Indoor Coarse and Fine Particulates in Elementary Urban Schools

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Abstract

The issue of more elementary children is seen to have respiratory sickness such as asthma especially the younger ones age 5-13 years old is highlighted in this research. By fact 20 - 38% of acute pediatric admissions in the country and the third most common death in children between the age of 1 and 13 are caused by respiratory illness. Children are frail during their growth because of their immature immune systems; makes them more susceptible to the health effects of air pollution compare to adults. The indoor air quality (IAQ) in classrooms plays a major role in the children health since they spend at least 71% of their time in school building, approximately seven or more hours a day in school. This research aims to assess the elementary schools IAQ profile using filter-based sampler in Kota Kinabalu, with 8 hours measurement time for total twelve sampling days. Overall, the average concentration of coarse and fine particulates in weekdays found higher compared to weekends with average $PM_{0.3}$ 312.09±73.28μg/m^3 (weekdays) and 156.77±41.56μg/m^3 (weekends); $PM_{2.0}$ 5.71±1.80μg/m^3 (weekdays) and 1.37±0.44μg/m^3 (weekends), and $PM_{5.0}$ 1.45±0.68μg/m^3 (weekdays) and 0.06±0.03μg/m^3 (weekends). The I/O ratio indicates that major of the indoor airborne particulates are not generated from the outdoors but predominantly from indoor source namely from bio effluents from occupants and their activities, building materials, furnishings and ventilation rates. The importance of the study is to provide a baseline data in developing the IAQ standard for children, thus improvement for a better school facility for the children.

Introduction

Nowadays, often seen children, even infants, are increasingly infected with respiratory illness more than other health problems. The effects of air pollution on children have been growing (Khan *et al.*, 2007) and the consequences can be seen by the increase of the allergic rhinitis and asthma disease on (Valavanidis *et al.*, 2007). For children compare to adults, are more vulnerable to air pollutants, dust and smoke because of their immature immune systems, undeveloped breathing airways (Stranger *et al.*, 2007), greater food intake, the breathing pattern which they breathe higher volumes of air relative to their body weights (inhaled breath per unit mass higher compare to adults), and their rapid growth where their tissues and organs are actively growing (USEPA, 1995; Mendell & Heath, 2005).The children breathing zone is lower than adults make them more exposed to heavier pollutants that fall and concentrate at lower levels in the air (Brabin *et al.*, 2008). It is reported that the prevalence of respiratory symptoms in primary school children is recorded as 13.8% higher compare to age 14 years and above which is reported only at 9.6%. Indoor air quality (IAQ) in school is more serious than in other categories of indoor buildings, due to higher occupants density and insufficient air ventilation, aggravated by frequent inadequate construction and poor maintenance of the school buildings (Pegas *et al.*, 2010). Schools are always seen to have construction deficiencies because of chronic shortages of funding that contributes to inadequate operation and maintenance of the facilities (Jacqueline-Zweig *et al.*, 2009).

Other than that, the IAQ in school building plays major role in students learning environment, as they spend more time in school rather than at home. Epidemiologic studies provide evidence of a relationship between the higher levels of air pollutants with decreased of the brain development and intelligent quotient (IQ) in school children. Jacqueline-Zweig *et al.* (2009) study for example, found that higher levels of $PM_{2.5}$ and PM_{10} have consistently lowered the students math scores, while higher level of $PM_{2.5}$ consistently reduce the reading test scores. Similarly Halterman *et al.* (2008) found that kindergarten-age children with asthma sickness had lower scores than non-asthmatic kindergarten-age children in readiness skills. Higher levels of black carbon (marker for traffic particles) were also associated with the decreased of cognitive function and memory of children age 10 years old (Suglia *et al*., 2008). Apart from that, coarse and fine particulates with aerodynamic diameter less than 10 µm can penetrate deeper into lungs through inhalation system and can even reach to blood stream and eventually causing heart problems (Longhurst & Brebbia, 2014). On the other hand, schools in urban area are mostly located near to roadways with higher volume of traffic thus more exposed to air pollutants from vehicles combustion, construction and industrial emissions (Rivas *et al*., 2014). As a result, the dispersion if air contaminants from outdoor into indoor classroom initiates by the mechanical transport from wind and air ventilation (Chithra & Shiva, 2012).makes the urban school children more expose to air pollutants throughout the year. Therefore, the aim of this research is to establish whether the indoor air quality in selected elementary school is clean or not for the children thus to avoid elevated exposure by mitigation and adaptation purposes.

