/m^3, respectively. The average concentration for January, February, and March are 15.74 μg/m^3, 16.35 μg/m^3, and 17.07 μg/m^3, respectively. Unlike NO_2, SO_2 does not show any seasonal variation in its concentration.

Nitrogen dioxide

The quantitative assessment of NO_2 across all the five hospital buildings is depicted in the chart Fig. 5D. The mean concentration for the measured NO_2 during the 3-month study ranged between 14.38 and 17.53 μg/m^3. The highest value for NO_2 among the sampled hospital building ranged from 20.2 to 23.9 μg/m^3, which is relatively lower than the ASHRAE Class A standard value of 40 μg/m^3. The concentration of NO_2 was higher in January than that in March's sampled concentrations. In this occupancy, there is no direct source of NO_2, and the only source seems to be polluted outdoor air. In some cases, the concentration level was also varied because of the infiltration and decay rates.

Volatile organic compound

There are various sources of VOC indoors, but specifically in institutional buildings, electrically operated medical equipment can be one significant source of it other than outside air that also contributes to it. Figure 5F shows the variation in concentration of volatile organic compounds in all the five institutional buildings. During sampling, higher VOC concentration was detected near emergency ward where care products are used on patients to disinfect or for cleaning purposes. The measured concentration of VOC ranged between 0.2 and 1.32 ppm across all the five hospitals, and the average concentration was 0.75 ppm which exceeded the Leeds standard of value of 0.5 ppm.

Formaldehyde

In institutional buildings, there was significantly less concentration of formaldehyde detected. The concentration of formaldehyde observed was between 8.6 and 26 μg/m^3, and the average for all the five hospital buildings was 18.77 μg/m^3 as shown in Fig. 5H. The range was below because the source presence was deficient compared to other occupancies such as residential. Hospital buildings such as multispecialty had installed particle board, foam insulation, and fabrics for decorative purposes, one of the sources. The common source for formaldehyde among these hospital buildings was cleaning fluids used regularly. It was also found that the variation in formaldehyde concentration may depend on the course of a day or season to season. A summary of all the institutional indoor air pollutants collected has been tabulated in Table 6.

Group D: business occupancy

Urbanization has resulted in several sources of indoor pollutants with the increased usage of manufactured products. Modern offices are equipped with various technology and products to provide comfort to the occupants, which sometimes becomes a significant source of the problem. In many offices, centralised air conditioning systems are installed, which significantly improve the occupancy only if operated and maintained correctly. Similarly, many building usage materials for decorative purposes which are sources of many indoor air pollutants and other than these various kinds of furnishing have been used for the same purpose. For indoor pollution, outdoor air contributes to a great extent, which is

Table 6 Descriptive statistics of sampled concentration of institutional indoor air quality

Parameters	Hospital A			Hospital B			Hospital C			Hospital D			Hospital E			Average mean of all 5 occupancies	AQG (air quality guideline)
	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean		
PM_{10} in mg/m^3	114	324	236.2	87	256	188	83	245	162	45	284	175	79	268	194	175.08	100[a]
CO_2 in ppm	520	1135	890	635	1215	962	735	1420	1040	540	1980	1227	932	1260	1144	1035.6	1000[b]
CO in ppm	0.05	0.98	0.49	0.03	0.86	0.46	0.09	1.5	0.61	0.09	1.4	0.65	0.08	1.4	0.68	3.1	9[a]
Ozone in ppm	0.04	0.17	0.082	0.03	0.156	0.09	0.02	0.12	0.078	0.03	0.18	0.073	0.01	0.15	0.084	0.087	0.1[c]
SO_2 in μg/m^3	10	22	15.42	8	24	16.4	11	24	16.66	10	23	17.03	8	26	16.9	16.56	40[a]
NO_2 in μg/m^3	9.2	22.1	17.53	7.6	14.38	20.2	7.4	23.9	15.3	9.1	20.8	15.6	9.87	21.8	16.49	15.4	40[a]
VOC in ppm	0.2	1.32	0.64	0.35	1.23	0.77	0.29	1.2	0.76	0.38	1.2	0.75	0.29	1.2	0.71	0.75	0.5[d]
Formaldehyde in μg/m^3	13	25	19.3	14	23	18.2	14	25	18.74	8.6	25	18.27	14	26	19.46	18.77	100[b]

[a]"American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE) (Taylor 1999)

[b]Hong Kong Indoor Air Quality Objective Level I and II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999)

[c]"Occupational Safety and Health Administration" (OSHA) Permissible Exposure Limit (Administration, O. S. and Health, Tide 29, n.d.)

[d]Leeds standard

generally polluted by industrial emission and vehicle exhaust whether the building is mechanically ventilated or naturally ventilated.

Generally, specific electronic equipment can be found easily in office space, such as photocopiers, fax machines, and printers, which are important to carry out the activity, but it is also essential to check the ventilation system. This electronic equipment and computers should be used with care because their heat-producing nature generates pollutants above the nominal value. Table 7 shows many activities, and sources are generally present near office buildings, such as smoking lounges, parking garages, emergency generators, and laboratories. In the office setting, several workstations and photocopiers and printers were present in observed places.

Particulate matter

Figure 6A shows the variation of particulate matter in office setting. PM_{10} sources were mainly wooden furniture and subsequent access and egress of humans from one space to another, which brings particulates along with their shoes. The human movement also creates resuspension of particulates present in the indoor environment. In the office, carpeting was also present, which increased the concentration of PM_{10}. The measured concentration of PM_{10} was detected from 28 to 112 $\mu g/m^3$, and the average concentration was ranged between 68 and 72 $\mu g/m^3$. The mean concentration was below the ASHRAE Class B standard permissible level for PM_{10} since the concentration was above the Class A standard value of 50 $\mu g/m^3$. The reason for detecting a lower level of PM_{10} concentration can be the enclosed space, which avoided any medium of the entrance of unnecessary particles.

Carbon dioxide

In a business occupancy, the primary source of CO_2 is respiration by the occupant and outside air. Since the modern office settings are air tight, which gives very little space to the egress of outside air, hence, in this case, the concentration of CO_2 more relied on types of human activities. Figure 6C shows the measured concentration level of CO_2 in all five offices. The concentration level detected among the offices was ranged between 520 and 1362 ppm. The average concentration of offices was ranged between 820 and 956 ppm, which was below the HKIAQO Level II standard permissible limit of 1000 ppm. The highest level of CO_2 concentration was sampled in Office D; the reason behind it was the poor ventilation rate of the office space.

