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Programme and Abstract

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Indoor and Outdoor Particulate Matter Concentrations in Primary Schools in Phitsanulok, Thailand

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Abstract

Ambient air pollutants enter into buildings and affect indoor air quality. Several studies have investigated the relationships between the concentrations of pollutants in ambient and indoor air. Numerous air quality measurements have been carried out in ambient the domestic environment and adult exposure. Apart from home, school is the most important indoor environment for children. The aim of the study was to investigate the exposure of children to indoor air pollutants in primary schools. The mass of air particulate matter (PM₁₀) and its elemental concentration have been determined at five primary schools in Phitsanulok and Phitchit, Thailand during dry seasons (September–December 2011 and 2012). The study has been conducted for weekdays during school hours (8am–4pm). Simultaneous 8-h PM₁₀ indoor and outdoor measurements were taken using a portable air sampler (Airmetrics Minivol®) at flow rate of 5 Lmin⁻¹. Results indicated that average indoor PM₁₀ in schools at urban sites ranged between 14.34±0.35 and 40.79±5.26 µg m⁻³, while the PM₁₀ outside the schools ranged between 198.29±16.42 and 295.83±25.38 µg m⁻³. For the rural areas, the average indoor and outdoor PM₁₀ concentrations ranged from 17.49±0.55 to 33.46±4.28 µg m⁻³ and 140.39±10.81 to 144.79±19.69 µg m⁻³, respectively. Indoor concentration levels seem to be mainly affected by PM of outdoor origin, since the calculated indoor-to-outdoor concentrations ratios (I/O) were much lower than 1.00. Enrichment factor calculations obtained from the elemental composition results showed that all elements have a significant crustal source and contributed to indoor air pollution levels in these schools.

Keywords: indoor air pollution; traffic-related; PM₁₀; schools; children

1. Introduction

Numerous studies have been shown that indoor air quality (IAQ) has increased dramatically in recent years (Almeida et al., 2011; Braniš et al., 2009; Crist et al., 2008; Diapouli et al., 2008; Macedo et al., 2013; Pegas et al., 2011; Sofian and Ismail, 2012). Indoor pollutants may be the dominant risk factor in relation to personal exposure, as most people spend an average of 87% of their time within enclosed (Klepeis et al., 2001). Indoor exposure may pose more harmful health effects, as the indoor concentrations of many pollutants are often higher than those typically encountered outside (Jones, 1999). The cause of indoor air pollution is a combinatory effect of physical, chemical and biological factors, and the adequacy of ventilation in the environment. Indoor air pollutant sources are from the outdoors, building equipment, furnishings, and human activities (Latif et al., 2009).

Major outdoor air pollution comes from traffic, industrial, construction, and combustion sources (WHO, 2010). These ambient air pollutants enter into buildings and affect indoor air quality. Other than that, indoor air pollution also influence by operations and activities that occur within the indoor environment. The concentration of an indoor pollutant depends on its indoor emission rate, the rate at which it is being transported from outdoors to indoors, and the rates at which it is scavenged by indoor surfaces, consumed by indoor chemistry and removed by ventilation or filtration (Weschler, 2009). These air pollutants have been associated with adverse health effects that have significant socio-economic impact (Ganick et al., 1995). In general, air borne fine particles are considered to be of greater health significance than any other air pollutants (Ashmore and Dimitroulopoulou, 2009). Epidemiological studies show that particulate matter has been characterized as the mass concentration of particles with the aerodynamic diameter less than 10 µm (PM₁₀) or less than 2.5 µm (PM_{2.5}). These particles have large surface area per unit mass pollution and dominate ambient particle number and

surface area concentrations, both indoors and outdoors, because of their small size, which makes them an excellent carrier for adsorbed inorganic and organic compounds, some of which present potential cancer hazards (Massey et al., 2012).

