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Appraisal of Indoor Air Quality and Its Impacts in School Buildings: A Case Study of Haldwani City, India

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Abstract

Due to continuously increasing levels of air pollution as well as an ever-increasing consciousness of the hazardousness of air pollutants, new rules and regulations have recently been passed. While in the present time, a lot of advanced research is carried out by many researchers on this topic. Therefore, this study provides systematic approaches to monitoring air pollution in school buildings. In these descriptive-analytical studies, a portable analysis device (Model HTO-136) Toolkit was used to examine the condition of school buildings. The findings of this study showed that more than 59% of teachers and students face health related problems during schooling periods, yet they largely ignored their complaints of headaches, weariness, and inadequate ventilation. The concentration of $PM_{2.5}$, PM_{10}, TVOC, HCHO and CO2 were measured with the help of portable analysis devices and its result ranges from 52-198 µg/m^3, 128-468 µg/m^3 0.21-5.709 mg/m^3, 0.003-785 mg/m^3, and 506 to 778 ppm respectively which are higher than permissible limits of CPCB. Result also show that location of school, age, and air tightness of school buildings, as well as the room designs, ventilation rates, construction and furnishing materials, inhabitant activities, and outdoor pollution, have significant roles in the concentration of indoor pollutants in school buildings. Therefore, it is essential to adopt some superb practices to save the health of younger children who are more vulnerable to environmental toxins. But it is necessary to pay special consideration during selection of site for school building.

Keywords: Air pollution, Classroom air quality, Exposure risk, Air quality monitor, HCHO, Indoor Air Quality, PM, TVOC.

Introduction

A number of studies have classified indoor pollution as one of the greatest environmental risks to public health today. In India, it is approximate that about half a million women and children die per year due to indoor air pollution (Nagendra and Harika, 2010). School children spend a lot of time at school (almost 12% of their time inside classrooms) (Sadrizadeh et al, 2022). As many schools lack central heating, cooling and ventilation due to a long construction history, it can be more difficult to ensure a comfortable indoor climate and good indoor air quality for students (Robertson, 2016). Especially during the

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transition period, when windows and doors are closed, the IAQ deteriorates, because fresh air only comes from air penetration (Li et al., 2015; Shi et al. 2015). Hence, indoor air pollution in schools has become more and more problematic. The term indoor air quality (IAQ) refers to air quality in an enclosed environment, expressed in pollutant concentrations and thermal comfort conditions (temperature and relative humidity). Indoor air pollutants such as hazardous gases, particulate matter, biological agents, and volatile organic compounds all affect the health, comfort, and productivity of occupants, which in turn damage materials. Inadequate indoor air quality can cause reduced performance, and health associated problems such as headaches, angry symptoms of asthma, other respiratory illnesses, nasal congestion, eye and skin irritations, coughing, sneezing, fatigue, dizziness, and nausea, allergic reactions, and sick building syndrome. High levels of pollution and humidity can destroy materials, collections, and objects, causing them to rot, deteriorate, discolour, corrode, and have other negative effects. As a result, IAQ has a direct impact on student health and performance. Many studies have been conducted to assess the indoor air quality (IAQ) of many schools (Fantuzzi et al., 1996; Guneset al., 2015; Hizrriet et al., 2015; Yang, 2017; Li et al., 2017; Wu et al., 2017; 2018; Sahuet et al., 2018,2019; Zhang, 2019). The effect of PM10 on school staff and student health was investigated and it was found that the limits were exceeded during exam times (Guneset et al., 2015). In the development of ventilation systems for school buildings, a different study focused on the importance of usage and the requirement for clean air (Wu et al., 2018). These studies illustrate that schools have inadequate ventilation, poor indoor air and pose a risk to students and staff. To ensure sufficient IAQ, air temperature and relative humidity should be maintained at a level suitable for health, dust collectors and air purifiers should be used, ventilation should be improved, and most importantly, pollution sources should be regulated (Yalcin, 2017).Paints, varnishes, furniture, wood preservatives, disinfectants, aerosol sprays, cleaners, air fresheners, hobbies, dry cleaning clothes, combustion products, pesticides, office equipment, and adhesives are the most important causes of volatile organic compounds (VOCs) in the indoor environment (EPA, 2020a). Furniture, floor coverings, wall coverings, and building materials are all associated with acetone, formaldehyde, acetaldehyde, glyoxal, benzaldehyde, and methyl isobutyl ketone. Respiratory disorders are caused by highly hazardous and carcinogenic substances, including volatile organic compounds and formaldehyde (Ashford and Caldart, 2001; Bu et al., 2016; Wu et al., 2018). High concentrations of VOCs and formaldehyde have been associated with skin, lung, melanoma, and endocrine malignancies, as well as risk factors for asthma and rhinitis (Boeglin et al., 2006; Eigurenfernandez et al., 2010; Kelly and Hussel, 2011; Hulin et al., 2012; Bakian et al., 2012), 2015). The gas formaldehyde (CH_2O) is toxic, odorless, and colorless. It negatively affects the respiratory, digestive, and neurological systems (Unsaldi and Çiftçi, 2010; Yalcin, 2017). The main sources of CH_2O in indoor air are wood composite products (such as parquet veneer, chipboard, and medium-density fibreboard), building materials, insulation, adhesives, permanent printing textiles, paints and coatings, plastics, varnishes, and stationery (Nielsen et al. ., 2010). The use of stoves, heaters and fireplaces, and cooking are all sources of indoor particulate matter (PM) (EPA, 2020b). High concentrations of PM2.5

