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Indoor air quality (IAQ) investigation in primary schools at Hamirpur (India)

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The poor indoor air quality (IAQ) can lead to low productivity, reduced learning ability, health hazards, lack of concentration etc. Occupant's long exposure to poor IAQ can cause various health problems. If the building occupants repeatedly report a complex range of health complaints, then they might be suffering from sick building syndrome. The information about IAQ in schools in Hamirpur has not been investigated at any level in the past, though it is very important for children of 5–6 year age. This article summarizes the investigation of 8 naturally ventilated schools in Hamirpur city of Himachal Pradesh (India). The investigation had been performed for IAQ physical parameters i.e. carbon monoxide (CO), carbon dioxide (CO_2), particulate matter ($PM_{2.5}$), indoor temperature, humidity and wind rate. Higher indoor particulate matter ($PM_{2.5}$) concentration was found influenced by many design parameters of school building. Some recommendations are made to reduce the exposure of pollutants to the occupants.

Keywords: Indoor Air Quality (IAQ), Particulate Matter (PM), CO_2, classrooms.

Introduction

IAQ refers to quality of air within building and indoor air pollution (IAP) has been identified as the cause for the death of 1.6 million people per year worldwide, i.e. one death in every 20 seconds[1]. The death rate, because of the air pollution, roses by 4% worldwide and by 12% in India during the period of 2005-2010. Especially children of the age group of 5 to 15 years are suffering with respiratory diseases and lung infections due to air pollution[2]. Respiratory suspended PM is the main ambient indoor air pollutants in India as citizens are exposed to about 15–32 times higher $PM_{2.5}$ concentration than the permissible limit given by World Health Organisation (WHO) guidelines[1]. Further, the scientists predicted that, $PM_{2.5}$ concentration would double by 2050 in mega cities like Delhi in addition to this the rate of respiratory diseases and premature mortality will increase by 75% from 2015-2050 due to air pollution[1]. The WHO has reported IAQ as 8th most important risk factor for carrying burden of diseases (3.7% of overall disease burden). Therefore, indoor environment has become a major source for mankind to long exposure to air pollutants. Eventually, the extended exposure of indoor pollutants may cause the chronic as well as acute health problems to the occupants. The epidemiological studies conducted in the area of IAQ underlined role of IAQ in affecting respiratory health, especially for school children as they are in growing age, inhale more volume of air in relation to their body weight at a lower level and spend seven to eight hours' time of a day in classrooms at schools[5].

IAQ could enumerate in building interiors in terms of the air pollutants concentration (PM, CO, CO_2, VOC, NO_2, HCHO etc.) and thermal comfort parameters (temperature and relative humidity (RH)) as thermal comfort parameters can influence air pollutants significantly.

The studies conducted in the field of IAQ have revealed some important findings;

(a) The classroom air may contain a wide range of indoor air pollutants that may cause a great direct risk to health of children and indirect effect on their learning ability[6–8].

(b) The indoor concentration of pollutants could be higher than the outdoor concentration as indoor pollutants can be generated inside besides transported from outside into buildings.

(c) High temperature and humidity levels increases particulate concentrations and give room to the microbiological growth.

(d) In naturally ventilated rooms proper air movement was not found due to poor maintenance and cleanliness.

(e) The indoor pollutants could generate inside any buildings because of use of chemical pollutants in the form of synthetic building materials and furnishing, reduced ventilation rate on account of tight building envelopes, crowded conditions due to more students in small classrooms, and location of classroom at different floor levels, less landscaping, lack of maintenance, use of chemical based cleaning products, use of black board, floor finish type (carpets) and wall finishes (paints) etc.[9,10].

Literature review reveals the interest of researchers in the measurement of particulate matter (PM) and carbon dioxide (CO_2) in classrooms, considering them as main pollutants in primary classrooms[11–14]. These studies have established a direct relationship of classroom concentrations of particulate matters (PM) and carbon dioxide (CO_2) with inadequate ventilation, insufficient cleaning of classes, resuspension of the particles due to students activity in class and close proximity of vehicular as well as industrial areas etc. However, very little is known about the IAQ related information of primary classrooms in India. When it comes to Himachal Pradesh, it is considered as the purest form of the environment, therefore no study has been attempted to know about the IAQ in primary classrooms of Himachal Pradesh at India. The present study is an effort to bridge this gap and to build on earlier studies conducted in schools at Delhi, India[15]. Earlier researches investigated the indoor PM and CO_2 concentrations and predicted their occurrence due to some design parameters. In the present study, impact of physical parameters (PM and CO_2) and thermal comfort parameters (temperature and RH) on IAQ were studied. Field data were collected from eight naturally ventilated primary schools in summer season from May 2018 to June 2018.

