ARTICLE IN PRESS

International Journal of Sustainable Built Environment (2017) xxx, xxx–xxx

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Gulf Organisation for Research and Development

International Journal of Sustainable Built Environment

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Original Article/Research

Indoor air quality of non-residential urban buildings in Delhi, India

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Received 3 November 2016; received in revised form 2 June 2017; accepted 1 July 2017

Abstract

Nearly 30% of total population and over 2 million students of Delhi spent above 1/3rd of their daily time in different office buildings and educational institutions of Delhi, of which the ambient air quality is reportedly worst in the globe. However, studies on indoor air quality of non-residential buildings are scarce in India. Present study was conducted in two office buildings and one educational building in Delhi during pre-monsoon. CO_2, $PM_{2.5}$ and VOCs were measured inside each building at every 5 min interval between 9:30 AM and 5:30 PM for 5 days every week. The average CO_2 concentration in both office buildings (1513 ppm and 1338 ppm) was recorded much higher than the ASHRAE standard. Ductless air-conditioning system couple with poor air-circulation and active air-filtration could be attributed to significantly higher concentration of $PM_{2.5}$ in one of the office buildings (43.8 μg m^{-3}). However, there was significant variation in the concentration of different pollutants at different locations in a building. Among different non-residential buildings, significantly lower concentration of all pollutants was recorded in the educational building (CO_2: 672 ppm; $PM_{2.5}$: 22.8 μg m^{-3} and VOC: 0.08 ppm). Total hazard ratio analysis ranks one of the office buildings as most hazardous to workers health compared to others.
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Keywords: Indoor air quality; Non-residential building; $PM_{2.5}$; Carbon dioxide; Total VOCs; Delhi

1. Introduction

People spend more than 90% of their daily life in indoor environments either inside office, school, college, commercial, industrial buildings or inside residential houses. Study suggests that the concentration of pollutants in the indoor environment is much higher than that of the urban outdoor ambient environment with average traffic (EPA Indoor air quality, 2013). However, the indoor air quality received considerably less attention than that of the outdoor air quality until last decade. Poor indoor air quality can be especially harmful to vulnerable groups such as children, elderly, and those with cardiovascular and chronic respiratory diseases *viz*. asthma. Apart from its profound effect on health, the indoor air pollution reduces the comfort, and productivity of occupants of the building. On the other side, the indoor air quality (IAQ) in educational and office buildings may affect the health of the children and workers as well as indirectly affect their learning ability and productivity. Surprisingly, given the magnitude of the educational institutional population, information on IAQ in educational buildings is very limited.

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Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2017.07.005
2212-6090/© 2017 The Gulf Organisation for Research and Development. Production and hosting by Elsevier B.V

Please cite this article in press as: Datta, A. et al. Indoor air quality of non-residential urban buildings in Delhi, India. International Journal of Sustainable Built Environment (2017), http://dx.doi.org/10.1016/j.ijsbe.2017.07.005

The particulate matter (especially $PM_{2.5}$) concentration in the ambient air of Delhi is the highest among 1600 cities around the world (World Health Organization, 2014). Most outdoor pollutants enter into the indoor environment and their concentration increases many folds owing to inefficient air-circulation. Long-term exposure to $PM_{2.5}$ is associated with reduction in average life-expectancy from 8.5 to 20 months and increase in the long-term risk of cardiopulmonary mortality by 6–13% per 10 $\mu g\ m^{-3}$ of $PM_{2.5}$ (Krewski et al., 2009). This indicates the importance of the assessment of IAQ of different buildings in the capital city. However, apart from the outdoor air, there are other factors which affect the IAQ e.g. cooking, cleaning products, different building materials like plywood, flame retardants, aerosol pesticides and even the exhaled air contains significant amount of carbon dioxide (CO_2). Concentrations of CO_2 inside buildings range from outdoor levels up to several thousand parts per million (Persily and Gorfainm, 2008). The indoor CO_2 level is one commonly used approach which has been referred as an IAQ indicator (Lin and Deng, 2003) for inefficient and ill-functioning air-filtration system.