cause significant health effects on the heart, lungs and bronchitis. Pollution with a diameter of 10 microns (PM10) can penetrate deep into the lungs and cause serious health problems. The most important sources of VOCs and very fine particles size (0.1 mm) are probably printers, computers, scanners and copiers (Lee et al., 2001; Kagi et al., 2007; Atarodi et al., 2018; Gaur et al., 2018).

The World Health Organization (WHO), researchers, and national ambient air quality standards are reputable organisations and independent agencies that work to protect the public's health, particularly that of those who have "vulnerable" lung conditions (like asthma, cough, and wheezing), children, and the elderly. (NAAQS) and the Environmental Protection Agency (EPA) have established indoor limits and standards. Limit values for parameters affecting indoor air quality are given in Table 1. According to several studies conducted in different hospital locations in India, the amount of pollution varies significantly depending on location, time, duration of sampling, and duration of sampling, weather conditions.

Table 1: Indoor air quality standard value:

Parameters	Indoor air limit	Reference
$PM_{2.5}$(24-hr)	30 μg/m^3	CPCB
PM_{10}(24-hr)	50 μg/m^3	CPCB
TVOC (30-min)	0.6 mg/m^3	WHO
HCHO (30-min)	0.1 mg/m^3	WHO
CO_2(30-min)	700 ppm	WHO

The main purpose of this study was to assess the indoor air quality in three schools located in Haldwani city, Uttarakhand. The main aims of this study's are to assess the quality index and analysis of health risk, and also measure the concentrations of pollutant while avoiding affecting the school's circumstances. In addition to the impact of building age on indoor air quality, other influencing factors were also assessed.

Materials and Methods

Location of study area

The study area (Haldwani City) is located on the right bank of the Gaula River, in the immediate foothills of the Kumaon Himalayas, Haldwani is located in the state of Uttarakhand at latitude 29.22°N and longitude 79.52°E (Fig.1). It is part of the Nainital district. 44.11 Square Kilometres. Study area is the second-most heavily populated area in state of Uttarakhand. There are 350,762 individuals living in this city. Since it houses the majority of the state's business, economic, and industrial enterprises, Haldwani is referred to as Uttarakhand's financial capital. The city has experienced significant urbanisation since the establishment of the SIDCUL Integrated Industrial Estate (IIE). Additionally, various companies, industrial sites, and small enterprises are also situated very close to most towns and cities.

