Environmental Engineering and Management Journal

August 2018, Vol.17, No. 8, 1781-1790
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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COMPOSITION OF TRACE METALS IN INDOOR DUST DURING AND AFTER BUILDING RENOVATION

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Abstract

A study was conducted to determine the composition and concentration of trace metals in suspended particulate matter (PM_{10}) and indoor dust in two academic buildings of Universiti Kebangsaan Malaysia. One building was in the final phases of renovation (UR) and the other building had just finished renovation (AR). PM_{10} sampling of air was performed using a low volume sampler (LVS), and samples of indoor dust were obtained using a brush and a small plastic bag. The compositions of trace metals in both samples were determined by inductively coupled plasma mass spectrometry (ICP-MS). PM_{10} concentrations in the building under renovation (UR) were found to be higher (77.1 ± 32.4 μg m^{-3} to 355.4 ± 38.3 μg m^{-3}) than those in the building after renovation (AR) (91.7 ± 41.2 μg m^{-3} to 147.9 ± 3.0 μg m^{-3}). Higher concentrations of PM_{10} were found in the open areas (foyer and corridor) than in closed areas (classroom and laboratory). The concentrations of trace metals in PM_{10} and indoor dust were found to be dominated by Zn, followed by Pb > Cu > Cd. There is no indication of health adverse effect based on the concentration of trace metals recorded in the UR and AR buildings from this study.

Key words: health risk, indoor dust, PM_{10}, renovation, trace metals

Received: June, 2013; Revised final: October, 2014; Accepted: October, 2014; Published in final edited form: August, 2018

1. Introduction

It is generally assumed that air pollution is solely an outdoor phenomenon. In reality however, indoor air can be several times more polluted than outdoor air (Abdul-Wahab, 2006; Diapouli et al., 2007; Gioda et al., 2011; Noor et al., 2015; Schecter et al., 2010). Moreover, people, particularly children, spend much of their time (up to 90%) indoors; school and university students may stay indoors far longer than those at work (Mohamad et al., 2016; Sulaiman et al., 2017; Vassura et al., 2015). As a consequence, the health risks posed by pollutants in the indoor environment are of significant concern; potential hazards of indoor pollutants are now becoming widely recognised (Diapouli et al., 2008; Ekmekcioglu and Keskin, 2007; Majumdar et al., 2016; Zhong et al., 2010). The United States Environmental Protection

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Agency (USEPA) has ranked indoor air pollution as a high priority risk to public health (Sexton, 1993). Research on human exposure to pollutants has suggested that suspended particulate matter and indoor dust pose significant risks of indoor exposure to potentially dangerous elements (Manohar and Kavuri, 2017; Mohd Tahir et al., 2009; Rothweiler and Schlatter, 1993). Exposure to environmental pollutants in the indoor environment has been associated with adverse health effects, such as allergies and immune system effects, respiratory, reproductive, cardiovascular and central nervous system problems, irritation of the skin and mucous membranes, and cancer (Massey et al., 2012; Sloan et al., 2012; Young et al., 2011).

Indoor air pollutants originate from several sources including building occupant activities, biological sources, fuel combustion and emissions from building materials (Du et al., 2011; Klinmalee et al., 2009). Penetration of outdoor contaminants through water, air or soil is known to be the principal source of indoor air pollutants (López-Aparicio et al., 2011; Srivastava and Jain, 2007). Building renovation is recognised as a contributing factor to the release of pollutants into the indoor environment (Hameed et al., 2004; Hasegawa et al., 2009). Building expansion, flooring exchange and the replacement of building components such as carpets, roofing materials, heating appliances and ventilation can affect indoor air quality (Frumkin, 2006; Latif et al., 2011). Indoor air pollutants are adsorbed onto the particulate matter in indoor air that later settles as indoor dust.

The objectives of this study were to determine the concentration of suspended particulates with a diameter of less than or equal to 10 μm (PM_{10}) and to evaluate the composition of particulates suspended in air and present in indoor dust, specifically hazardous trace metals (Pb, Cd, Zn and Cu) in two different academic buildings at Universiti Kebangsaan Malaysia, Bangi, one of which was under renovation (UR) and the other had recently undergone renovation (AR).

2. Material and methods

2.1. Sampling sites

The study was conducted between August and October 2009 in four locations within two buildings, one under renovation (UR) and one just after renovation (AR), of the Faculty of Science and Technology located on the main campus of the Universiti Kebangsaan Malaysia (UKM) at Bangi, Malaysia. UKM Bangi is located within a sub-urban area about 30 km south of Kuala Lumpur city centre. The four locations were either on the ground floor or first floor of a four-storey building. Each building consisted of lecturer and staff rooms, lecture rooms, laboratories and the school main office. All measurements were performed from 09.00 until 17.00, during lecturing and working hours. This time frame was chosen as most of the occupants (students and lecturers) were likely to be exposed to high levels of contaminants. The ventilation systems for these two buildings were mechanical supply type and exhaust type.