Carbon monoxide

The sources that contribute to business buildings' indoor environment are mainly tobacco smoke and attached parking garages where it comes out from vehicle exhaust. In some of the business building, there was also facility for pantry which is also a contributing factor to it. Figure 6E shows the variation of carbon monoxide across the five office buildings. The measured concentration of CO was detected between 1.1 and 4.1 ppm, and the average concentration of office buildings was between 2.3 and 2.9 ppm. These values are below the ASHRAE Class B standard value of 9 ppm, but slightly more significant than the Class A value of 2 ppm. Since the concentration level was below the permissible value, it does not harm the occupant, but it can cause occupational gas poisoning in case of increased concentration.

Table 7 General description of the sampled office indoor occupancy

Indoor occupancy	District condition	Age of the occupancy in year	Area of the occupancy	Indoor finishing material	Type of ventilation	No. of occupants
Office A	Mixed residential area with number of private dwellings, medium traffic flow,	6	155	Plastering wall, marble floor	Centralised AC	32
Office B	Mixed residential area with number of private dwellings, medium traffic flow	9	135	Plastering wall with wood furnishing	Centralised AC	28
Office C	Mixed residential area low traffic flow, high population and vehicle density	8	210	Plastering wall, marble floor	Mechanical ventilation and AC	55
Office D	Mixed residential area with Number of private dwellings, medium traffic flow	11	130	Plastering wall, marble floor	Mechanical ventilation and air conditioning	35
Office E	Mixed commercial area, medium traffic flow	11	125	Plastering wall, marble floor	Mechanical ventilation	30

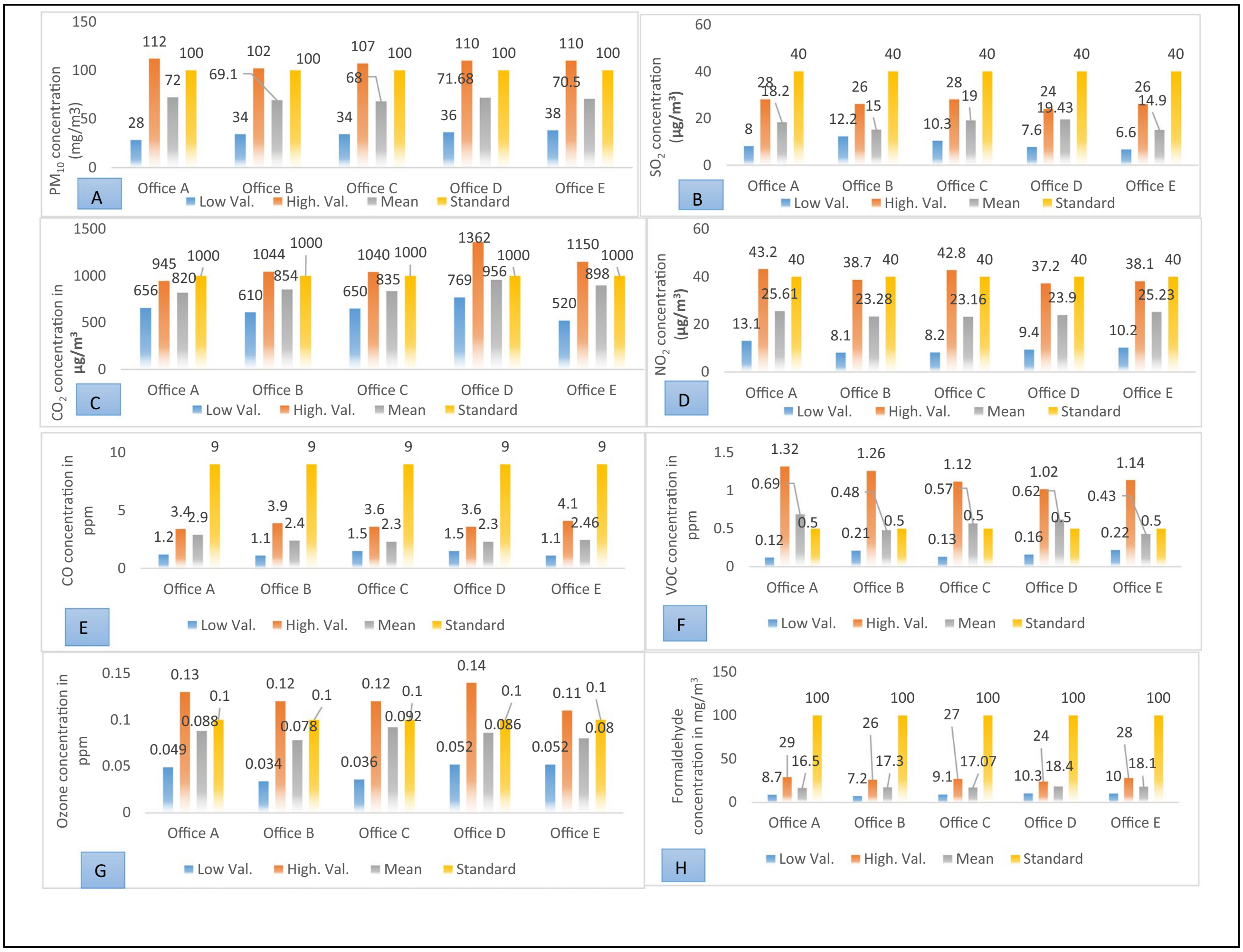

Fig. 6 Concentration of different types of **A**–**H** indoor air pollutant in different business occupancy

Ozone

Ozone has a very adverse impact on human health if it gets inhaled or comes in contact with the skin. Previous studies have shown the operator's daily exposure using photocopiers and other electronic equipment, which are familiar sources in offices. Several studies have shown that a higher ozone concentration level reduces human performance if it heavily taxes the respiratory system. Ambient ozone concentration is also a significant influence on indoor air quality levels. Figure 6G shows the variation between observed ozone levels in business buildings. The measured range of ozone ranged between 0.034 and 0.14 ppm, and the average concentration across the five offices was 0.083 ppm which was lower than the OSHA PEL standard value of 0.1 ppm (Barrese et al. 2014).

Sulfur dioxide

In-office occupancy, there is no primary source for SO_2; whatever the concentration detected indoors is from secondary sources, i.e., outside air, which gets polluted by burning of fossil fuels, industrial emission, and vehicles that use fuel of high sulfur content. Hence, the concentration will differ according to the proximity of these secondary sources. Figure 6B shows the variation of measured SO_2 between all the five offices. The concentration of SO_2 ranged between 8 to 28 µg/m^3, and the average concentration ranged between 15 to 19.43 µg/m^3. These values were below the ASHRAE Class A standard permissible limit of 40 µg/m^3. High concentration was detected in the office because of the attached parking garage and pantry facility in the business building.