Participating Schools

Three schools were chosen for study of air pollution at distinct Haldwani. Out of these, One schools is very close to the village settlement and industrial zone (latitude 29°04'19" N, longitude 79°30'35" E). The second school is situated in the commercial zone (latitude 29°06'19" N, longitude 79°31'13" E), while the third school is situated in the residential zone (latitude 29°13'35" N, longitude 79°30'17" E). The floor in the entrance area is made of marble and stone. Natural ventilation is used to ventilate schools. Ventilation took place in the winter for up to 25 minutes in the mornings and was typically kept closed during the day. In the summer and fall, the windows were typically open during the day. A natural gas heating system is used. Measurements were taken simultaneously in various rooms (Class Room No.1, Class Room No.2, and Principal Room).

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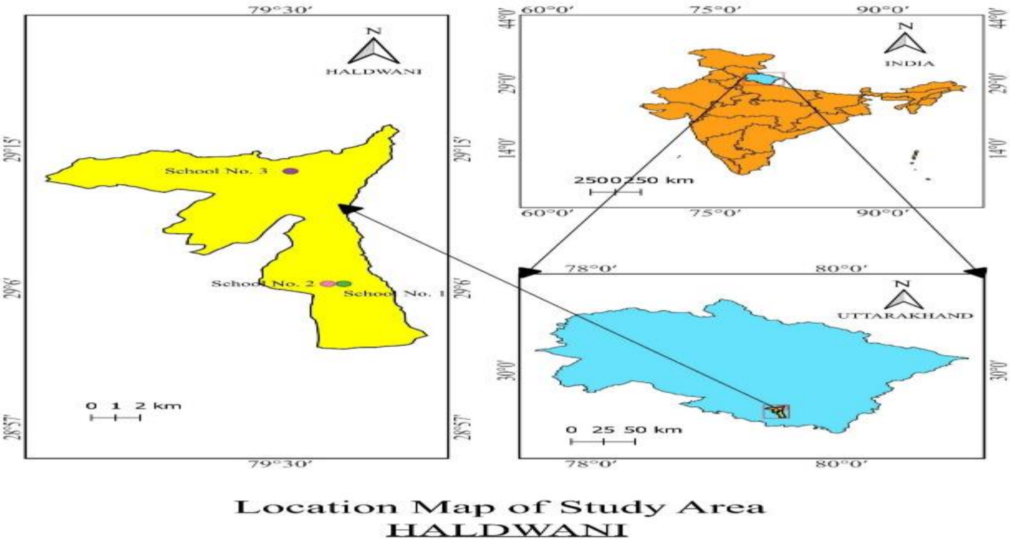

Fig.1 Location of study area

Methodology

Air Pollution Monitoring

An indoor air quality monitor (model HTO-136) was used to monitor HCHO, TVOC, CO2, $PM_{2.5}$, and PM_{10} concentrations in the school. Already part of the indoor air quality monitor, DART electrochemical sensors provide accurate measurements during real-time monitoring. Real-time monitoring took place during the morning and evening hours on three days. The indoor monitor was installed in the middle of the corridors or rooms of the three participating schools (class 1, classroom 2, and the principal). The air quality sampling device was placed 1.5 meters above the ground or in the breathing zone of an adult. For three days, air quality was monitored at each monitoring site twice a day, once in the morning (08:10-12:10) and once in the afternoon (13:20-15:20). During the sampling campaign, each sampling location was observed for a total of 75 minutes. Air quality information was collected and values were recorded using an AQI monitor. Statistical analysis during the summer months, the median, mean and standard deviation of each air quality indicator ($PM_{2.5}$, PM_{10}, CO_2, HCHO, and TVOC) were calculated and the variability of concentrations was examined to determine regional differences between sampling sites in every school. Table 2 shows the average results of the three studied school buildings based on indoor air quality indices. The minimum and maximum values of volatile organic compounds in the main room (second school) and classroom no. 2 (third school) The lowest formaldehyde concentrations reported were 0.021 and 5.709 mg/m^3, compared to above-average VOCs found in the first school. The highest formaldehyde concentrations recorded were 0.785 mg/m^3 in classroom no. 2 (third school), while the lowest formaldehyde pollutant concentration reported was 0.003 mg/m3 in classroom no. 2 (the third school), which was below the other two schools. The maximum and minimum concentration of particles below PM_{10} in classroom no. 1 (First school) was 468 µg/m^3 and 128 µg/m^3 in classroom no. 1 (secondary school). The maximum and minimum values of particles below $PM_{2.5}$ were 198 µg/m^3 in classroom 1 (first school) and 52 µg/m^3 in the classroom. 2 (second school).