All the schools were selected from the urban areas (municipality boundary) to make out the standard of present IAQ conditions at Hamirpur city of Himachal Pradesh (Fig. 1).

This paper aims to evaluate outdoor and indoor concentrations of the air pollutant $PM_{2.5}$, CO_2, CO and their relation with thermal comfort parameters i.e. RH, and temperature. The study will also make some recommendations for the improvement of the IAQ to protect health of the children being in the classrooms through spatial and non-spatial design parameters.

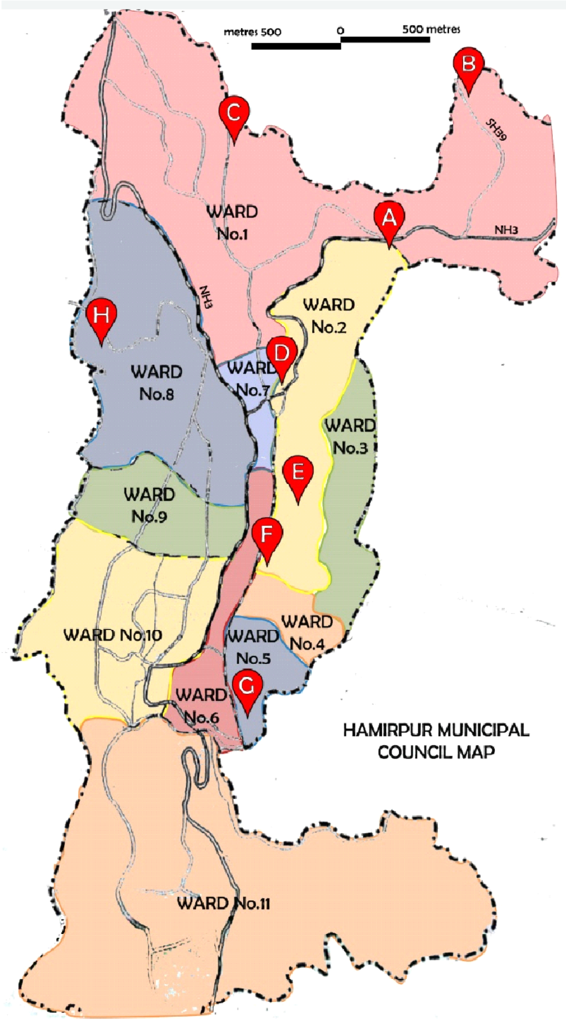

Fig. 1. Location of selected school at Hamirpur.

Materials and methods:

Field investigation of IAQ at schools of Hamirpur was assimilated in 3 stages. These stages includes: (i) selection of schools, (ii) investigation of spatial and non-spatial parameters of building design, and maintenance and (iii) on site data collection for indoor pollutants, thermal conditions and ventilation.

In the first stage Hamirpur educational block has been selected for execution of investigation. It consist of about 32 schools in total, out of them eight schools were randomly selected for detailed on site investigation after getting ap-

Table 1. Classroom characteristics of each school

Schools	No. of student	Area/Students (M^2)	Floor finish	Wall finish	Cleaning frequency	Area of opening	Landscape provided	Located at floor
A	12	0.63	Concrete	Distemper	0.5× day	1.89	No	Ground
B	12	2.51	Tile	Distemper	1× day	6.93	No	Ground
C	25	1.73	Concrete	Paint	1× day	6.60	Yes	Ground
D	23	1.08	Concrete	Paint	2× day	7.29	No	First
E	30	0.81	Marble	Distemper	1× day	5.80	No	Ground
F	42	0.46	Concrete	Distemper	0.5× day	4.05	Yes	Ground
G	14	1.18	Concrete	Distemper	0.5× day	5.76	Yes	Ground
H	21	1.50	Concrete	Distemper	1× day	4.25	No	First

proval from the schools. In the second stage primary investigation of all eight schools was done through questionnaire to tabulate spatial and non-spatial parameters schools and classrooms (Table 1). In last (third) stage detailed measurements of air pollutants ($PM_{2.5}$, CO_2 and CO) at indoor and outdoor of the classrooms along with thermal conditions was carried out through calibrated instruments during the period from May 2018 to June 2018 (summer season). The collection of physical data were performed for 6 continuous days in first standard classroom of every school to keep the age of the occupant constant.

Sampling and analysis:

Forbix Semicon CO_2 monitor and Mlabs HT-1000 CO monitor were used to measure outdoor and indoor concentrations of CO_2, CO, RH and temperature. The carbon dioxide sensor is a high quality NDIR (Non Dispersive Infra-Red) sensor. It gives the reading between 600 to 800 ppm. Though the device is for indoor use purpose, many users use it for outdoor air monitoring as well. Outdoor and indoor samplings of $PM_{2.5}$ was conducted simultaneously using Forbix Semicon $PM_{2.5}$ monitoring sensor works on optical scattering technology and gives a very accurate reading of the ambient air condition. The calibration time is for the instrument was 8–10 min. It gives $PM_{2.5}$ readings between 20–1400 µg/m³.