Nitrogen dioxide

Figure 6D shows the variation of NO_2 among the five office occupancies. In an office setting, the measured concentration ranged between 8.1 and 43.2 μg/m^3, and the mean concentration was between 23.1 and 25.6 μg/m^3. In some instances, the concentration of office A and office C exceeded the ASHRAE Class A of 40 μg/m^3 standard value, but all the five office building was lower than the ASHRA Class B of 80 μg/m^3 standard value. The lowest mean was 23.1, which was detected in Office C, which was equipped with a mechanical ventilated air conditioning system. The trend line during measurement of NO_2 showed higher concentration during winter due to usage of room heater in the occupancy. The concentration of NO_2 from outdoor air is also influenced in naturally ventilated occupancies.

Volatile organic compound

In-office spaces, the primary sources of VOC are electronic equipment such as photocopiers, printers, and fax machines. Certain cleaning products are also one of the sources of VOC in office buildings. Specific types of VOCs are produced not only during printing or photocopying but also by processed paper, which is a significant source. Wood furniture is also one of the sources, specifically new desks, which could release a relatively high amount of VOCs. The figure shows the variation in VOC concentration among five office occupancy. The measured concentration of VOC ranged between 0.16 and 1.32 ppm is shown in Fig. 6F. The mean concentration of all the five office buildings was 0.55 ppm, slightly more significant than the recommended standard of Leeds, i.e., 0.5 ppm.

Formaldehyde

In business buildings, for decorative purposes, various kinds of products are used: sources of formaldehyde such as finishing material used in wooden products, resins, particle board and fiberboard, press fabrics used on a desk, and foam insulation used along with the ductwork. Tobacco smoke is also one of the sources of formaldehyde. Hence, it is essential to give consideration to the distance between the smoking lounge and offices. Figure 6H shows the variation of measured formaldehyde in the business building. The measured concentration ranged between 7.2 and 29 μg/m^3 across all the five office occupancy. The offices' average concentration measured from January to March is 17.3 μg/m^3, 16.2 μg/m^3, and 19.02 μg/m^3, respectively. The concentration level was far below the HKIAQO Level II Standard of 100 μg/m^3. Since the exposure level was below the air quality guideline, it is essential to be aware of these kinds of pollutants (Barrese et al. 2014; Baek et al. 1997). A summary of all the office indoor air pollutants collected has been tabulated in Table 8.

Group E: mercantile occupancy

According to National Building Code (NBC), mercantile building includes shops, store, and for display and sale of merchandise which can be wholesale or retail. Under NBC, this category is again subdivided in three parts depending upon the area and underground facility. These places are such which is a center of attraction in terms of purchasing products or spending time. For this study, we have taken five photocopier shops in order to investigate the indoor air of this mercantile occupancy (Table 9). This type of occupancy contains various sources of indoor air pollutants as such wooden furniture and products used for decorative purposes, painting and furnishing of wall, and photocopier and computers used for commercial purposes.

Generally, at mercantile buildings/photocopier stations, some of the hazards that occupant or consumer may exposed to are various indoor air pollutant, electromagnetic radiation, and ergonomics condition. The major sources of indoor air pollutant which highly contributes in photocopier shops are photocopy machines which uses toner and selenium. In this type of mercantile building, the district condition of the shops also holds a greater significance because it provides outdoor-polluted air to indoors of these shops.

Particulate matter

The photocopy shops sampled are situated adjacent to roads, where dust particles and vehicle exhaust emit particulates that contribute to mercantile indoors. Figure 7A shows the detected variation of PM_{10} across all the five observed photocopy shops. The measured range concentration of PM_{10} was between 25 and 260 μg/m^3, and the average concentration was between 110 and 126.6 μg/m^3. These concentrations exceeded the ASHRAE Class B standard value of 100 μg/m^3. The indoor source in this mercantile that contribute to the increased concentration of particulates other than outside air is that the photocopier emits toner particles. Poor ventilation of these shops is also a contributing factor to the increased concentration of these pollutants. Human movement in the shops also creates the excitation of suspended particles from shoes, clothes, and other sources. The concentration level was low during the morning period due to less vehicle movement on the road. High exposure of particulate matter to human health impacts the respiratory system, and if the exposure remains consistent, it may also result in chronic disease.

Table 8 Descriptive statistics of sampled concentration of office indoor air quality

Parameters	Office A			Office B			Office C			Office D			Office E			Average mean of all 5 occupancies	AQG (air quality guideline)
	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean		
PM_{10} in mg/m^3	28	112	72	34	102	69.1	34	107	68	36	110	71.68	38	110	70.5	70.25	100[a]
CO_2 in ppm	656	945	820	610	1044	854	650	1040	835	769	1362	956	520	1150	898	872.6	1000[b]
CO in ppm	1.2	3.4	2.9	1.1	3.9	2.4	1.5	3.6	2.3	1.4	4.3	2.6	1.1	4.1	2.46	2.4	9[a]
Ozone in ppm	0.049	0.13	0.088	0.034	0.12	0.078	0.036	0.12	0.092	0.052	0.14	0.086	0.052	0.11	0.08	0.083	0.1[c]
SO_2 in µg/m^3	8	28	18.2	12.2	26	15	10.3	28	19	7.6	24	19.43	6.6	26	14.9	16.9	40[a]
NO_2 in µg/m^3	13.1	43.2	25.61	8.1	38.7	23.28	8.2	42.8	23.16	9.4	37.2	23.9	10.2	38.1	25.23	24.07	40[a]
VOC in ppm	0.12	1.32	0.69	0.21	1.26	0.48	0.13	1.12	0.57	0.16	1.02	0.62	0.22	1.14	0.43	0.55	0.5[d]
Formaldehyde in µg/m^3	8.7	29	16.5	7.2	26	17.3	9.1	27	17.07	10.3	24	18.4	10	28	18.1	17.4	100[b]

[a]"American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE) (Taylor 1999)

[b]Hong Kong Indoor Air Quality Objective Level I and II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999)

[c]"Occupational Safety and Health Administration" (OSHA) Permissible Exposure Limit (Administration, O. S. and Health, Tide 29, n.d.)