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Compared with the above-average carbon dioxide of another school, the minimum and maximum measurement values of carbon dioxide in classroom no. 1 (third school) and the main room (first school) were 508 ppm and 778 ppm, respectively. With the help of air tests, when the direction and manner of airflow were determined in different schools of the building, it was found that in some places (about a third of the cases) the direction or distribution of the airflow is through doors or slots for rear ventilation. The system is not enough. According to the measurements made for this study, the third school had the lowest temperature (29°C) and the second school had the highest temperature, 36°C. Finally, the data were examined using a questionnaire. The following survey examined the frequency of student and staff opinions on factors related to indoor air health: never, rarely, sometimes, and always, and the following survey examined the frequency of staff and student opinions related to indoor air health factors affecting indoor air quality: very unsuitable, unsuitable etc.

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Table 2: Summary statistics for target pollutant concentrations in schools, in indoor area.

Air Quality Parameters	Minimum Measured value	MaximumMeasured value	Mean (In total classes)	Standard Deviation	Median (In total classes)	Range (In total classes)	Unit
$PM_{2.5}$	0052	0198	96.5	46.96	0087	149	µg/m^3
PM_{10}	0128	0468	242.2	112.2	0215	340	µg/m^3
TVOC	0.021	5.709	1.761	2.038	0.714	5.688	mg/m^3
HCHO	0.003	0.785	0.243	0.279	0.101	0.782	mg/m^3
CO_2	0506	0778	671.4	102.7	0723	270	ppm

Data Analysis

Table 3 lists the health repercussions that students and staff at the school reported after looking into the signs of sick building syndrome. A survey respondent was gathered for the survey, with nearly similar numbers from each of the nine rooms. A summary of the questionnaire's 32 questions on fundamental information, indoor environment assessment, symptoms and perceptions when leave the rooms. 120 persons completed them, with a 15-year-old average age and younger as well as elder's respondents. 30 people were females, 35 people were males, 25 students were girls and 30 students were boys. 100% of the staff management and students under investigation were present in the school for more than 6 hours, 100% of students and staff members entered the school before 8:00 am, and 90% of students and staff left the school building after 2:30 PM. The evaluation of the indoor environment and the symptoms were the three main areas of concentration. A scale model with a range of 1 to 4 was utilised to quantify the indoor environment, indicating the staff and student perception levels from "never" to "always."Results indicated that weariness, headaches, weakness, pain and itching in the eyes were the most often reported problems.

The students and staff involved in the study have said that they sometimes or always suffer the aforementioned repercussions. Table 4 shows the regularity with which staff members and students express their opinions about the school environment. A scale model with a range of 1 to 5 was utilised to quantify the indoor environment which indicating the staff and student perception levels from 'Very inappropriate 'to 'Very convenient.' As can be seen in the Table dust, ventilation, desk placement in relation to windows, and light reflection are among the most frequently reported complaints from staff and students regarding the conditions in their classrooms.