This monitor can collectively showcase particulate ($PM_{2.5}$) levels. Table 2 shows the details and uncertainty details of the equipment's used in onsite investigation.

The measurement was carried out in peak occupancy period (10:30 am to 11:30 am), after approximately 1:30 hours of the commencement of teaching in the classes. The instruments were placed opposite to the black board at a distance of 2 m towards the center of the class. The height of the measuring instruments was kept around 0.8 m above floor level to take measurement near the breathing zone of the seated students. The measurement location was chosen away from door, to avoid disturbances and interferences from air currents. In the same way, all measurements for the outdoor were conducted at the same height and immediate outdoor area of the classroom. All the concentration measurement was carried out when the classrooms were occupied.

Results and discussion

Table 3 shows the onsite monitoring details of comfort parameters i.e. temperature, relative humidity and wind rate

Table 2. Details and uncertainty of instruments

Name of instrument	Uses	Range	Accuracy (%)	Placement
MEXTECH CO-180	Carbon monoxide (CO)	0–1000 ppm	5	One location at middle of
Air quality monitor	Carbon dioxide (CO_2)	0–10,000 ppm	±5	classroom on the height of
	Temperature (Temp.)	0–70°C	±0.5	0.8 m from floor
	Relative humidity (RH)	0–100%	±2	
	Particulate matter	10–1400 µg/m³	±10	
HTC AVM-08 Hot Wire Anemometer	Wind rate	0.10–25.0 m/s	±5	

Table 3. Indoor data of pollutants and comfort parameters in investigated schools

	Temp. (°C)	Rh (%)	CO_2 (ppm)	$PM_{2.5}$ (μg/m^3)	Ventilation rate (m/s)
Minimum	31.66	30.5	424.5	145	0.61
Maximum	33.55	48.5	694	564.67	0.77
Mean	32.17	40.78	535.78	281.67	0.67
Std. deviation	0.59	6.14	101.30	151.32	0.059

for indoor environment along with indoor air pollutants i.e. carbon dioxide (CO_2), and particulate matter ($PM_{2.5}$) in summer season for all classrooms. The concentrations of carbon monoxide (CO) were not included in the study because CO concentrations were found out to be very less during investigations. Average temperature and relative humidity were found 32.17°C and 40.78% with Standard Deviation of ±0.59 and ±6.14 at 95% of confidence level. The mean indoor temperature was found more than ASHRAE standard i.e. 24°C to 27°C[16–18]. This high temperature could reduce the attentiveness and learning ability among students, therefore temperature needs to be maintained in the classrooms through providing adequate ventilation by maintaining the wind rate of 0.8 m/s in school classrooms, however the existing mean wind rate in the classroom was found 0.67 m/s (Table 3). The average indoor CO_2 concentration of 535.7 ppm was recorded with Std. deviation of ±101.31 ppm. That is within the permissible limit given by ASHRAE standard i.e. 800 ppm. The average indoor concentration of $PM_{2.5}$ was found 281.67 μg/m^3 with Std. deviation of ±151.32. This is much more than the prescribed limit i.e. 35 μg/m^3. It indicates that the main indoor pollutant in primary classrooms at Hamirpur is particulate matter. It may cause adverse health effects and respiratory health problems in children. As, young children are more vulnerable due to their developing immune system. It is quite important to reduce their exposure to high PM concentration in indoors of primary classrooms. A significant relationship was found between the outdoor and indoor concentrations of air pollutants (Table 4) in all eight investigated schools. Mean indoor CO_2 concentration with mean outdoor CO_2 concentration ($r = 0.77$, $p < 0.05$). It suggests that source of CO_2 concentration is similar to outdoor conditions and influencing indoor CO_2 levels. Mean outdoor $PM_{2.5}$ concentration were strongly correlated with mean indoor $PM_{2.5}$ ($r = 0.7$, $p < 0.05$), signifying the similar source of origin. The mean indoor wind rate measured in the classrooms was found to correlate with the wind rate measured outdoor. It indicates a significance impact of outdoor condition on classrooms indoor environment. ASHRAE standard 62.1-2007 recommends, the primary classrooms should have a minimum ventilation rate of 0.8 m/s to provide a healthy indoor conditions. However, poor ventilation rate was found in all investigated classrooms. It has been observed that the CO_2 concentration varied depending on available ventilation rate and student density within the classrooms. A strong correlation was found ($R^2 = 0.79$) between measured wind rate and CO_2 concentration inside of the classrooms (Fig. 2). The correlation analysis shows that if adequate ventilation rate as per standard are provided in the investigated classrooms CO_2 concentration will be reduced.