[d]Leeds standard

Carbon dioxide

Since the number of occupants in photocopy shops is not as much as other occupancy classifications, due to its district condition, the adjacent sources highly contribute to its concentration level. Figure 7C shows the variation of CO_2 levels across all the five observed photocopy shops. The concentration range was sampled between 510 and 1950 ppm, and the average concentration was between 788 and 1214 ppm (Fig. 7B). Shop E's average concentration exceeded the HKIAQO Level II Standard of 1000 ppm, whereas other photocopy shops remained under the level II standard. The sources for CO_2 in these indoor are mainly from outdoor air, and these are polluted by the vehicle emission and smoke from the industrial emission.

Carbon monoxide

The district condition of these photocopy shops is commercial and mixed residential where population and traffic densities were high, which contributed to these pollutants in every means. The figure shows the variation sampled of CO in photocopy centers. The measured concentration was ranged between 1.4 and 11 ppm, and the average concentration was 4.09 to 5.14 ppm as shown in Fig. 7E. Since the average concentration was below the ASHRAE Class B standard value of 9 ppm, shop D recorded a high concentration up to 11 ppm in some instances. Shop D was situated beside the restaurant, which emitted gaseous products from the combustion process.

Ozone

Figure 7G shows the measured variation of sampled ozone in all the five photocopy shops. The measured ozone range was between 0.02 and 0.82 ppm, and the average value was detected between 0.076 and 0.085 ppm. The sampled concentration exceeded the OSHA PEL value of 0.1 ppm. The sources in photocopy shops are photocopier machines and outdoor air. The concentration level was directly proportional to the volume of printing done by the machine and the outdoor temperature. The ozone concentration in the surroundings increases with the increased intensity of the photocopying process (Destaillats et al. 2008).

Sulfur dioxide

Data for SO_2 in mercantile/photocopy shops were collected for 90 days from Jan to March. Figure 7B shows the measured concentration of SO_2 across all the five assessed photocopy centers. The measured concentration range was detected between 22 and 80 µg/m^3, and the average concentration was between 48.2 and 58.5 µg/m^3. These concentrations exceeded

Table 9 General description of the sampled mercantile indoor occupancy

Indoor occupancy	District condition	Age of the occupancy in year	Area of the occupancy	Indoor finishing material	Type of ventilation	No. of occupants
Shop A	Mixed commercial area, high traffic flow, medium population density	10	144	Plastering wall, tile floor	Natural ventilation	3
Shop B	Mixed residential area with number of private dwellings, medium traffic flow	12	180	Plastering wall	Natural ventilation and exhaust fan	4
Shop C	Mixed residential area low traffic flow, high population and vehicle density	7	121	Plastering wall, marble floor	Natural ventilation with ceiling fan	2
Shop D	Mixed residential area with number of private dwellings, medium traffic flow	6	168	Plastering wall, plastered floor	Natural ventilation and exhaust fan	3
Shop E	Mixed commercial area, medium traffic flow	11	120	Plastering wall, vinyl floor	Natural ventilation and exhaust fan	4

[a]"American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE) (Taylor 1999)

[b]Hong Kong Indoor Air Quality Objective Level I and II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999)

[c]"Occupational Safety and Health Administration" (OSHA) Permissible Exposure Limit (Administration, O. S. and Health, Tide 29, n.d.)

[d]Leeds standard

Fig. 7 Concentration of different types of **A**–**H** indoor air pollutant in different mercantile occupancy

the ASHRAE Class A standard value of 40 µg/m^3, but it was less than the Class B value of 80 µg/m^3. The sources that may have contributed to mercantile indoors are outside polluted air and the combustion process of a nearby restaurant.

Nitrogen dioxide

Figure 7D depicts the variation of measured NO_2 in mercantile buildings. The range of NO_2 concentration measured was between 20.8 and 57.4 µg/m^3. And the average concentration was ranged between 27.6 and 38.2 µg/m^3. Since the mean pollutant level in mercantile buildings was below the ASHRAE Class A standard value of 40 µg/m^3, it was detected more than it at some time. The sources that contributed to it are tobacco smoke and vehicle exhaust emission, and the values of concentration values showed variation depending upon the density of traffic near the photocopy shops.

Volatile organic compound

The concentration of VOC in indoor air is typically higher than that in outdoor air. Figure 7F depicts the variation of measured VOC in mercantile buildings. The range of VOC concentration was measured between 0.16 and 1.65 ppm, and the average was between 0.87 and 1.03 ppm. This concentration exceeded the standard value of Leeds of 0.5 ppm. Higher VOCs were detected during the continuous operation of photocopy machines, and the lowest level was detected during morning periods.

Formaldehyde

The quantitative assessment of formaldehyde has been done for five photocopy shops for over 90 days. The sampling of HCHO was done before the start of the photocopy machine, and after the start of the machine for understanding the variation of concentration, a summary of all the mercantile indoor air pollutant collected has been tabulated in Table 10. Figure 7H shows the concentration variation across the observed mercantile/photocopy shops. The measured concentration ranged between 16 and 46 µg/m^3, and the average concentration was 31.03 to 32.6 µg/m^3. The detected concentration level was below the HKIAQO Level II Standard of 100 µg/m^3.

Findings and recommendations

General findings

Table 11 consists of the average indoor concentration of each pollutant from every building occupancies. The

Table 10 Descriptive statistics of sampled concentration of office indoor air quality

Parameters	Shop A			Shop B			Shop C			Shop D			Shop E			Average mean of all 5 occupancies	AQG (air quality guideline)
	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean	Low val	High val	Mean		
PM_{10} in mg/m^3	25	190	110	56	164	117.7	55	235	122	36	195	119	40	260	126.16	118.9	100[a]
CO_2 in ppm	734	1298	952	520	1044	788	634	1272	910	510	1350	975	450	1950	1214	967.8	1000[b]
CO in ppm	1.8	9	5.14	1.6	9.1	4.16	1.8	8.9	4.71	1.4	11	4.09	1.5	8.9	4.23	4.46	9[a]
Ozone in ppm	0.01	1.5	0.085	0.021	1.69	0.088	0.035	1.56	0.083	0.03	1.6	0.081	0.02	1.4	0.076	0.08	0.1[c]
SO_2 in µg/m^3	31	70	50.35	22	66	48.2	29	78	52.4	32	80	58.5	34	78	57.86	53.46	40[a]
NO_2 in µg/m^3	20.8	51.2	28.2	23.2	48.4	32.3	21.9	57.4	38.2	19.1	47.9	34.5	22.9	49.8	27.6	32.16	40[a]
VOC in ppm	0.16	1.65	0.89	0.31	1.56	0.92	0.43	1.56	0.87	0.5	1.6	1.03	0.45	1.35	0.83	0.9	0.5[d]
Formaldehyde in µg/m^3	23	42	32.4	22	40	31.2	24	46	31.03	18	41	32.2	16	41	32.65	31.89	100[b]

[a]"American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE) (Taylor 1999)

[b]Hong Kong Indoor Air Quality Objective Level I and II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999)

[c]"Occupational Safety and Health Administration" (OSHA) Permissible Exposure Limit (Administration, O. S. and Health, Tide 29, n.d.)

