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Modelling of particulate matters distribution inside the multilevel urban classrooms in tropical climate for exposure assessment

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ABSTRACT

The characteristics of indoor air quality (IAQ) parameters such as PM mass (PM_{10}, $PM_{2.5}$, PM_1) and particle number concentrations (PNC), carbon monoxide (CO), carbon dioxide (CO_2), temperature (T) and relative humidity (RH) in multilevel urban classrooms of a school in tropical climate were studied. The PNC in the range 0.35–22.5 μm was monitored for 2 days in each classroom during the working hours using environment dust monitor and converted to mass concentrations. The 8hr-mean concentrations of PM_{10}, $PM_{2.5}$, PM_1 mass, CO, CO_2, T, and RH inside ground floor (GF) classroom were found to be 942.84 ± 248.49, 61.59 ± 17.19 and 16.13 ± 3.65 μg/m^3, 458.86 ± 58.60 ppm, 34.80 ± 0.81 °C, 55.06 ± 4.10%, 0.93 ± 0.43 ppm, respectively. The PM_{10} mass concentrations were found to decrease by 8.35 and 46.67%, respectively in first and second floor classrooms. Similarly, PM_1 and $PM_{2.5}$ values were increased by 4.60 and 12.99%, respectively in first floor and decreased by 32.35 and 16.61%, respectively in second floor classrooms. The PNC for particles of size 0.3–1 μm were 58.04, 71.24 and 55.47 particles/cm^3 for ground floor, first and second floor classrooms, respectively. The PNC of coarse particles were found to decrease with increase in floor heights. The thermal comfort parameters namely; CO_2, T, and RH were more or less showing same trend in all the three classrooms. The distribution of $PM_{10,}$ $PM_{2.5}$ and PM_1 mass data in ground and first floor classrooms fitted with lognormal 3-parameter (3-P) distribution while the second floor PM mass data best fitted to the log-logistic 3-parameter (3-P) distribution.

1. Introduction

Indoor Air Quality (IAQ) has gained immense interest among people in the past few decades. Among the indoor microenvironments, the IAQ in schools has been considered important since the children spend considerable time of their day in the indoor environment of schools than in the outdoor environment [1]. Children have higher average respiration rate than adults; older children having 16–25 breaths per minute (bpm) as compared to 12–20 bpm by adults [2]. Thus children breathe more volume of air compared to their body mass and are more susceptible to diseases when exposing to indoor pollution. Poor IAQ has also been linked to poor learning and recapitulating capabilities, thus affecting the student's performance in schools, increasing absenteeism and causing long-term or short–term health effects like respiratory problems, cardiovascular illness, bronchial hyper-responsiveness, asthma, skin allergies, headache and eye irritation [3,4].

In schools, IAQ is mainly characterized by improper ventilation, inadequate cleaning and high occupancy in a classroom [5]. Among the IAQ parameters, particulate matter (PM) of different sizes (PM_{10}, $PM_{2.5}$, and PM_1), carbon monoxide (CO), carbon dioxide (CO_2), temperature (T), relative humidity (RH) and ventilation rate (VR) are important. Particles in an indoor environment can arise from a number of sources and due to several factors. Source emissions, penetration, surface deposition, re-suspension, coagulation have been identified as main sources for indoor PM concentration [6–8]. Re-suspension has been considered important since the deposited particles become airborne due to human activities and enter the human respiratory tract easily. Re-suspension depends on factors like; type and size of the particle present in the environment, type of activity by the occupants, shoe type, type of flooring and environmental factor [9,10]. Many a times, re-suspension of PM cause higher indoor concentrations than in the outdoor environment, especially in tropical climate. Monitoring in elementary schools of Germany [11,12], France [13] and Palestine [14] indicated that during class hours the PM_{10} concentration inside

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classrooms was several times higher than that of outdoor environment. A study conducted in an urban school of Delhi, India which experiences tropical climate, showed that the daily 6-h average PM concentrations in classrooms was higher on weekdays ($PM_{10} = 410.6\ \mu g/m^3$, $PM_{2.5} = 71\ \mu g/m^3$ and $PM_1 = 45.8\ \mu g/m^3$) than on weekends ($PM_{10} = 133.5\ \mu g/m^3$, $PM_{2.5} = 54.6\ \mu g/m^3$ and $PM_1 = 41.3\ \mu g/m^3$) due to difference in occupant densities and activities [15]. Similar measurements made by Gadkari in three different schools of an industrial zone of India, showed that classrooms had higher concentrations of coarse particulates compared to laboratories and teacher offices [16]. All the above mentioned studies also observed that finer particles infiltrated from outdoor environment in absence of any indoor sources. The fine particles are mainly contributed from traffic sources, mainly from the diesel engines. Fine particles have larger surface area than coarse particles and are highly toxic in nature. Due to the small size of fine particles they are usually expressed in number concentrations since their contributions to mass concentrations are small. The 8-h average ultrafine number concentrations were found to be of the order of 10^3– $10^4/cm^3$ in the different indoor microenvironments of schools like classrooms, library, gymnasium, computer laboratory, teacher office during various activities or in presence of several sources like art activities, cooking, smoking, physical training and ventilation systems like heaters and air conditioners [17–21]. All the above mentioned studies have focused on understanding the time-averaged concentrations of particulates which does not give much information on the frequency of high and low concentration events.