During sampling, the UR building was in the final phase of renovation of its upper floor while renovation had just been completed on the AR building. The main renovation stages comprised demolition, blowing, cutting, supporting, epoxy painting, the installation of a new steel grid and concrete sheets, cementing or adding of gypsum and, finally, painting. The building under renovation, however, was not completely evacuated, and there was no barrier between the upstairs area under renovation and the occupied zones. Air and dust samples were collected from both upper and lower floors, including the foyers, corridors, lecture rooms and laboratories of both buildings. Lecture rooms consist of a white board and chairs for 40 students. The two laboratories are general laboratories used for undergraduate students of physics and chemistry. The laboratories contain five rows of benches and are used for general classes for at least three times per week. Information on sampling sites is shown in Table 1.

Table 1. Sampling sites of Under Renovation (UR) and After Renovation (AR) buildings

Building	***Station***	***Sampling site***	***Level***
Under Renovation (UR)	1	Foyer	Ground Floor
	2	Corridor	1st Floor
	3	Lecture room	1st Floor
	4	Laboratory	Ground Floor
After Renovation (AR)	1	Foyer	Ground Floor
	2	Corridor	1st Floor
	3	Lecture room	1st Floor
	4	Laboratory	Ground Floor

2.2. Particulate matter (PM_{10}) and dust sampling

PM_{10} was collected in the breathing zone at a height of 150 cm above the floor. Samples were collected during the renovation period using a low volume air sampler, LVS (MiniVol, Airmetrics, USA) equipped with weighted filter paper (47 mm diameter; Whatman, USA) for 8 h at a flow rate of 5.0 L min^{-1}. The filter paper was dried in a desiccator and weighed both before and after sampling to measure the concentration of PM_{10} at the sampling sites. A total of 16 samples (two replications) were taken at each sampling site.

Dust from the indoor environment was collected using a soft paint brush and sieved to less than 63 μm particle size before sample digestion. The particle size of 63 μm was chosen due to the availability of mass collected (1 g) after the dust was sieved. It is also possible that small particles can be re-suspended and generate PM_{10} in an indoor environment. Dust that has a diameter of less than 63 μm could affect human health when inhaled and can

be distributed through the body via the respiratory and cardiovascular systems (Latif et al., 2009). Three replication of dust samples were taken at each sampling site.

2.3. Analysis of trace metals in PM_{10} and indoor dust

For the analysis of PM_{10} samples, the filter papers were cut into small pieces before heating on a hot plate for one hour in a mixture of nitric and perchloric acid (v/v, 4:1) to leach the trace metals in the acid mixture. Indoor dust samples (1 g each) were also dissolved on a hot plate in a 20 mL mixture of nitric acid (65%, GR, Merck, Germany) and perchloric acid (40%, GR, Merck, Germany) (v/v, 4:1). Each sample solution was filtered using cellulose acetate filter papers with 0.2 µm pore size and 47 mm diameter (Whatman, USA). The filtered solution was diluted to 100 mL with ultra-pure water (18.2 MΩ) in a volumetric flask and kept at 4˚C in a polyethylene bottle until analysis was conducted. Filter blanks for the aerosol samples were prepared using unused filter paper that was treated with identical procedures.

Trace metals with a potential ingested dose of higher than 5% of the tolerable daily intake were analysed: Cd, Cu, Pb, and Zn (Le Bot et al., 2010). The concentration of selected trace metals in each solution was determined using inductively coupled plasma mass spectrometry (ICP-MS) (ELAN 9000, PerkinElmer, USA). Standard solutions of the trace metals were prepared through the dilution of each standard solution (1000 mg L^{-1}) with ultra-pure water (18.2 MΩ) in volumetric flasks. To validate the extraction and analysis procedure by ICP-MS, a recovery of the trace metals was conducted using a standard solution of 1 µg L^{-1}. The standard solutions were then treated the same as the extracts from the samples (both PM_{10} and dust).

2.4. Statistical analysis

Correlation coefficients and correlation significances were determined by a one-way ANOVA test using the Statistical Package for the Social Sciences (SPSS) to estimate any notable differences between the mean concentrations of trace metals in PM_{10} and dust as well as to determine correlations among the parameters under study.