[d]Leeds standard

Table 11 Comparative parameter statistics of each occupancy with the air quality guideline

Parameters	Residential	Educational	Institutional	Business	Mercantile	Air quality guidelines
PM_{10} in mg/m^3	144.9	128.42	175.08	70.25	118.9	100[a]
CO_2 in ppm	681.42	1008.9	1035.6	872.6	967.8	1000[b]
CO in ppm	8.9	1.83	3.1	2.4	4.46	9[a]
Ozone in ppm	0.05	0.07	0.087	0.083	0.08	0.1[c]
SO_2 in µg/m^3	34.8	8.18	16.56	16.9	53.46	40[a]
NO_2 in µg/m^3	42.32	27.12	15.4	24.07	32.16	40[a]
VOC in ppm	0.65	0.36	0.75	0.55	0.9	0.5[d]
Formaldehyde in µg/m^3	30.2	10.58	18.77	17.4	31.89	100[b]

[a]"American Society of Heating Refrigerating and Air Conditioning Engineering" (ASHRAE) (Taylor 1999)

[b]Hong Kong Indoor Air Quality Objective Level I and II Standard (The Goverment of the Hong Kong Special Administrative Region Indoor Air Quality Management Group 1999)

[c]"Occupational Safety and Health Administration" (OSHA) Permissible Exposure Limit (Administration, O. S. and Health, Tide 29, n.d.)

[d]Leeds standard

concentration of pollutants that exceeded the air quality guidelines has duly been highlighted, and for those concentration levels, the chronic daily intake shall be calculated. From residential building PM_{10}, NO_2 and VOC exceeded the guideline value because of tobacco smoke and kitchen activities. In-home occupancies' various decorating and furnishing materials also gave the rise of VOCs in it. There were no particular sources of pollutants in educational building occupancies compared to other occupancies. Only the concentration values of PM_{10} and CO_2 exceeded the guidelines value because of the higher number of occupants and due to the frequent movement and resuspension of the particulates. The institutional building has a larger area than other building occupancies, and due to the nature of the operation, there is frequent access of occupants. Due to the usage of various medical equipment, ozone concentration was found higher than other occupancies, but it was under the guideline level. The concentration of PM_{10} and CO_2 exceeded the guidelines values, which may be because of a higher number of occupants, and the district condition of the hospital was mixed commercial. Business occupancies recorded most of the pollutants under air quality guidelines only except VOCs. Due to the air tight characteristics and reasonable ventilation rate of offices that avoided the access of unwanted pollutant indoors, which may be the reason for the lower concentration of indoor air pollutants, the office uses various decorative products and photocopiers, which may be given the rise in the concentration of VOCs. Mercantile building includes various types of retail and shopping facilities, but for the study purpose, photocopy shops were taken. Due to the frequent use of photocopying machines, it gave the rise in concentration of VOCs. Other than VOCs, PM_{10} and SO_2 values also exceeded the guideline values. The main contributing factor in this was the district condition of it. Continuous traffic on the road and dust particles was the secondary factor exceeding the pollutant concentrations.

Determining chronic daily intake

The study includes several indoor pollutants, and as per the study, 65% of time spent by humans are indoors; hence, there is a chronic health risk to the occupant. Hence, the health risk assessment is mainly committed to chronic exposure to indoor air pollutants that may have a carcinogenic or non-carcinogenic impact on human health, since chronic exposure may lead to long-term health hazards which can be very dangerous to human health, whereas acute exposure does not result in such effects on human. The primary pollutants examined in this study exceeded the air quality guideline values. According to each occupancy, the receptors of interest were the respective occupants in the health risk assessment, and the prevalence route of entry was inhalation. The chronic daily intake (I) was used to determine the cancerous risk and noncancerous effects from chronic exposure of indoor pollutants and was calculated by averaging sampled concentration of pollutant daily intake over the given exposure period. The chronic daily intakes for the indoor air pollutants that may have health hazards on the occupants of respective buildings were calculated by Lee et al. (2006)

$$I = \left(\mathrm{Ca}^{*}\mathrm{IH}^{*}E_T^{*}E_F^{*}E_D\right)/\left(365^{*}\mathrm{AT}^{*}\mathrm{BW}\right)$$

where

I indicate the inhalation intake (mg/kg day),

Ca is the concentration of pollutant in (mg/m^3), IH is inhalation rate (m^3/h), E_T is the exposure time (h/week),

E_F is the exposure frequency (weeks/year), E_D is the exposure duration (year),

AT is the averaging time (years), and BW denotes the body weight (kg).

Chronic daily intake is associated with the exposure frequency, duration, type of pollutants, and the pollutant's concentration. Different indoor occupancies are considered; hence, the daily intake will also influence the type of activity pattern. For the given formula, the data required are given in Table 12. Data for inhalation rate was referred from Exposure Factors Handbook for the respective age group as given in the handbook. Inhalation rate was taken in m^3/day, and the exposure time was in weeks, which varied along with building occupancies. Exposure frequency for pollutant exposure was taken as 50 weeks/year, on behalf of the usage frequency for that occupancy. Inhalation intake was calculated for carcinogen and non-carcinogenic pollutant exposure. An averaging time of 70 years was taken to calculate for carcinogenic evaluation, and for the calculation on non-carcinogenic evaluation, 30 years of a lifetime was taken. The averaging lifetime for carcinogenic exposure remains an averaging lifetime of humans, whereas, for non-carcinogenic, it is only the averaging lifetime of the occupational period. Exposure duration for carcinogen and the non-carcinogenic product has taken the occupant exposure time concerning the occupancy usually in case of working its averaged 30 years indoors. Bodyweight for the occupant was referred from the model factories act for adults. An occupant's chronic daily intake was evaluated on the 3-month sampling data and the concentration pattern indoors. Other criteria such as exposure time and frequency were made upon several assumptions and by asking general series of questionnaires to the occupants. Health risk assessment for worker exposure to indoor pollutants in the five different occupancies was determined by collected reference data. The aggregated daily intake in mg/kg-day of pollutants exceeding air quality guidelines are summarised in Table 13.