Methodology

Standard methodology based on Almeida *et al*. (2011), Fromme *et al*. (2008) and MetOne (2014) was used in this paper. Concentrations of airborne particulates ($PM_{0.3}$, $PM_{2.0}$, and $PM_{5.0}$) were measured using portable filter-based sampler GT-321 hand-held portable particle monitor. Four elementary schools in Kota Kinabalu area were selected as case studies, with average floor area (m^2) of classrooms at 4860 m^2, approximately 30 to 45 students occupying the classrooms and with open windows and average 2 ceiling fans of ventilation mode. Measurements were conducted during school days when the classrooms are occupied with school children for about 8 hours and each day a different school were monitored. The particulates were also sampled during weekends to compare the concentrations during teaching hours and when the classrooms are not occupied by students. In each school, at least three classrooms sampling with one sampler per classroom selected that are routinely occupied during school hours. All selected schools for this research have natural ventilation and no forced ventilation or air conditioning system, and ventilation is by opening doors and windows. The sampling and measuring position in the classroom is opposite to the teaching board, about one meter above the floor level, the level at which the school children would normally inhale. This is chosen as a typical location inside the classroom, and a distance away from the door to avoid disturbances from air currents from the outside air. In addition, outdoor air samplings were also conducted to analyze the correlation from outside ambient pollutants transport into the indoor air.

Result and discussion

It was found that the average concentration of coarse and fine particulates in weekdays found to be higher with average $PM_{0.3}$ 258.65 ± 45.76 µg/m^3; $PM_{2.0}$ 3.55 ± 1.46 µg/m^3; $PM_{5.0}$ 0.30 ± 0.19 µg/m^3 compared to weekends reported at$PM_{0.3}$ 210.84 ± 42.48 µg/m^3; $PM_{2.0}$ 1.45 ± 0.25 µg/m^3 and $PM_{5.0}$ 0.06 ± 0.02 µg/m^3. As shown in Table 1, the highest $PM_{0.3}$ reading recorded at 399.24 ± 13.85 µg/m^3 and minimum concentration of 133.24 ± 21.37µg/m^3; $PM_{2.0}$ maximum concentration recorded at 8.76 ± 2.91µg/m^3 and minimum at 1.01 ± 0.42 µg/m^3; and $PM_{5.0}$ the maximum reading is observed at 0.95 ± 0.18 µg/m^3 and the minimum is at 0.03 ± 0.01 µg/m^3. Li *et al*. (2001) strongly suggest that higher physical activities or more movements and mobility inside the classrooms from the occupants during weekdays which is on schooldays would contribute to higher human bio-effluents from the school children that might affecting the elevated PM levels (Yip *et al*., 2004; Yoon *et al*., 2011; Harrison *et al*., 2005).Other factors may also influence from building material, furnishings, ventilation rates, temperature and humidity (Branco *et al*., 2014; Nunes *et al*., 2015; Yang *et al*., 2009).

Table 1. The average concentrations of $PM_{0.3}$, $PM_{2.0}$ and $PM_{5.0}$ in all schools

Pollutant	Concentration (µg/m^3)					
	Indoor			Outdoor		
	Mean	Max	Min	Mean	Max	Min
$PM_{0.3}$	152.21 ±41.19	399.24 ±13.85	133.24 ±21.37	28.54 ±9.22	41.47 ±0.55	21.15 ±2.14
$PM_{2.0}$	2.50 ±0.29	8.76 ±2.91	1.01 ±0.42	0.43 ±0.01	0.61 ±0.02	0.21 ±0.13
$PM_{5.0}$	0.18 ±0.06	0.95 ±0.18	0.03 ±0.01	0.06 ±0.00	0.36 ±0.10	0.01 ±0.00