Schools are an important microenvironment for students and where they spend a large fraction of their time. In addition, children suffer from higher exposure to air pollutants than adults because of their higher physical activity, higher metabolic rate and the resultant increase in minute ventilation (Chalupa et al., 2004). Indoor air pollution might increase the chance of both long and short term health problems for students and staff, reduce the productivity of teachers and degrade the student's learning environment and comfort (Kim et al., 2007; Shaughnessy et al., 2006). Therefore, investigation of the indoor air quality in school classrooms will help to understand the characterization of pollutants and to suggest ways of reducing the exposure of school children. The purposes of this study were to examine the PM₁₀ concentrations and its elemental concentration (Fe, Pb, Cd, Zn and Cu) in the indoor and outdoor air at primary schools in two different locations at Phitsanulok and Phichit provinces, lower north of Thailand, one of which was an urban area and another was a rural area. The comparison of this will be useful for source apportionment.

2. Materials and Methods

2.1. Site description

Indoor and outdoor PM₁₀ samples were collected from five classrooms at five different schools in Phitsanulok and Phichit, lower north of Thailand. The five schools were Watjan school (WJ), Wattamaprang school (WT), Bankrang school (BK), Nongpai school (NP) and Watkongkaram school (WK). The site selection was based on the location of the schools (residential and rural areas). A five-day indoor and outdoor air quality investigation at each school were carried out during September to December 2011 and 2012. The WJ, WT and BK schools are located at urban areas in Phitsanulok with major traffic roads surrounding the school buildings. The NP and WK schools are located in Phichit rural areas with rice paddy fields nearby. The five locations were located on the ground floor and first floor of a 2-storey building. The main materials of these buildings are wood and concrete. Each building was consisted with lecturer and staff rooms, lecture room and school main office. All measurements were performed during lecturing hours. The classrooms of schools located in the rural area were ventilated by natural ventilation through open windows or mechanical ventilation using fan whereas the classrooms in the urban area were naturally ventilated and mechanically ventilated by air-conditioner. Information on sampling sites is shown in Table 1.

Table 1. Characteristics of sampling stations

	Station	Station name	Level
Urban areas in Phitsanulok	1	WJ	Ground Floor
	2	WT	1st Floor
	3	BK	1st Floor
Rural areas in Phichit	1	NP	Ground Floor
	2	WK	1st Floor



2.2. Sampling and analysis

Indoor and outdoor PM₁₀ levels were collected on a quartz filter paper (47 mm, Whatman) using a MiniVol portable air sampler (Airmetrics Minivol®) at flow rate of 5 L min⁻¹. The air sampling was performed simultaneously 8-h during school hours (8 am - 4 pm) on weekdays (Monday-Friday). The classroom samples were collected from the middle of the classroom. Inlet heads were positioned as close as possible to head height for simulating location of the breathing zone of the occupant. For outdoor measurements sampling was made 5 m away from the boundary of the school. The instrument was kept 1.5 m above the ground level. These measurements were conducted during September–December 2011 and 2012. The quartz filters were Whatman QA-M filters pre-heated at 550 °C for 4 h prior to sampling to remove possible organic contaminants. Field blank filters were also obtained. The samples were placed in polycarbonate Petri dishes and were stored in a freezer until analyses.

Each filter was weighed three times by a high precision mass balance before and after the sampling. The average values were used. The mass concentrations of both the PM₁₀ were found by subtracting the initial mass of the blank filter by the final mass of the sampled filter and dividing the difference by the total volume of air passing through the filter. After weighing the sampled filter for PM₁₀, elemental compositions in the PM₁₀ samples were analyzed by Atomic absorption spectroscopy (AAS) method (Shimadzu, AA-6200). The one of four portions were digested in the mixture of pure concentrated acids (HNO₃ and HClO₄ in proportion 4:1) and diluted with deionized water to make 25 mL. Concentrations of heavy metals (Cd, Cu, Fe, Pb and Zn) were measured in this study. The accuracy of the analyses was checked against the standard reference material. The heavy metals were selected in this research based on the basis of health risk via dust ingestion assessed using mean contamination in dust and toxicity (both available in literature and toxicological databases). Metals whose potential ingested dose was higher than 5% of the tolerable daily intake were considered: Cd, Cu, Pb, and Zn (Le Bot et al., 2010).

Quality control was practiced throughout the sampling and analysis to avoid any interference and minimize the risk of error. Powderless gloves were used while performing all stages of the experiment. All the polyethylene bottles and glassware utilized for heavy metal analysis were pre-cleaned by being soaked in nitric acid overnight before being rinsed with deionised water. Additionally, any instruments involved in this analysis were calibrated before use.