Conclusion

This study investigated pollutant in different environmental setup based on building code specially for nonindustrial indoor environments, i.e., office buildings, public buildings (schools, hospitals, theatres, restaurants), and private dwellings in Dehradun, India. The five indoor occupancies were investigated for particulate matter, carbon dioxide, carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, volatile organic compound, and formaldehyde. All these pollutants have various primary and secondary sources

Table 12 Chronic daily exposure and health risk assessment factor for the indoor occupants

Exposure setting	Value											
	R			*E*		*I*			B	*M*		
	PM_{10}	NO_2	VOC	PM_{10}	CO_2	PM_{10}	CO_2	VOC	VOC	PM_{10}	SO_2	VOC
Concentration (Ca)	144.9	42.32	0.65	128.42	1008.9	175.09	1035.6	0.75	0.55	118.9	53.4	0.9
Inhalation rate (m^3/h)	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Exposure time (h/weeks)	98	98	98	36	36	48	48	48	45	56	56	56
Exposure frequency (weeks/year	50	50	50	50	50	50	50	50	50	50	50	50
Exposure duration (year) carcinogenic	–	–	30	–	–	–	–	30	30	–	–	30
Exposure duration (year) non-carcinogenic	30	30	–	30	30	30	30	–	–	30	30	–
Body weight (kg)	55	55	55	55	55	55	55	55	55	55	55	55
Average time (year) carcinogenic	–	–	70	–	–	–	–	70	70	–	–	70
Average time (year) non-carcinogenic	30	30	–	30	30	30	30	–	–	30	30	–

Table 13 Toxicity values (inhalation intake) for various pollutants that exceeded air quality guidelines

Parameters	Chronic daily intake values in mg/kg-day				
	Residential	Educational	Institutional	Business	Mercantile
PM_{10}	0.74×10^2	0.24×10^2	0.43×10^2	–	0.34×10^2
CO_2	–	1.89×10^5	2.59×10^5	–	–
SO_2	–	–	–	–	0.15×10^2
NO_2	0.21×10^2	–	–	–	–
VOC	1.42×10^2	–	0.8×10^2	0.55×10^2	1.12×10^2

that contribute to indoor concentrations and pose a health concern to the occupants. All eight pollutants were investigated for an 8-h average concentration and compared with the air quality guidelines. The average indoor concentration of PM_{10}, NO_2, and VOCs in homes exceeded the air quality guideline values of 100 µg/m^3, 40 µg/m^3, and 0.5 ppm, respectively. It was probably due to the kitchen activities, LPG and laminates used in wooden furniture and finishing product used such as lacquer. In addition to measuring pollutant concentration, tobacco smoke and outdoor air have a more significant impact. In educational buildings, the concentration of PM_{10} and CO_2 values exceeded the 8-h average air quality guideline values. Since there were fewer indoor sources compared to other indoor occupancies, other pollutant concentration levels met the permissible level of guideline values. The increased concentration of PM_{10} and CO_2 levels in classrooms was due to occupants' respiration and resuspension of particulate matter present in the environment.

Similarly, in-hospital occupancy, the investigated concentration level of PM_{10}, CO_2, and VOCs exceeded the air quality guideline values. The increased concentration level is probably the same as the educational buildings. Out of all the five occupancies, business buildings were found to meet the air quality guideline values for most pollutants except for VOCs. The result was due to tight air characteristics and adequate occupancy ventilation. Electrically operated medical equipment can be one significant source of it, and outside air also contributes to it. In-office spaces, the primary sources of VOCs are electronic equipment such as photocopiers, printers, and fax machines. Other than this, wood furniture and furnishing material contributed to it. The indoor concentration levels of PM_{10} and SO_2 in photocopying shops were higher due to the frequent movement of vehicles which creates the excitation of dust particles, and emission of vehicle exhausts contributed to it. VOC levels were also found to be exceeding the air quality guideline values. It is most probably due to the increased usage of photocopier machines as the quantitative assessment suggests that the lowest level was detected during morning periods.

This work concludes that chronic exposure to indoor air pollutants in different indoors may have cancer and non-cancer health risks according to the measured concentration level.

Data availability There is no associated data.

Declarations

Ethical approval The paper reflects the authors' own research and analysis in a truthful and complete manner. The paper properly credits the meaningful contributions of co-authors and co-researchers. The results are appropriately placed in the context of prior and existing research. All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference. All authors have been personally and actively involved in substantial work leading to the paper and will take public responsibility for its content.

Consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

References

Abdel-Salam MMM (2022) Indoor exposure of elderly to air pollutants in residential buildings in Alexandria. Egypt Build Environ 219:109221

Abhijith KV, Kukadia V, Kumar P (2022) Investigation of air pollution mitigation measures, ventilation, and indoor air quality at three schools in London. Atmos Environ 289:119303

Ali MU et al (2021) Health impacts of indoor air pollution from household solid fuel on children and women. J Hazard Mater 416:126127

Alnuaimi A, Natarajan S, Kershaw T (2022) The comfort and energy impact of overcooled buildings in warm climates. Energy Build 260:111938

Amoatey P et al (2020) Association between human health and indoor air pollution in the Gulf Cooperation Council (GCC) countries: a review. Rev Environ Health 35(2):157–171

Baek SO, Kim YS, Perry R (1997) Indoor air quality in homes, offices and restaurants in Korean urban areas - indoor/outdoor relationships. Atmos Environ 31(4):529–544

Bao J et al (2022) Atmospheric carbonyls in a heavy ozone pollution episode at a metropolis in Southwest China: characteristics, health risk assessment, sources analysis. J Environ Sci 113:40–54

Barrese E et al (2014) Indoor Pollution in Work Office: VOCs, formaldehyde and ozone by printer. Occup Dis Environ Med 02(03):49–55

Bhat MA et al (2022) Investigation of indoor and outdoor air quality in a university campus during COVID-19 lock down period. Build Environ 219:109176

Boré A et al (2022) Monitored air pollutants from waste-to-energy facilities in China: human health risk, and buffer distance assessment. Atmos Pollut Res 13(7):101484

Bralewska K, Rogula-Kozłowska W, Bralewski A (2022) Indoor air quality in sports center: assessment of gaseous pollutants. Build Environ 208:108589

Choi N, Yamanaka T, Takemura A, Kobayashi T, Eto A, Hirano M (2022) Impact of indoor aroma on students' mood and learning performance. Build Environ 223:109490