Results and discussion

The variations in average values for the metrics measuring indoor air quality in the schools were displayed in fig 1.The average temperature, which was 36 °C, was within the ideal range for an indoor setting. Relative humidity levels were also altered to fall between 40 to 70 %; the average was 55% and exceeded the IAQ criteria. Following column chart in fig.1 can be drawn from the observation table above:

The $PM_{2.5}$ concentration ranges from 52 µg/m³ to 198 µg/m³. The highest number measured was 198 µg/m³ in classroom of first school and the lowest number measured was 52 µg/m³ in classroom of second school. $PM_{2.5}$ has a permissible limit of 30 µg/m³. The observation that $PM_{2.5}$ is being measured above the permissible limits indicates that $PM_{2.5}$ partials are the cause of the air pollution that is being observed. The PM_{10} concentration ranges from 126 µg/m³ to 469 µg/m³. The highest number measured was 469µg/m³ in classroom of first school and the lowest number measured was 126 µg/m³ in classroom of second school.

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Table 3: Health problems reported by students and staff in the school buildings.

Row	Questions	Never	Rarely	Sometimes	Always
1	Fever	60	29	11	0
2	Headache	20	26	47	7
3	Weakness	26	36	26	12
4	Fatigue	10	31	55	4
5	Nausea	68	26	6	0
6	Dizziness	42	28	24	6
7	Chest pain	54	23	19	4
8	Neck pain	16	35	42	7
9	Back pain	33	35	23	9
10	Muscle pain, hand or arm	34	22	39	5
11	Itching in the eyes	48	26	14	12
12	Respiratory problems	64	22	12	2
13	Symptoms of flu or cold	24	47	22	7
14	Nervousness or tense	31	46	19	4
15	Feeling cold	46	28	20	6
16	Depression	53	22	23	2
17	Itching, swelling or dry skin	62	23	11	4
18	**Average**	40.64	29.70	24.29	5.35

Table 4: Students and Staff opinions about the environmental factors inside the school building.

Row	Questions	Highly Inappropriate	Inappropriate	Normal	Appropriate	Very Appropriate
1	Bench and Chair	9	16	35	37	3
2	Position of desk relative to the window	15	29	22	30	4
3	Topical environment light over the work desk	11	9	32	42	6
4	Work space	18	19	31	28	4
5	Environment light in work station	6	9	34	46	5
6	Reflection of light	8	14	37	32	9
7	Office equipment	16	22	32	27	3
8	AC system	15	24	24	33	4
9	Heat	14	26	28	29	3
10	Odour smell	16	22	37	22	3
11	Humidity	7	26	31	28	8
12	Dust	5	16	28	37	14
13	Surrounding Voice	36	24	21	16	3
14	Air flow	20	14	20	34	12
15	Cold	22	24	28	22	4
16	**Average**	14.5	19.6	29.3	30.8	5.66

PM_{10} has a permissible limit of 50 µg/m³. The observation that PM10 is being measured above the permissible limits indicates that PM_{10} partials are the cause of the air pollution that is being observed. The TVOC concentration ranges from 0.021 mg/m^{3}to 5.709 mg/m^3. The highest number measured was 5.709 mg/m3in in the principal room of second school and the lowest number measured was 0.021 mg/m^3 in the classroom of third school. TVOC has a permissible limit of 0.6 mg/m^3. The observation that TVOC is being measured above the permissible limits indicates that TVOC partials are the cause of the air pollution that is being observed. The HCHO concentration ranges from 0.003 mg/m^3 to 0.785 mg/m^3. The highest number measured was 0.785 mg/ m^3 and the lowest number measured was 0.003 mg in a classroom at third school. HCHO has a permissible limit of 0.1 mg/m3. The observation that HCHO is being measured above the permissible limits indicates that HCHO partials are the cause of the air pollution that is being observed. The CO_2 concentration ranges from 506 ppm to 778 ppm. The highest number measured was 778 ppm in the principal room of first school and the lowest number measured was 506 ppm in the classroom of third school. CO2 has a permissible limit of 700 ppm. The observation that CO_2 is being measured above the permissible limits indicates that CO_2 partials are the slight cause of the indoor air pollution that is being observed in particular buildings.