2.3. Enrichment Factor

Enrichment factor (EF) analysis provides a preliminary picture of whether the indoor particulate matters come from the crust or from other industrial processes or indoor activities (Chao and Wong, 2002). The crustal enrichment factors of elements in indoor dust were calculated using the average concentration of heavy metals and indoor dust applying the formula used by Hassan (2012). The EFs were calculated from;

$$EF_x = \frac{(X/Y)_{\text{indoor dust}}}{(X/Y)_{\text{earth crust}}}$$

where (X/Y)_{indoor dust} is the concentration ratio calculated starting from X-concentration and Y-concentration measured in the indoor dust sample, and (X/Y)_{crust} is the concentration ratio in the crust (Taylor et al., 1983). Aluminum (Al), Iron (Fe), Scandium (Sc) and Barium (Ba) were commonly considered as the reference elements of crustal material (Gao et al., 1992). In this study, Fe was used as a reference element of earth crust composition. EF values lower than 10 indicate that the element

investigated has a significant crustal source, while EF values higher than 10 are ascribed to elements of anthropogenic origin (Biegalski et al., 1998). The value of EF between $10 < EF < 100$ can be considered as moderately enriched whilst the value > 100 can be deemed as highly enriched (Wang et al., 2006).

3. Results and Discussion

3.1. Concentrations of Suspended Particulate Matter (PM_{10})

All measurements were conducted for dry seasons in Phitsanulok and Phichit. Table 2 lists the average concentrations of PM_{10} indoor and outdoor in schools at rural and urban sites. The average indoor PM_{10} concentrations and standard deviations (SD) in schools at urban sites ranged between 14.34 ± 0.35 and $40.79 \pm 5.26 \mu\text{g m}^{-3}$, while the concentration of PM_{10} outside the schools ranged between 198.29 ± 16.42 and $295.83 \pm 25.38 \mu\text{g m}^{-3}$. For the schools in rural areas, the average indoor and outdoor PM_{10} concentrations ranged from 17.49 ± 0.55 to $33.46 \pm 4.28 \mu\text{g m}^{-3}$ and 140.39 ± 10.81 to $144.79 \pm 19.69 \mu\text{g m}^{-3}$, respectively. This indicates that air quality in the urban areas shows a higher concentration of PM_{10} . The standard of indoor air quality has not been proposed in Thailand. Therefore, we compared our data with the Indoor Air Quality Standards of Hong Kong (less than $20 \mu\text{g m}^{-3}$ 8-h mean: excellent class and less than $180 \mu\text{g m}^{-3}$ 8-h mean: good class) (Pang, 1994), the indoor concentrations were found to be acceptable in this standard. These results also did not exceed the value of $150 \mu\text{g m}^{-3}$ 8-h mean recommended by the Malaysian Department of Safety and Health (DOSH) for respirable dust in indoor environments.

High concentrations at the sampling sites may be attributed to a heavy vehicular traffic flow especially, at roadside sites in urban areas whereas for the rural areas, indoors and outdoors concentrations were variable and this may be due to the opening of windows and the presence of proper ventilation systems by using ceiling fans in this type of location. The PM_{10} have larger deposition velocities than finer particles which lead to reduction in their indoor concentrations (Thatcher and Layton, 1995). Concentration of particulate matter inside the schools may also decrease due to gravity sedimentation.

Table 2. Average concentration with their standard deviations of PM_{10} (in $\mu\text{g m}^{-3}$)

Site	Site characteristic	PM_{10} indoor	PM_{10} outdoor	I/O
WJ	Urban (n=50)	14.34 ± 0.35	198.29 ± 16.42	0.07
WT	Urban (n=50)	40.79 ± 5.26	237.49 ± 21.35	0.17
BK	Urban (n=50)	34.64 ± 3.45	295.83 ± 25.38	0.11
NP	Rural (n=50)	33.46 ± 4.28	140.39 ± 10.81	0.24
WK	Rural (n=50)	17.49 ± 0.55	144.79 ± 19.69	0.12

n = number of samples

For all sites, high outdoor concentration levels and daily variations of I/O ratio observed for PM_{10} may be associated with outdoor sources. Overall, the concentrations of PM_{10} recorded in this study were found to be lower than those recorded in previous studies on the concentration of PM_{10} in school classrooms e.g. by Janssen et al., (1999), Diapouli et al., (2008), Chithra and Shiva Nagendra (2012) and Tran et al., (2012) (Table 3).