2.5. Quality control

To ensure quality assurance and quality control (QA/QC) of the analytical results, the method detection limits (MDL) for trace metal in PM_{10} were calculated as 0.17 ng m^{-3} for Pb, 0.10 ng m^{-3} for Zn, 0.03 ng m^{-3} for Cd and 0.07 ng m^{-3} for Cu. The MDL of trace metals in indoor dust were determined as 0.04 µg g^{-1} for Pb, 0.03 µg g^{-1} for Zn, 0.09 µg g^{-1} for Cd and 0.02 µg g^{-1} for Cu. Furthermore, the recovery (%) of each metal was performed to evaluate the suitability of the digestion procedures. Results showed that the recoveries for all trace metals measured were in the range of 82% to 121%. The LVS used in this study was calibrated before use. Powderless gloves were used for all stages of the analysis work.

2.6. Risk assessment analysis

Risk analysis is a procedure that involves hazard identification, exposure assessment, dose-response assessment and risk characterization. In this study, Cd, Cr, Pb and Zn were identified as potential hazardous agents with respect to human health. According to the USEPA (1997), the chronic daily intake (*CDI*) (mg kg^{-1} day^{-1}) of a pollutant via ingestion, dermal contact and inhalation as exposure pathways is estimated using Eqs. (1, 2 and 3). The definition and values of parameters used for risk calculation are shown in Table 2.

$$CDI_{ing} = \frac{C\ x\ IngR\ x\ EF\ x\ ED}{BW\ x\ AT}\ x\ 10^{-6} \quad (1)$$

$$CDI_{inh} = \frac{C\ x\ EF\ x\ ET\ x\ ED}{PEF\ x\ 24\ x\ AT} \quad (2)$$

$$CDI_{dermal=}\ \frac{C\ x\ SA\ x\ AF\ x\ ABS_d\ x\ EF\ x\ ED}{BW\ x\ AT}\ x\ 10^{-6} \quad (3)$$

For non-carcinogenic risk, the *CDI* for each element and exposure pathway were divided by the corresponding reference dose (R_fD) to yield a Hazard Quotient (*HQ*) (Eq. 4). Hazard index (*HI*) is equal to the sum of *HQ* for each exposure pathways (Eq. 5).

$$HQ = \frac{CDI}{R_fD} \quad (4)$$

$$HI = \sum HQ = HQ_{ing} + HQ_{inh} + HQ_{dermal} \quad (5)$$

For carcinogenic risk, the *CDI* of Cd and Pb was multiplied by the corresponding slope factor (*CSF*) to produce a level of excess lifetime cancer risk (Eq. 6).

$$Risk = CDI\ x\ CSF \quad (6)$$

If *HI* < 1, the concern for potential adverse health effects is low and not considered a threat to public health. If *HI* > 1, there is a significant health threat and may represent potential adverse health effects. The cancer risk value of the selected metals would be considered to be potentially harmful to human health if the value exceeds the threshold of 1 x 10^{-4} to 1 x 10^{-6} as recommended by the USEPA.

3. Results and discussion

3.1. Concentrations of suspended particulate matter (PM_{10})

The concentrations of PM_{10} found at each study site are summarized in Table 3. The concentration of PM_{10} ranged from 77.1 ± 32.4 µg m^{-3} and 355.4 ± 38.3 µg m^{-3} in the UR sites and between 91.7 ± 41.2 µgm^{-3} and 147.9 ± 3.0 µg m^{-3} in the AR sites.

Table 2. Definitions and values of the parameters for the human health risk assessments

Parameter	*Unit*	*Value*	*References*
Absorption factor (*ABS*)	-	0.001 for Cd 0.01 for other metals	USEPA (2011)
Dust to skin adherence factor *(AF*)	mg cm^{-2}	0.07 for adult	USDOE (2011)
Averaging time for carcinogenic effects (*AT*)	d	70 x 365 for carcinogenic effects ED x 365 for non-carcinogenic effects	
Average body weight (*BW*)	kg	66 for adult (18 - <70 years)	Jamhari et al. (2014)
Concentration of metal (*C*)	mg/kg for dust µg m^{-3} for PM10		
Chronic daily intake or dose contacted through oral ingestion (CDI_{ing})	mg kg^{-1} d^{-1}		
Chronic daily intake or dose contacted through inhalation (CDI_{inh})	mg m^{-3} for non-cancer and µg m^{-3} for cancer		
Chronic daily intake or dose contacted through dermal contact with soil particles (CDI_{dermal})	mg kg^{-1} d^{-1}		
Chronic oral slope factor (CSF_{ing})	mg kg^{-1} d^{-1}		
Chronic dermal slope factor = CSF_{ing}/ABS (CSF_{dermal})	mg kg^{-1} d^{-1}		
Exposure duration (*ED*)	yr	52 for adult	Jamhari et al. (2014)
Exposure frequency (*EF*)	d yr^{-1}	350	USDOE (2011)
Exposure time (*ET*)	h d^{-1}	Assumption: based on 8 h (working hours)	
Ingestion rate (I*ngR*)	mg d^{-1}	100 for adult	USDOE (2011)
Chronic inhalation unit risk (*IUR*)	µg m^{-3}		
Chronic inhalation reference concentration (R_fC_{inh})	mg m^{-3}		
Chronic oral reference dose (R_fD_{ing})	mg kg^{-1} d^{-1}		
Chronic dermal reference dose = RfD_{ing} x *ABS* (R_fD_{dermal})	mg kg^{-1} d^{-1}		