Conclusion

The main aim of this study was to compile important findings regarding the air quality inside school buildings. In particular, reports on chemical contaminants, associated sources, and monitoring techniques were made. The findings of this study offer suggestions that particular situations, frequently encountered in schools, may have negative effects on the air quality and, consequently, on occupants' health. It was emphasised in particular that the location, age, and air tightness of school buildings, as well as the room designs, ventilation rates, construction and furnishing materials, occupant activities, and outdoor pollution, all have significant roles in the concentration of indoor pollutants. Therefore, it is important to adopt some excellent practices to protect the health of the occupants, especially young children who are more susceptible to environmental toxins. These steps include using low-emitting buildings and furniture materials as well as building schools with sufficient ventilation systems to improve air exchange. In order to improve air quality and lessen the effect on students' health, it is crucial that schools are not situated in regions with significant traffic or industrial emissions because many indoor concentrations of pollutants are significantly influenced by outdoor sources. Several states are currently attempting to establish standards for setting reference values, regulating the control procedures, and prescribing best practices to improve the quality of air inside school buildings. This is necessary since many of the contaminants that are monitored in indoor spaces don't have reference levels readily available (WHO 2010).

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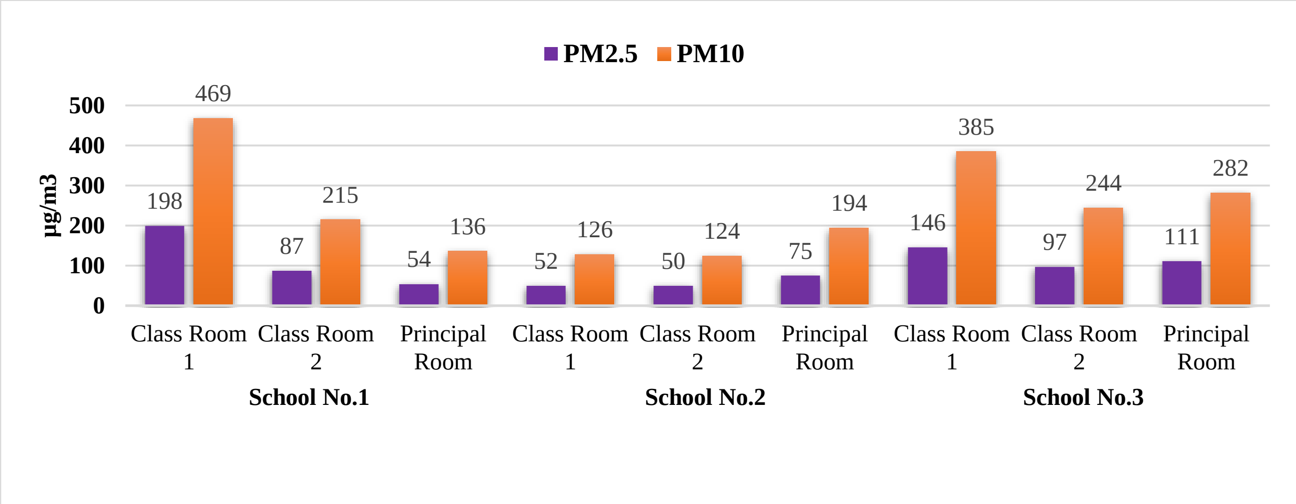

Fig 2: Comparison between $PM_{2.5}$ and PM_{10} parameters in certain rooms of the schools.