Table 3. Comparison of the indoor PM₁₀ (in µgm⁻³) from this study with other studies

Source	Averaging Time (hour)	Measurement Site	PM ₁₀
This study	8	School classrooms, urban ares	14.3 – 40.8
	8	School classrooms, rural ares	17.5 – 33.5
Janssen et al. (1997)	8	School classroom, Amsterdam, Netherlands	80.8 - 157.0
Diapouli et al. (2008)	8	School classroom, Athens, Greece	236.13
Xie et al. (2010)	8	Urban and rural area, Baoji City, China	402.0 - 410.0
Chithra and Nagendra (2012)	8	School classroom, Chennai, India	149.0 ± 69.0
Tran et al. (2012)	8	School classroom, North of France	72.7 - 85.2

3.2. Indoor/outdoor ratios

Indoor/outdoor ratio (I/O) is an indicator for evaluating the difference between indoor concentrations and the corresponding outdoor levels or as an indicator for the strength of indoor sources (Huang et al., 2007). Indoor air pollutant concentrations are affected by infiltration of outdoor pollutants into the schools and indoor sources. To quantify the impact of outdoor air and indoor sources on indoor air quality, indoor/outdoor ratios were calculated. Indoor/outdoor (I/O) concentrations can vary largely due to a large number of factors (including locations, building design and different activities) (Massey et al., 2012). The average I/O ratios for five sampling sites show in Table 2. The I/O ratios for PM₁₀ in urban areas ranged from 0.07 to 0.17 whereas the I/O ratios in rural areas ranged from 0.012 to 0.24. It was found that the I/O ratios for all sites were less than 1.

Higher I/O ratios indicate additional sources in indoor environment. The fine particulate matters are attributed from vehicle emissions, which directly enter the indoor environment adding up the concentration levels (Oosterlee et al., 1996). The coarse particles have larger deposition velocities than fine particles which lead to reduction in their indoor concentrations, as they fall out by gravitational settling or deposit on window and door frames (Thatcher and Layton, 1995). Concentration of particulate matter inside the schools may also decrease due to sedimentation onto furnished surface. The I/O ratio significantly varied at the sampling locations. The ambient air may have a predominant influence on the indoor air levels due to correlations of indoor and outdoor PM₁₀ ranged between 0.56-0.81 while indoor activities and may contribute significantly to indoor air pollution.

3.3. Elemental compositions and enrichment factor

The results of the indoor and the outdoor element species are shown in Table 4. The average elements concentrations in observed schools ranged from 0.33 ± 0.28 to 15359 ± 1806 ng m⁻³ in PM₁₀. The element levels in outdoor PM₁₀ varied from 0.35 ± 0.24 to 2801.70 ± 487.62 ng m⁻³. Overall, the heavy metals studied in PM₁₀, Zn was found in the highest concentration at all sites, followed by Fe, Pb, Cu and Cd. The Zn concentration of indoor PM₁₀ in urban areas ranged $1166 \pm 305.25 - 15359 \pm 1806$ ng m⁻³, followed by Fe ($1842.15 \pm 129.68 - 683.93 \pm 344.91$ ng m⁻³), Pb ($18.27 \pm 13.07 - 187.14 \pm 82.74$ ng m⁻³) Cu ($9.46 \pm 2.54 - 131.25 \pm 25.65$ ng m⁻³) and Cd ($0.35 \pm 0.24 - 390.45 \pm 29.68$ ng m⁻³), respectively. For indoor PM₁₀ in rural areas, the average concentrations of Zn ranged from 6708.17 ± 811.79 to 7710.29 ± 666.66 ng m⁻³ and Fe varied from

623.14 $\pm$ 166.81 to 711.65 $\pm$ 160.87 ng m⁻³. The average concentration of Cu was 11.74 $\pm$ 7.74 ng m⁻³ and Cd was 7.70 $\pm$ 3.40 ng m⁻³ whereas Pb was not detected. The concentrations of Zn in PM₁₀ recorded in this study were much higher than that of Zn in PM₁₀ as reported in other studies such as El-Hougeiri and El Fadel (2004) Chao and Wong (2001) Janssen et al.(1999) Gemenetzis et al.(2006) and Wang et al. (2006).