Cobbold AT et al (2022) Perceptions of air quality and concern for health in relation to long-term air pollution exposure, bushfires, and COVID-19 lockdown: a before-and-after study. J Clim Chang Health 6:100137

Destaillats H et al (2008) Indoor pollutants emitted by office equipment: a review of reported data and information needs. Atmos Environ 42(7):1371–1388

Dong Z et al (2022) The impact of space design on occupants' satisfaction with indoor environment in university dormitories. Build Environ 218:109143

Du Y et al (2022) Impact of natural window views on perceptions of indoor environmental quality: an overground experimental study. Sustain Cities Soc 86:104133

Elsaid AM et al (2021) A critical review of heating, ventilation, and air conditioning (HVAC) systems within the context of a global SARS-CoV-2 epidemic. Process Saf Environ Prot 155:230–261

Fonseca Gabriel M et al (2021) Environmental quality in primary schools and related health effects in children. An overview of

assessments conducted in the Northern Portugal. Energy Build 250:111305
Fromme H et al (2007) Particulate matter in the indoor air of classrooms-exploratory results from Munich and surrounding area. Atmos Environ 41(4):854–866
Ganesh HS et al (2021) Indoor air quality and energy management in buildings using combined moving horizon estimation and model predictive control. J Build Eng 33:101552
Goujon-Ginglinger C, Mitova MI (2021) Environmental impact: influence of ENDPs on indoor air quality. In: Toxicological Evaluation of Electronic Nicotine Delivery Products. Academic Press, pp 137–187
Haines SR et al (2020) Ten questions concerning the implications of carpet on indoor chemistry and microbiology. Build Environ 170:106589
Halios CH et al (2022) Chemicals in European residences – Part I: a review of emissions, concentrations and health effects of volatile organic compounds (VOCs). Sci Total Environ 839:156201
Heracleous C, Michael A (2019) Experimental assessment of the impact of natural ventilation on indoor air quality and thermal comfort conditions of educational buildings in the Eastern Mediterranean region during the heating period. J Build Eng 26:100917
HKEPD Indoor Air Quality Management Group (1999) Guidance notes for the management of indoor air quality in offices and public places. Hong Kong Environmental Protection Department
Huang Q et al (2022) Comparison of indoor and outdoor polycyclic aromatic hydrocarbons from multiple urban residences in Northern China: coastal versus inland area. Build Environ 212:108800
Izadyar N, Miller W (2022) Ventilation strategies and design impacts on indoor airborne transmission: a review. Build Environ 218:109158
Jie L et al (2014) Comprehensive assessment grade of air pollutants based on human health risk and ANN method. Procedia Eng 84:715–720
Jung C-R et al (2021) Indoor air quality of 5,000 households and its determinants. Part B: volatile organic compounds and inorganic gaseous pollutants in the Japan Environment and Children's study. Environ Res 197:111135
Kaikiti C, Stylianou M, Agapiou A (2022) TD-GC/MS analysis of indoor air pollutants (VOCs, PM) in hair salons. Chemosphere 294:133691
Kumar S, Singh MK (2021) Seasonal comfort temperature and occupant's adaptive behaviour in a naturally ventilated university workshop building under the composite climate of India. J Build Eng 40:102701
Lee CW et al (2006) Characteristics and health impacts of volatile organic compounds in photocopy centers. Environ Res 100(2):139–149
Li L et al (2020) Characterization of precipitation in the background of atmospheric pollutants reduction in Guilin: temporal variation and source apportionment. J Environ Sci 98:1–13
Li J et al (2022) Effects of residential building height, density, and floor area ratios on indoor thermal environment in Singapore. J Environ Manage 313:114976
Liu X (2021) ASTM and ASHRAE standards for the assessment of indoor air quality. In: Handbook of Indoor Air Quality. Springer Singapore, Singapore, pp 1–36
Liu L et al (2022) A critical review on air pollutant exposure and age-related macular degeneration. Sci Total Environ 840:156717
Louie AP et al (2018) Effect of the environment on the risk of respiratory disease in preweaning dairy calves during summer months. J Dairy Sci 101(11):10230–10247
Ma S et al (2022) Occurrence and fate of polycyclic aromatic hydrocarbons from electronic waste dismantling activities: a critical review from environmental pollution to human health. J Hazard Mater 424:127683
Mannan M, Al-Ghamdi SG (2022) Investigating environmental life cycle impacts of active living wall for improved indoor air quality. Build Environ 208:108595
Marć M (2017) Problems and challenges associated with estimating the emissions of organic compounds from indoor materials. TrAC Trends Anal Chem 97:297–308
Mazzarino JM, Turatti L, Petter ST (2020) Environmental governance: media approach on the united nations programme for the environment. Environ Dev 33:100502
Mentese S et al (2020) A long-term multi-parametric monitoring study: indoor air quality (IAQ) and the sources of the pollutants, prevalence of sick building syndrome (SBS) symptoms, and respiratory health indicators. Atmos Pollut Res 11(12):2270–2281
Mousavi SE et al (2022) Air pollution and endocrine disruptors induce human microbiome imbalances: a systematic review of recent evidence and possible biological mechanisms. Sci Total Environ 816:151654
Nair AN et al (2022) A review of strategies and their effectiveness in reducing indoor airborne transmission and improving indoor air quality. Environ Res 213:113579
Nandan A, Siddiqui N, Kumar P (2019) Assessment of environmental and ergonomic hazard associated to printing and photocopying: a review. Environ Geochem Health 41(3):1187–1211
Nandan A, Siddiqui NA, Kumar P (2020a) Estimation of indoor air pollutant during photocopy/printing operation: a computational fluid dynamics (CFD)-based study. Environ Geochem Health 42(11):3543–3573
Nandan A et al (2021a) COVID-19 pandemic in Uttarakhand, India: environmental recovery or degradation? J Environ Chem Eng 9(6):106595
Nandan A, Siddiqui NA, Singh C, Aeri A (2021b) Occupational and environmental impacts of indoor air pollutant for different occupancy: a review. Toxicol Environ Heal Sci 13(4):303–322
Nandan A, Siddiqui NA, Kumar P (2020b) Estimation of indoor air pollutant during photocopy/printing operation: a computational fluid dynamics (CFD)-based study. Environ Geochem Health 1–31
Ninyà N et al (2022) Evaluation of air quality in indoor and outdoor environments: impact of anti-COVID-19 measures. Sci Total Environ 836:155611
Pal R, Roy S, Thakur B (2022) Assessment of energy efficiency for traditional non-engineered and engineered residential buildings – a case of North-Eastern India. Mater Today: Proceedings 61:440–451
Paleologos KE, Selim MY, Mohamed AMO (2021) Indoor air quality: pollutants, health effects, and regulations. In: Pollution assessment for sustainable practices in applied sciences and engineering. Butterworth-Heinemann, pp 405–489
Permissible Exposure Limits - Annotated Tables | Occupational Safety and Health Administration. (n.d.) https://www.osha.gov/annotated-pels
Pettit T, Irga PJ, Torpy FR (2018) Towards practical indoor air phytoremediation: a review. Chemosphere 208:960–974
Raziani Y, Raziani S (2021) The effect of air pollution on myocardial infarction. J Chem Rev 3(1):83–96
Sadrizadeh S et al (2022) Indoor air quality and health in schools: a critical review for developing the roadmap for the future school environment. J Build Eng 57:104908
Salthammer, Tunga, et al. 'Formaldehyde in the Indoor Environment'. Chemical Reviews, vol. 110, no. 4, Apr. 2010, pp. 2536–72. (Crossref), https://doi.org/10.1021/cr800399g.
Sajeev V, Anand P, George A (2022) Indoor air pollution, occupant health, and building system controls—a COVID-19 perspective. In: Hybrid and Combined Processes for Air Pollution Control. Elsevier, pp 291–306
Saquib S, Yadav AK, Prajapati KB (2021) Chapter 19 - Emerging pollutants in water and human health. In: Ahamad A, Siddiqui