In the past, many studies have reported the importance of statistical distribution models in exposure assessment. Most of the studies were used to fit the ambient air quality data for exposure analysis. Studies have shown that the particulates followed unimodal, bimodal or multimodal behaviour due to contribution from different sources like dust from paved and unpaved roads, construction activities, wind erosion, transport of smaller size particles [22–25]. In addition to the frequency distribution, the statistical models may be important to understand the risk associated with the different concentrations of PM. The statistical models such as normal, lognormal, lognormal 3-parameter (3-P), Weibull, logistic, log-logistic-3P, gamma, generalized extreme value, have been used in previous studies to fit the outdoor air quality data [26–30]. Studies have shown different statistical distributions for different pollutants under different conditions of meteorology and emission rates. This shows that there is no universal statistical distribution model that can fit to all data of air pollutants. These statistical distributions are very important for exposure assessment and studies focused on indoor PM distribution are scanty. It was also observed by Larsen that in some urban areas the pollutant concentrations fit to 3-parameter distributions and not to the 2-prameter distributions as observed in most cases [31]. The frequency distribution can help to predict the exceedance of air quality standards which may further help in making decisions regarding management of pollutant levels [27,30].

Other than particulates, it is also important to understand the thermal comfort parameters namely T, RH, CO_2 to know the thermal comfort of occupants. A study carried out in office environment revealed that 40% of people expressed dissatisfaction when ventilation rate was 10 L/s/person, temperature = 23 °C and relative humidity (RH) = 50%. It indicates that temperature and humidity plays an important role in determining the thermal comfort of occupants [32]. In another study, IAQ was assessed in 64 classrooms of different schools in USA and found that CO_2 concentrations were exceeding the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards of 1000 ppm in most classrooms due poor ventilation [33]. In a mechanically ventilated lecture hall of a university in Budapest showed CO_2 concentrations in the range of 1405–390 ppm on workdays. The maximum temperature and relative humidity (RH) were 28 °C and 48%, respectively [5].

The aim of this study is to characterize the selected IAQ and thermal comfort parameters and identify the best fit statistical distribution models for classroom PM mass concentrations. The present study is first of its kind to understand the statistical distribution of PM mass concentrations at different floors of the classroom in tropical climate.

2. Methodology

2.1. Study area description

Chennai (13.0827°N, 80.2707°E) lies in the south-eastern coast of India. It experiences tropical wet and dry climate (KÖppen). As per the Indian Meteorological Department (IMD), the months of January–February are considered as winter, March–May as summer, June–September as southwest monsoon and October–December as north east monsoon. Chennai receives most of its rains in the north-east monsoon while late May to early June is considered as the hottest time of the year. Since the month of June is considered as hot and dry it causes lot of dust resuspension.

In Chennai, the schools are either run by government (*municipal corporations* or city corporation) or private organizations. The school selected for monitoring is a government-run school. It is multistoried, naturally ventilated (free from mechanical systems for air exchange) school building built in the year 1976. The school is rectangular in shape and it has classrooms in three wings/blocks. The school is located at 146.65 m from the urban bypass road (Velachery Bypass) which is a busy traffic road and 21.20 m away from a minor road (see Fig. 1). It has a playground in the centre of the school where students of all classes assemble before and after the class hours. The school has about 3000 students. Whenever, students and teachers assemble in the playground, dust clouds are visible due to re-suspension. For the present study, three classrooms located at the ground, first and second floors of the school were selected for monitoring. All the three rooms are having natural ventilation. The ground floor classroom was facing the playground. The windows and door in all the classrooms are made up of metal (steel frame) and they are rectangular in shape. Since windows and doors are made from metal, they are free from joints. The windows and doors were kept open only during the school hours. The classrooms were swept after class hours every day. A detailed description of the classrooms characteristics is presented in Table 1.

2.2. Monitoring protocol

Monitoring was carried out as per the IAQ protocol suggested by Central Pollution Control Board (CPCB) and US Environmental protection Agency (EPA) [34,35]. Measurements were undertaken in the month of June (2015) for 2 consecutive days in each classroom during the school working hours (8:00–16:00) every day. The number concentrations of different size ranges of PM were monitored using GRIMM environmental dust monitor model 1.108. The instruments allow particles to pass through 15 different channels from 0.35 to 22.5 μm, according to their size and collect on a 47 mm polytetrafluoroethylene (PTFE) filter. An internal volume controlled pump allows air to pass at a rate of 1.2 L/minute. This dust monitor works on the principle of light scattering of particles. The instrument uses a laser diode as a light source of 780 nm (infrared range). The scattered light signal is collected on a mirror and led onto the detector which is at 90° to the incident laser light. The size of the particles is proportional to the signal intensity of the scattering