The enrichment factors (EF) can be calculated to show the degree of enrichment of a given element compared to the relative abundance of that element in crustal material and used as a first step in attempting to evaluate the strength of the crustal and non-crustal sources (Gao et al., 1992). Overall results show that EF values of all elements were lower than 10 indicate that the element investigated has a significant crustal source. The calculation of the EF of heavy metals in the PM₁₀ also showed that the average value of the EF for each heavy metal is between 0.001 and 5.40, indicating that those heavy metals in the PM₁₀ are not significantly enriched by anthropogenic sources. The concentrations of Zn of the schools in urban areas were higher than that of in rural areas but showed low enrichment factor, thus suggesting not significant contribution of anthropogenic sources and mainly originating from the street dust and their activities. Fe is the major element in the surface soil and hence has the ability to influence the level of Fe in indoor dust. In general, Pb and Zn are traditional tracers of vehicle emissions (Janssen et al., 1997) but showed EFs < 10 in both urban and rural areas indicating that these elements were most likely derived from resuspension of dust due to indoor human activities. Heavy metals may originate from various sources in urban areas, including emissions from vehicles, discharges from industrial facilities and other activities (Gibson and Farmer, 1986; Shi et al., 2008; Wong and Li, 2004). Related to their crustal abundances, heavy metals show considerable enrichment in indoor environments (Rasmussen, 2004). Color of the wall paints is also a significant source of heavy metals in indoor dust, for instance, yellow paint is associated with very high levels of Cd, Cu, Pb, and Zn, purple color is related with higher concentrations of Zn and Pb and green color is related to Cu (Chattopadhyay et al., 2003; Tong and Lam, 2000).

Table 4. Average element concentration with their standard deviations of PM₁₀ (in ng m⁻³)

		Heavy metals in PM ₁₀									
Location	name	Zn		Fe		Cu		Pb		Cd	
		Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Urban	WJ	15359	2480	683	1284	10	9	18	30	0.3	8
		± 1806	± 342	± 344	± 304	± 2	± 6	± 13	± 11	± 0.2	± 2
	WT	1166	952	1842	1544	131	109	187	390	390	nd
		± 305	± 242	± 129	± 349	± 25	± 22	± 82	± 50	± 29	
	BK	9650	2801	726	1434	9	32	nd	69	nd	4
		± 1613	± 487	± 158	± 370	± 2	± 25		± 25		± 2
Rural	NP	7710.29	862	711	12	11	1.2	nd	8	7	0.3
		± 666	± 47	± 160	± 10	± 7	± 0.5		± 4	± 3	± 0.2
	WK	6708	1094	623	42	nd	1.1	nd	nd	nd	nd
		± 811	± 29	± 166	± 20		± 0.1				

nd : non detectable

4. Conclusion

The mass concentration and the elemental composition of PM_{10} were measured in five primary schools locating in urban and rural areas of Phitsanulok and Phichit, lower north of Thailand. The average outdoor 8-h mean PM_{10} ranged from 140.39 ± 10.81 to $295.83 \pm 25.38 \mu g m^{-3}$ whereas the indoor PM_{10} concentrations ranged from 14.34 ± 0.35 to $40.79 \pm 5.26 \mu g m^{-3}$. The highest concentration of PM_{10} was observed at the schools nearby a major road with high traffic density. The indoor PM_{10} concentration levels seem to be mainly affected by PM of outdoor origin, since the I/O ratios were much lower than 1.00 during indoor and outdoor concentrations. The heavy metals studied in PM_{10} , Zn was found in the highest concentration at all sites. The enrichment factor calculations showed EFs < 10 in both urban and rural areas indicating all elements were probably from the crust and of soil nature.

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