Outdoor samplings were also conducted to monitor the concentration of outdoor pollutants with particulates size of $PM_{0.3}$, $PM_{2.0}$, $PM_{5.0}$ and to examine the effects of outdoor air quality towards the indoor air quality. From the result, it was recorded that the outdoor coarse and fine particulates showed higher concentration during weekdays compared to weekend with average level of $PM_{0.3}$ 32.47 ± 3.18 µg/m^3; $PM_{2.0}$ 0.36 ± 0.08 µg/m^3; $PM_{5.0}$ 0.06 ± 0.04 µg/m^3 compared to weekends reported at$PM_{0.3}$ 24.61 ± 1.77 µg/m^3; $PM_{2.0}$ 0.49 ± 0.06 µg/m^3 and $PM_{5.0}$ 0.05 ± 0.01 µg/m^3. Indoor-outdoor ratio (I/O) assessment was performed in this study to determine the strength of indoor sources towards the indoor air quality (IAQ) (Elbayoumi *et al*., 2013). The assumption is that if the value I/O ratio is less than 1 means pollutants that presence in indoor are mostly transported from outdoors. In contrast, if it is greater than 1 then the main source is from indoor (Long *et al*., 2000). From the results, I/O ratio for all PM size in all elementary schools is ranged from 3.00 to 5.81 as shown in Table 2. This shows that the I/O ratio for indoor particulates with size $PM_{0.3}$, $PM_{2.0}$ and $PM_{5.0}$ for all elementary school has exceeded the unity value and this indicates that the indoor pollutants are generated from indoor sources itself.

Table 2. The I/O ratio between indoors and outdoors in all elementary schools

Pollutant	Indoor (µg/m^3)		Outdoor (µg/m^3)		
	Weekdays	Weekends	Weekdays	Weekends	Ratio (I/O)
$PM_{0.3}$	258.65 ± 45.76	210.84 ± 42.48	32.47 ± 3.18	24.61 ± 1.77	5.33
$PM_{2.0}$	3.55 ± 1.46	1.45 ± 0.25	0.36 ± 0.08	0.49 ± 0.06	5.81
$PM_{5.0}$	0.30 ± 0.19	0.06 ± 0.02	0.06 ± 0.04	0.05 ± 0.01	3.00

High contaminations of outdoor air is the prime cause of indoor air quality problems, especially in buildings that is naturally ventilated with doors and windows are open, such as schools building. Inadequate ventilation like this can increase indoor pollutant levels by bringing in the high level of outdoor contaminants to indoor, but not carrying it out from indoor and out of the classroom (Hagerhed *et al*., 2006). If the air exchange rate is low, the indoor air pollutants can accumulate to levels that can pose health and comfort problems (Long *et al*., 2000).For meteorological measurements, temperature, humidity and air flow were performedto analyze the link to the thermal comfort inside the classroom. The weekdays average temperature is recorded at 28.01±1.59 °C and 27.61±1.93 °C for weekends, which both were exceeded the Industry Code of Practice on Indoor Air Quality (ICOP-IAQ 2010) 23-26 °C for temperature. Higher temperature during weekdays can be linked to the occupancy at the classroom during the period, which will increase the heat released from their activity (Valavanidis *et al*., 2008).

For humidity, it does not exceed the standard limit by ICOP-IAQ within 40-70 %. In the classrooms, average humidity during the weekends is 48.83±3.75 % which is higher compared to weekdays recorded at 45.76±1.87 %. Humidity in the classrooms can be due to natural ventilated school buildings design (Elbayoumi *et al*., 2013); or rainy days whereby water vapor in the atmosphere may wash out pollutants and therefore would lower the concentration of particulate matters (Putus *et al*., 2004). Besides, higher humidity will favor an increase in hygroscopic particles which in turn increase particles growth and indirectly enhance the formation and deposition of particulates to bigger size (Wolkoff & Kjaergaard 2007). For air flow, only during the weekdays has exceeded the ICOP-IAQ 0.5 ms^{-1} standard limit. The classrooms average air flow has recorded at 0.59±0.29 ms^{-1} during weekdays and at 0.39±0.18 ms^{-1} during weekends. The prevailing winds play an important role in indoor pollutants concentration since infiltration of particles is driven by gradients pressure that are influenced by wind movement (Chithra & Shiva 2014). According to Ismail *et al*. (2010), air flow mainly affected by the opening of the buildings such as windows and doors, thus the movement of wind from outside will infiltrated the air particulates into the indoor environment (Radha *et al*., 2010).

Conclusion

The results from this research provide a baseline data for elementary schools when developing the indoor air quality (IAQ) standard for children as the OSHA 1994 and WHO 2005 standards that are currently being use to assess the IAQ are actually not meant for children as the existing standard is for adult and it has higher acceptance exposure limit for children. Hence, we can conclude that the average concentrations of coarse and fine particulates in weekdays were found higher compared to weekends. In addition, the I/O ratio for all PM concentrations exceeds the unity value of 1, indicates that major of the indoor airborne particulates are not generated from the outdoors, but it is predominantly generated from indoor source.

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