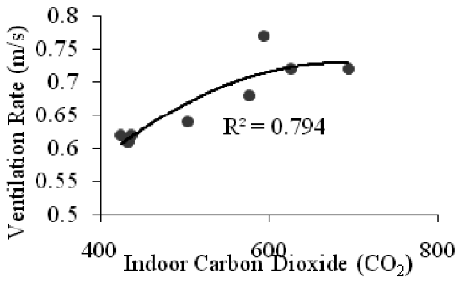

Fig. 2. Correlation between CO_2 and ventilation rate (m/s).

Table 4. Correlation between indoor and outdoor of pollutants and comfort parameters

	'A'	'B'	'C'	'D'	'E'	'F'	'G'	'H'
CO_2 (ppm)	0.932	0.983	0.577	0.910	0.534	0.682	0.690	0.897
$PM_{2.5}$ (μg/m^3)	0.974	0.721	0.928	0.439	0.56	0.57	0.58	0.881
Wind rate (m/s)	0.759	0.765	0.944	0.843	0.170	0.554	0.625	0.934

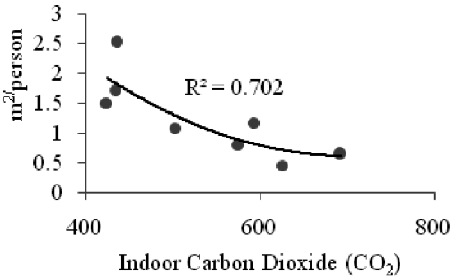

Fig. 3. Correlation between area per student and indoor CO_2 concentration.

Similarly, indoor CO_2 concentration also found depending upon the occupant density. Fig. 3 showed a strong correlation (R^2 = 0.70) between indoor carbon dioxide and area per students. It established the fact that students are also the source of CO_2 concentration. Therefore, more number of students in a defined space of classroom may cause higher level of CO_2 concentration.

Higher relative humidity increases the level of moisture in the atmosphere, that moisture make particulate heavier and results lesser suspension of particulates. The correlation analysis shows a strong impact (R^2 = 0.67) of the relative humidity on particulate concentration (Fig. 4). Student activity pattern strongly influence the indoor $PM_{2.5}$ concentration due to suspension of particles and possible particulate generation. In investigated schools, a relationship (R^2 = 0.73) found between student density and particulate concentration (Fig. 5) as young children highly contributes to re-suspension of particles.

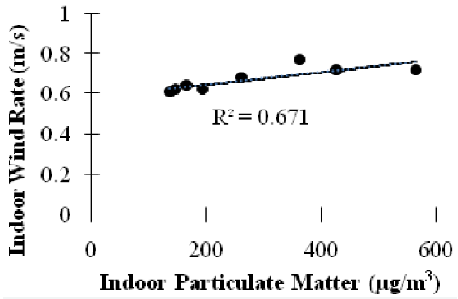

Fig. 4. Correlation between indoor wind rate and $PM_{2.5}$ concentration.

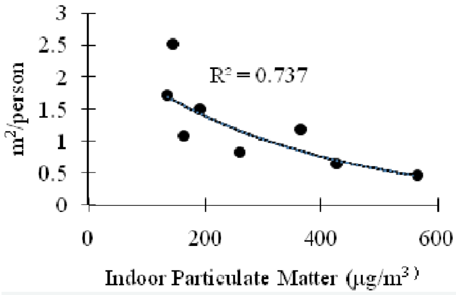

Fig. 5. Correlation between sq m area per student and $PM_{2.5}$ concentration.

Conclusion

This study presents the IAQ study of primary school classrooms for the first time at Hamirpur city in Himachal Pradesh. Indoor $PM_{2.5}$ and CO_2 levels were significantly found to be associated with outdoor levels. The CO_2 levels in classrooms were mainly found related with the high occupancy combined with the inadequate ventilation. The findings of present study, suggest the presence of very high $PM_{2.5}$ levels in primary classrooms and identifies particulate as a main source of pollution in Himachal Pradesh. The factors correlated with the increase of $PM_{2.5}$ level of classroomare student density and humidity. Small classroom size and crowded conditions are major cause of high $PM_{2.5}$ levels. Low relative humidity level decreases the amount of moisture in the air and makes the particulate dry. The combination of low relative humidity and crowded conditions create worst indoor condition for students, as student's inhales at lower level to the ground and become vulnerable to air borne diseases like allergy and eye irritation etc. However more elaborate future studies are required to determine extent of IAQ in primary schools.

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