The concentration of PM_{10} recorded at the UR sites was noted as being higher than those found in the AR sites, particularly in the foyer (Station 1) and the corridor (Station 2), presumably as a consequence of the renovation under way at the UR building.

The high concentration of PM_{10} in the UR building during renovation was assumed to have been caused by construction activities such as demolition, the removal of furniture, grilling and dry sanding. The concentrations of PM_{10} at the foyer and corridor stations in the UR building were found to exceed the value of 150 µg m^{-3} recommended by the Malaysian Department of Safety and Health (DOSH, 2005) for respirable dust in indoor environments. This was probably due to the lack of barriers between areas under renovation and the open spaces of the building. Stations 3 and 4 (closed door lecture room and laboratory, respectively) showed lower PM_{10} than that found in the open areas. The amount of PM_{10} in the AR building, especially in the laboratory, is due to the laboratory activities taking place after the renovation processes. Overall, the concentrations of PM_{10} recorded in the UR building were found to be higher than those recorded in previous studies on the concentration of PM_{10} in school classrooms e.g. by Janssen et al. (1999), Gemenetzis et al. (2006), Diapouli et al. (2008), Fromme et al. (2008), Braniš and Safranek (2011), Franck et al. (2011), Chithra and Shiva Nagendra (2012) and Tran et al. (2012) (Table 4). However, the PM_{10} concentrations found in this study were lower than the concentrations found in previous studies undertaken by Lee and Chang (1999) in schools in Hong Kong, Yang et al. (2009) in metropolitan areas in Korea and Xie et al. (2010) in Baoji City, China.

3.2. Concentration of trace metals in indoor PM_{10}

The concentrations of trace metals in PM_{10} recorded at the UR sites and AR sites are summarized in Table 3. The results showed significant difference ($p < 0.05$) between the trace metal concentrations in the UR and AR building at all sampling stations. Of the trace metals studied in PM_{10}, Zn was found in the highest concentrations at all sites, followed by Pb, Cu and Cd.

The concentration of Zn ranged between 3999.4 ± 678.0 ng m^{-3} and 5459.7 ± 983.5 ng m^{-3} at the UR sites and between 4092.7 ± 441.2 ng m^{-3} and 4873.4 ± 727.6 ng m^{-3} at the AR sites. The demolition processes, including the cutting of Zn and building materials containing Zn, were expected to have contributed to the high concentrations of Zn in PM_{10}, especially in the UR building.

The concentrations of Zn in PM_{10} recorded in this study were much higher than that reported in other studies such as Janssen et al.(1999), Chao and Wong (2001), El-Hougeiri and El-Fadel (2004), Gemenetzis

et al. (2006) and Wang et al. (2006), where it did not exceed 1000 ng m^{-3} (Table 5). The concentrations of Zn at all sites, however, were still below the ceiling of 5 000 000 ng m^{-3} recommended by the American Occupational Safety and Health Administration (OSHA) (Schaeffer et al., 1996).

The concentrations of Pb and Cu in PM_{10} recorded in this study were found to be higher than those reported by other researchers with the exception of the concentrations of Pb in PM_{10} found in public buildings by El-Hougeiri and El-Fadel (2004) and Wang et al. (2006). The shedding of old paint from walls is expected to have contributed to the concentrations of Pb while the concentrations of Cu are likely to have originated from copper piping and furniture.

The concentration of Cd in this study was found to be significantly lower than that found in previous studies. Overall, the concentrations of Pb, Cu and Cd were still below the OSHA-recommended values of 50 000 ng m^{-3}, 1 000 000 ng m^{-3} and 5000 ng m^{-3}, respectively (Schaeffer et al., 1996).