Effects of CO_2 on human health range from physiologic (e.g., ventilatory stimulation) to toxic (e.g., cardiac arrhythmias and seizures) and anaesthetic (significantly depressed CNS activity) to lethal (severe acidosis and anoxia) (Rice, 2004). Prior research has documented direct human health effects of CO_2 at concentrations much higher than those found in normal indoor settings (Lipsett et al., 1994). Signs of asphyxia are evident when the atmospheric O_2 is $\leq$16% (HSDB, 2003). Kajtar et al. (2006) have reported adverse impact of CO_2 concentration between 2180 and 5455 ppm on proof reading ability of exposed persons from a research trial conducted in Hungary. In a controlled research study in USA, Satish et al. (2012) have reported that at 1091 ppm CO_2, decision-making performance was significantly diminished on six of nine metrics compared to the 600 ppm concentration. When the concentration was increased to 2730 ppm CO_2, decision making performance was further reduced to seven of nine metrics of performance, with percentile ranks for some performance metrics decreasing to levels associated with marginal or dysfunctional performance. This indicates that direct adverse effects of CO_2 on human decision making performance may be economically important.

On the other side, the chronic health effects provoked by VOCs can be classified as either non-carcinogenic or carcinogenic. The carcinogenic effects of VOCs are primarily visible in lung, blood, liver, kidney and biliary tract. The International Agency for Research on Cancer (IARC) has classified benzene as a Group 1 human carcinogen, while other VOCs such as tetrachloroethylene and ethylbenzene are considered as probable carcinogens for humans (ACS, 2016). Additionally, some VOCs may be associated with the symptoms of asthma, different allergic reactions, mucous membrane irritation and diseases of the central nervous system symptoms. The indoor concentrations of many VOCs were recorded higher than outdoor concentrations due to indoor sources (Weisel et al., 2008). In another study, in different naturally ventilated academic buildings in Italy, Gennaro de et al. (2013) have concluded that the indoor concentration of most of the VOCs are significantly higher than their outdoor concentrations during the activity hours. Significantly higher concentrations of different VOCs (e.g. benzene, toluene, ethyl benzene, xylene etc.) than their standard ambient concentrations were recorded in the fine arts faculty building of Anadolu University, Turkey (Can et al., 2015). However, in spite of their reported higher concentrations in the indoor environment, there are not many studies on the indoor concentrations of VOCs in office and academic buildings. VOCs are a broad range of compounds with boiling points from less than 0 °C to about 400 °C. Several 100 compounds of VOCs are present in the indoor air (WHO, 1989). The energy conservation measures in the office buildings rapidly increased the use of synthetic building materials. Building materials like vinyl floor, particle board, sealant, gypsum board, carpet, paint, varnish, thermal insulation, etc. also act as sources of different VOCs inside the office building. Apart from these, building elevator and ventilation system also act as the source of VOCs (C13 to C18 alkanes and broad spectrum VOCs respectively) in the office buildings (Wolkoff et al., 1995). Additionally, technological advancement increased the use of modern machines inside the office premises. Studies suggest that the use of electronics equipments (ECMA Standardizing Information and Co, 2006), PCBs (Kemmlein et al., 2003), notebook computer (Hoshino et al., 2003), Desktop computer/VDT (Nakagawa et al., 2003), copier machine (Leovic et al., 1998), carbon paper, copier paper, power cable (Shields and Weschler, 1992), correction fluid, cleaning agent, etc. in offices are indoor sources of VOCs.

Commercial primary energy consumption in India has grown by about 700% in the last four decades (UNDP, 2011). The commercial and institutional building area in India is expected to grow from 659 million m^2 in 2010 to 1900 million m^2 in 2030 (Kumar, 2011). This increases the energy demand for the sector. Heating and cooling of the outside air for the comfort of the building occupants, requires a significant amount of energy. Considerable energy saving is possible by minimizing the outdoor air used for ventilation. However, this deteriorates the indoor air quality if active air-filtration systems are not installed. This leads to compromising the health and comfort of the occupants (Turiel et al., 1983). The indoor air quality of the office and institutional buildings thus become the subject of much attention. Daisey et al. (2003) have reported strong positive association between the mixing ratio of CO_2 and ventilation level in classrooms in an institutional building in USA. They have reported asthma and ‘sick building syndrome’ among the students. In another study, from Denmark, Wargocky and Wycon (2013) have reported the CO_2 as 1092 ppm during the working hours

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