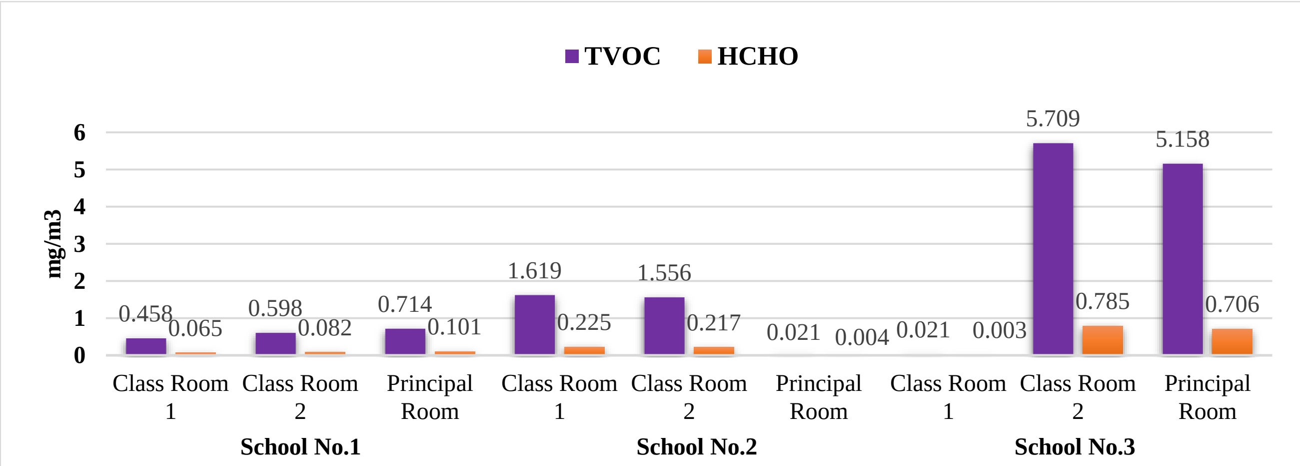

Fig 3: Comparison between TVOC and HCHO parameters in certain rooms of the schools.

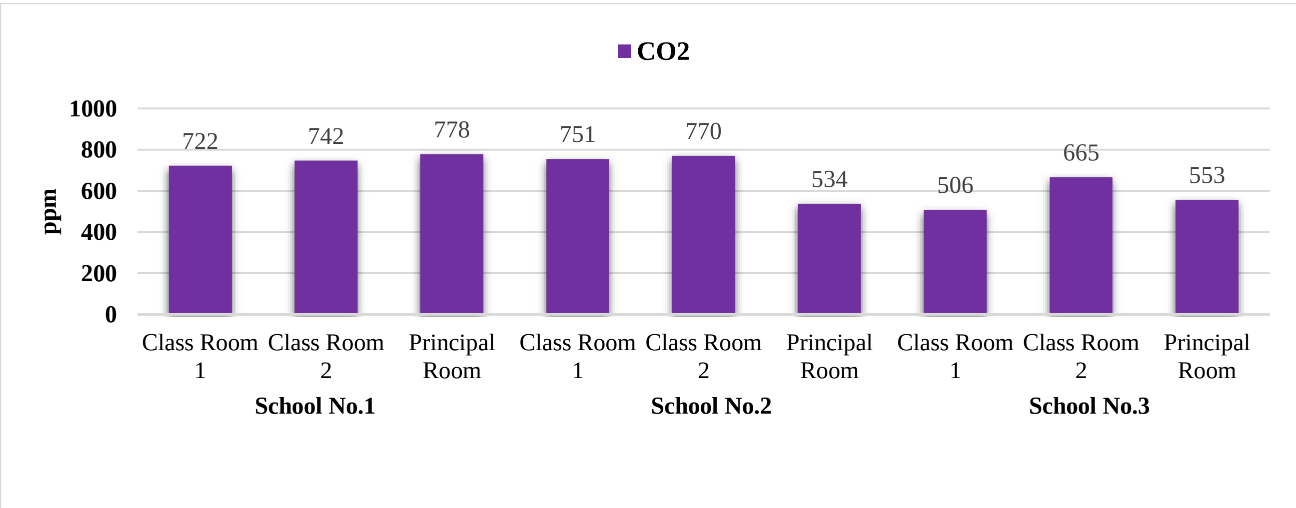

Fig 4: Changes in Carbon dioxide (CO_2) in certain rooms of the schools.

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