A correlation matrix between trace metals in PM_{10} at the UR sites (Table 6) showed that Cu and Cd are strongly correlated with each other (r = 0.93, p < 0.01). The Cu-Cd correlation may result from the transfer of Cu from dusty furniture and the Cd contained in polyvinyl chloride (PVC) and in the plastic materials from waste products of electric and electronic equipment (Ashton et al., 2010; Duarte et al., 2010) used during renovation. The correlation matrix between trace metals in PM_{10} at the AR sites (Table 5 and Table 6) demonstrated a good correlation between Cd and Pb (r = 0.80, p < 0.01). The negative correlations between Pb and Cu; Pb and Cd in PM_{10} collected in UR building and Cu-Zn, Cd-Zn collected in PM_{10} in AR building indicate that the trace metals not necessarily coming from the same sources.

Table 3. Concentrations of PM_{10} (n=2) and trace metals in PM_{10} and indoor dust (n=3) in UR and AR buildings with standard deviation

St.	*No*	*Location*	*PM_{10}*	*Trace metals in PM_{10}*				*Trace metals in indoor dust*			
				Pb	*Cd*	*Zn*	*Cu*	*Pb*	*Cd*	*Zn*	*Cu*
			μg m^{-3}	*ng m^{-3}*	*ng m^{-3}*	*ng m^{-3}*	*ng m^{-3}*	*μg g^{-1}*	*μg g^{-1}*	*μg g^{-1}*	*μg g^{-1}*
UR	1	Foyer	277.1 ± 138.5	58.9 ± 25.8	2.3 ± 0.3	5372.4 ± 696.9	180.8 ± 2.2	191.3 ± 92.8	0.19 ± 0.14	102.4 ± 87.0	10.0 ± 6.8
	2	Corridor	355.4 ± 38.3	85.0 ± 58.8	3.3 ± 1.0	5459.7 ± 983.5	186.8 ± 14.2	83.1 ± 37.3	0.15 ± 0.01	580.8 ± 125.9	6.0 ± 0.9
	3	Lecture room	93.8 ± 38. 3	56.3 ± 22.9	2.6 ± 0.6	3999.4 ± 678.0	188.9 ± 2.4	130.9 ± 20.1	0.15 ± 0.03	42.3 ± 7.5	5.2 ± 0.9
	4	Laboratory	77.1 ± 32.4	124.7 ± 15.7	0.4 ± 0.1	4433.4 ± 381.7	117.2± 2.3	227.2 ± 9.5	1.97 ± 0.12	179.7 ± 7.6	118.0 ± 6.7
AR	1	Foyer	127.1 ± 3.0	109.8 ± 0.2	0.4 ± 0.1	4092. 7 ± 441.2	106.1 ± 0.6	56.6 ± 42.9	0.10 ± 0.00	36.1 ± 3.2	15.3 ± 3.1
	2	Corridor	91.7 ± 41.2	103.5 ± 2.5	0.2 ± 0.1	4873.4 ± 727.6	101.9 ± 2.2	113.4 ± 3.3	0.15 ± 0.01	38.8 ± 1.2	132.9 ± 3.3
	3	Lecture room	95.8 ± 53.0	100.1 ± 17.4	0.3 ± 0.4	4128.6 ± 477.0	108.2 ± 0.9	7.8 ± 0.4	0.08 ± 0.01	48.4 ± 3.7	4.7 ± 0.2
	4	Laboratory	147.9 ± 3.0	112.5 ± 5.2	0. 6 ± 0.4	4623.1 ± 684.7	109.9 ± 0.5	361.7 ± 69.7	0.46 ± 0.55	420.9 ± 107.0	49.2 ± 24.0

Table 4. Comparison of the PM_{10} (μg m^{-3}) from this study with findings from other studies

Source	*Averaging Time (h)*	*Measurement Site*	*PM_{10}*
This study	8	UR building	77.1 - 355.4
		AR building	91.7 - 147.9
Janssen et al. (1999)	8	School classroom, Amsterdam, Netherlands	80.8 - 157.0
Lee and Chang (1999)	-	School classroom, Hong Kong	21.0 - 617.0
Fromme et al. (2008)	5	School classroom, Munich, Germany	58.8 - 210.0
Yang et al. (2009)	5-7	School classroom, Metropolitan area, Korea	8.0 - 403.0
Diapouli et al. (2008)	8	School classroom, Athens, Greece	236.13
Gemenetzis et al. (2006)	7	University room, Thessaloniki, Greece	118
Xie et al. (2010)	8	Urban and rural area, Baoji City, China	402.0 - 410.0
Franck et al. (2011)	10	Apartment (children's room), Leipzig, Germany	60.2 ± 3.3
Braniš and Safranek (2011)	24	Elementary school gyms, Prague, Czech Republic	1.2 - 29.4
Chithra and Shiva Nagendra (2012)	8	School classroom, Chennai, India	149.0 ± 69.0
Tran et al. (2012)	8	School classroom, Northern France	72.7 - 85.2