SI, Singh P (eds.) Contamination of Water. Academic Press, pp 285–299
Shendell DG (2011) Community outdoor air quality: sources, exposure agents and health outcomes. In: Nriagu JO (ed) Encyclopedia of Environmental Health. Elsevier, Burlington, pp 791–805
Silva LFO et al (2022) Effects of atmospheric pollutants on human health and deterioration of medieval historical architecture (North Africa, Tunisia). Urban Clim 41:101046
Sivanantham S et al (2021) Coexposure to indoor pollutants in French schools and associations with building characteristics. Energy Build 252:111424
Stewart GA, Robinson C (2022) 4 - Indoor and outdoor allergens and pollutants. In: O'Hehir RE et al (eds) Allergy Essentials (Second Edition). Elsevier, Philadelphia, pp 56–94
Standard ASHRAE (1999) Standard 62.1–1999. Ventilation for Acceptable Indoor Air Quality
Tran VV, Park D, Lee Y-C (2020) Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality. Int J Environ Res Public Health 17(8):2927
Vallero D (2014) Chapter 3 - The science of air pollution. In: Vallero D (ed) fundamentals of air pollution (fifth edition). Academic Press, Boston, pp 43–81
Vergerio G, Becchio C (2022) Pursuing occupants' health and well-being in building management: definition of new metrics based on indoor air parameters. Build Environ 223:109447
Wang Y et al (2022a) The impacts of economic level and air pollution on public health at the micro and macro level. J Clean Prod 366:132932
Wang H, Xiong J, Wei W (2022b) Measurement methods and impact factors for the key parameters of VOC/SVOC emissions from materials in indoor and vehicular environments: a review. Environ Int 168:107451
Wolkoff P, Azuma K, Carrer P (2021) Health, work performance, and risk of infection in office-like environments: the role of indoor temperature, air humidity, and ventilation. Int J Hyg Environ Health 233:113709
World Health Organization (2014) WHO guidelines for indoor air quality: household fuel combustion. World Health Organization
World Health Organization. Regional Office for Europe. Guidance Settings for Quality Standards?: Report on a WHO Working Group, Barcelona, Spain, 12-14 May 1997. EUR/ICP/EHPM 02 01 02, WHO Regional Office for Europe, 1998. apps.who.int, https://apps.who.int/iris/handle/10665/108084.
Xu C et al (2022) Air pollutant spatiotemporal evolution characteristics and effects on human health in North China. Chemosphere 294:133814
Xue Y et al (2022) Air pollution: a culprit of lung cancer. J Hazard Mater 434:128937
Yang B et al (2019) A review of advanced air distribution methods - theory, practice, limitations and solutions. Energy Build 202:109359
Ye W et al (2017) Indoor air pollutants, ventilation rate determinants and potential control strategies in Chinese dwellings: a literature review. Sci Total Environ 586:696–729
Yue X et al (2021) Mitigation of indoor air pollution: a review of recent advances in adsorption materials and catalytic oxidation. J Hazard Mater 405:124138
Zhang Y et al (2022) Study on the influence of thermo-physical parameters of phase change material panel on the indoor thermal environment of passive solar buildings in Tibet. J Energy Storage 52:105019
Zheng K, Zeng Z, Huang J, Tian Q, Cao B, Huo X (2022) Kindergarten indoor dust metal (loid) exposure associates with elevated risk of anemia in children. Sci Total Environ 851:158227

This material is the authors' own original work, which has not been previously published elsewhere.

The paper is not currently being considered for publication elsewhere.

Authors and Affiliations

Abhishek Nandan[1] · Prasenjit Mondal[2] · Sandeep Kumar[1] · Nihal Anwar Siddiqui[2] · Shambhavi Sinha[3] · Sudalai Subramani[4] · Akshi Kunwar Singh[1] · Sivashankar Raja[5] · Chaudhery Mustansar Hussain[6]

✉ Abhishek Nandan
abhisheknandan24@gmail.com;
abhisheknandanhseddn@gmail.com

Prasenjit Mondal
prsnjtmndl@gmail.com

Sandeep Kumar
sandyy.hse@gmail.com

Nihal Anwar Siddiqui
nsiddiqui57@gmail.com

Shambhavi Sinha
shambhavi.sinha@bennett.edu.in

Sudalai Subramani
ssudalai.cpe@gmail.com

Sivashankar Raja
rsivashankar2010@gmail.com

Chaudhery Mustansar Hussain
chaudhery.m.hussain@njit.edu

1 University of Petroleum and Energy Studies, Uttarakhand, Dehradun, India

2 Centre of Excellence in Occupational Health, Safety, Fire and Environment, GD Goenka University, Sohna, Gurgaon, India

3 Bennett University, Greater Noida, India

4 Center for Pollution Control & Environmental Engineering, Pondicherry University, Puducherry, India

5 National Institute of Technology, Warangal, India

6 Department of Chemistry and Environmental Science, New Jersey Institute of Technology, Newark, NJ 07102, USA