3.3. Concentration of trace metals in indoor dust

The concentrations of trace metals in indoor dust samples are summarised in Table 3. The overall concentrations of Zn were found to be the highest, followed by concentrations of Pb, Cu and Cd. The concentrations of Zn at the UR sites and at the AR sites ranged from 42.3 ± 7.5 μg g^{-1} to 580.8 ± 125.9 μg g^{-1} and from 36.1 ± 3.2 μg g^{-1} to 420.9 ± 107.0 μg g^{-1} respectively. The levels of trace metals were found higher at the UR sites ($p < 0.05$) compared to the AR sites due to renovation activities. The concentrations of Zn recorded in this study were found to be lower than those found in previous studies such as Al-Rajhi et al. (1996), Tong and Lam (1998), Rasmussen et al. (2001) and Chattopadhyay et al. (2003) (Table 7). However, the concentrations of Zn recorded in this study were found to be higher than the concentrations found in previous studies undertaken by Al-Rajhi et al. (1996), Mohd Tahir et al. (2009), Hassan (2012) and Tran et al., (2012). The presence of Zn metal as a pigment in lead-based paint coating is a likely cause for the Zn-Pb correlation. The correlation matrix between trace metals in indoor dust at the UR sites demonstrated significant positive correlations between Pb, Cu and Cd, while Zn indicated no significant correlations (Table 6). At the AR sites, Zn and Pb in indoor dust were shown to be strongly correlated with each other ($r = 0.95$, $p < 0.01$).

3.4. Correlation between trace metals in PM_{10} and trace metals in indoor dust

The correlations between the concentrations of trace metals in indoor dust and of trace metals in PM_{10} at both the UR and AR sites are shown in Table 8. No correlation was found between trace metals in PM_{10} and those in indoor dust in either study building ($p > 0.05$). At the UR sites the correlation between Cu in PM_{10} and Cu in indoor dust was negative ($r = -0.99$) and showed a significant difference ($p < 0.01$). A similar relationship was also noted between Cd in PM_{10} and indoor dust ($r = -0.95$, $p < 0.05$). These results suggest very little contribution of trace metals in the indoor dust, which had already settled and was accumulating on the ledges and furniture, to the amount of trace metals in the airborne particulate matter. Only small particles containing trace metals have the ability to re-suspend as trace metals in PM_{10}. This suggests that the Cd and Cu in PM_{10} and in indoor dust may come from different sources. Trace metals in indoor dust were thought to have originated from the physical activities or renovation in UR sites, such as drilling, grinding and cement work. While the trace metals in the indoor airborne particulate matter (PM_{10}) were thought to predominantly enter the airborne particulate matter through the re-suspension of fine particles through evaporation and coagulation processes.

Table 5. Comparison between the concentrations of trace metals in indoor PM_{10} (ng m^{-3}) recorded in this study with findings of several other studies

Source	*Measurement Site*	*Pb*	*Cd*	*Zn*	*Cu*
This study	UR building	56.3-124.7	0.4-3.3	3999.4-5459.7	117.2-188.9
	AR building	100.1-112.5	0.2-0.6	4092.7-4873.4	101.9-109.9
El-Hougeiri and El-Fadel (2004)	Public buildings, Urban Beirut, Lebanon	730	-	269	-
Chao and Wong (2001)	Urban houses, Hong Kong	104.8	-	171.8	19.3
Janssen et al. (1999)	School classroom, Amsterdam, Netherlands	46	-	83.5	17.5
Gemenetzis et al. (2006)	University lecture room, Thessaloniki, Greece	74	41	145	43
Wang et al. (2006)	Guangzhou hospital, China	280	9	817	68

Table 6. Correlation matrices among trace metals in PM_{10} in UR and AR buildings

Sample	*Parameter*	*UR building*				*AR building*			
		Pb	*Cd*	*Zn*	*Cu*	*Pb*	*Cd*	*Zn*	*Cu*
PM_{10}	Pb	1				1			
	Cd	-0.31	1			0.80**	1		
	Zn	0.31	0.46	1		0.12	-0.05	1	
	Cu	-0.57	0.93**	0.31	1	0.34	0.44	-0.39	1
Indoor Dust	Pb	1				1			
	Cd	0.62*	1			0.37	1		
	Zn	-0.36	-0.12	1		0.95**	0.32	1	
	Cu	0.63*	0.99**	-0.12	1	0.19	0.24	-0.07	1

*$p < 0.05$; **$p < 0.01$

3.5. Human health risk assessment

The results of the risk assessments for non-cancer and cancer risks are summarised in Table 9. The sum of *HQ* values estimated from Cd, Cu, Pb and Zn for UR (PM_{10}) were 6.62 x 10^{-2}, 5.74 x 10^{-4} and 7.52 x 10^{-4} and for AR (PM_{10}) were 7.05 x 10^{-2}, 2.98 x 10^{-4} and 7.93 x 10^{-6} via ingestion, inhalation and dermal routes, respectively. For UR (indoor dust) they were 6.89 x 10^{-2}, 2.26 x 10^{-5} and 4.14 x 10^{-4} and AR (indoor dust) were 5.88 x 10^{-2}, 1.65 x 10^{-5} and 2.79 x 10^{-4} via ingestion, inhalation and dermal routes, respectively. For non-cancer effects, ingestion of dust particles appears to be the main route of exposure to indoor dust and PM_{10}, followed by dermal and inhalation. All metals were found to have values below the safe level (*HQ* < 1). This indicated no significant non-carcinogenic risk was observed in the present study. Furthermore, the overall hazard index (*HI*) of each metal estimated from the exposure routes of inhalation, ingestion and dermal shows that there is no hazardous effect due to the exposure of PM_{10} and indoor dust for UR and AR. However, trace metals could accumulate in the body for a long time. For example, the adverse effects of Cd and Pb to the tissues of adults are quite serious. For the carcinogenic health risk, only Cd (inhalation) and Pb (ingestion, inhalation and dermal) were considered. The cancer risks for UR (PM_{10}) via ingestion, inhalation and dermal were 7.45 x 10^{-7}, 5.30 x 10^{-5} and 2.97 x 10^{-9}, respectively, while for AR (PM_{10}) were 9.77 x 10^{-7}, 2.94 x 10^{-5} and 3.90 x 10^{-9}, respectively. The estimated cancer risk of indoor dust for UR and AR were 1.45 x 10^{-6} and 1.24 x 10^{-6} (ingestion), 5.19 x 10^{-6} and 3.40 x 10^{-6} (inhalation), 5.79 x 10^{-9} and 4.94 x 10^{-9} (dermal). Total cancer risks of exposure to indoor dust and PM_{10} for UR and AR were below the acceptable level (1 x 10^{-4} - 1 x 10^{-6}).

However, these results strongly suggest that the presence of Cd and Pb raises concerns with regard to potential possible adverse effects on human health.

4. Conclusions

Study results showed that the average concentrations of PM_{10} in the buildings, whether UR or AR, were still below the level recommended by the Malaysian DOSH, with the exception of the station in the foyer at the lower floor of the UR building. The higher levels of PM_{10} in the open spaces like the foyer and corridor are expected to result from the proximity of renovation activities.

Laboratory and classroom areas were less affected by renovation dust due to the closed doors that acted as barriers to the spread of renovation dust, suggesting the importance of barriers to reduce the amount of PM_{10} in the open spaces (corridor and foyer) in the building under renovation.

Table 7. Comparison between the concentrations of trace metals (μg g^{-1}) in indoor dust recorded in this study with findings of several recent studies

Source	***Measurement Site***	***Pb***	***Cd***	***Zn***	***Cu***
This study	UR building	83.1-227.2	0.15-1.97	42.3-580.8	5.2-118.0
	AR building	7.8-361.7	0.08-0.46	36.1-420.9	4.7-132.9
Tong and Lam (1998)	Nursery schools and kindergartens, Hong Kong	199.96	8.48	2293.56	247.38
Rasmussen et al. (2001)	Urban house, Ottawa, Canada	405.56	6.46	716.9	206.08
Mohd Tahir et al. (2009)	Town nursery, Terengganu, Malaysia	59.00	2.50	56.00	7.40
Al-Rajhi et al. (1996)	Various sites, Riyadh, Saudi Arabia	639.10	2.00	547.10	271.10
Chattopadhyay et al. (2003)	Urban houses, Sydney, Australia	405.56	6.46	716.90	206.08
Hassan (2012)	Urban houses, Cairo, Egypt	303.81	3.71	134.00	256.40
Tran et al. (2012)	School classroom, Northern France	6.4 - 9.5	0.14 - 0.47	32.2 - 80.1	4.90 - 10.30

Table 8. Correlation between trace metals in PM_{10} and trace metals in indoor dust

Parameter	***Under Renovation (UR)***		***After Renovation (AR)***	
	r-value	*p*-value	*r*-value	*p*-value
Pb	0.44	0.28	0.74	0.13
Cd	-0.95*	0.03	0.82	0.09
Zn	0.63	0.19	0.33	0.34
Cu	-0.99**	0.01	-0.74	0.13

*$p < 0.05$; **$p < 0.01$

Table 9. Toxicity value based on risk assessment analysis of trace metals in PM_{10} and indoor dust

Parameter	*Sample type*	*Cd*		*Cu*		*Pb*		*Zn*		*Total*	
Building		*UR*	*AR*	*UR*	*AR*	*UR*	*AR*	*UR*	*AR*	*UR*	*AR*
Toxicity values											
RfD$_{ing}$ [a] **(mg kg^{-1} day^{-1})**		1.00 x 10^{-3}		4.00 x 10^{-2}		3.50 x 10^{-3}		3.00 x 10^{-1}			
RfC [a] **(mg m^{-3})**		1.00 x 10^{-5}		1.00 x 10^{-3}							
ABS [b]		0.025		1		1		1			
SF$_{ing}$ [a] **(mg kg^{-1} day^{-1})**						8.50 x 10^{-3}					
IUR [a] **(µg m^{-3})**		1.80 x 10^{-3}				1.20 x 10^{-5}					
***HQ*s**											
Ingestion	PM_{10}	3.12x10^{-3}	4.36x10^{-4}	6.12x10^{-3}	3.87x10^{-3}	3.37x10^{-2}	4.42x10^{-2}	2.33x 10^{-2}	2.20x10^{-2}	6.62x10^{-2}	7.05x10^{-2}
	Indoor dust	8.94x10^{-4}	2.87x10^{-4}	1.26x10^{-3}	1.84x10^{-3}	6.56x10^{-2}	5.60x10^{-2}	1.1 10^{-3}	6.59x10^{-4}	6.89x10^{-2}	5.88x10^{-2}
Inhalation	PM_{10}	2.97x10^{-4}	7.35x10^{-5}	2.77x10^{-4}	2.24x10^{-4}	-	-	-	-	5.74x10^{-4}	2.98x10^{-4}
	Indoor dust	1.44x10^{-5}	4.64x10^{-6}	8.17x10^{-6}	1.19x10^{-5}	-	-	-	-	2.26x10^{-5}	1.65x10^{-5}
Dermal	PM_{10}	4.99x10^{-4}	4.35x10^{-14}	2.44x10^{-5}	2.47x10^{-8}	1.35x10^{-4}	2.16x10^{-9}	9.31x10^{-5}	7.90x10^{-6}	7.52x10^{-4}	7.93x10^{-6}
	Indoor dust	1.43x10^{-4}	4.58x10^{-5}	5.04x10^{-6}	7.32x10^{-6}	2.62x10^{-4}	2.23x10^{-4}	4.37x10^{-6}	2.63x10^{-6}	4.14x10^{-4}	2.79x10^{-4}
HI	PM_{10}	-	-	-	-	-	-	-	-	6.75x10^{-2}	7.08x10^{-2}
	Indoor dust	-	-	-	-	-	-	-	-	6.93x10^{-2}	5.91x10^{-2}
CRs											
Ingestion	PM_{10}	-	-	-	-	7.45x10^{-7}	9.77x10^{-7}	-	-	7.45x10^{-7}	9.77x10^{-7}
	Indoor dust	-	-	-	-	1.45x10^{-6}	1.24x10^{-6}	-	-	1.45x10^{-6}	1.24x10^{-6}
Inhalation	PM_{10}	3.92x10^{-5}	9.73x10^{-6}	-	-	1.38x10^{-5}	1.97x10^{-5}	-	-	5.30x10^{-5}	2.94x10^{-5}
	Indoor dust	1.91x10^{-6}	6.14x10^{-7}	-	-	3.28x10^{-6}	2.79x10^{-6}	-	-	5.19x10^{-6}	3.40x10^{-6}
Dermal	PM_{10}	-	-	-	-	2.97x10^{-9}	3.90x10^{-9}	-	-	2.97x10^{-9}	3.90x10^{-9}
	Indoor dust	-	-	-	-	5.79x10^{-9}	4.94x10^{-9}	-	-	5.79x10^{-9}	4.94x10^{-9}
CR-overall	PM_{10}	-	-	-	-	-	-	-	-	5.37x10^{-5}	3.04x10^{-5}
	Indoor dust	-	-	-	-	-	-	-	-	6.65x10^{-6}	4.64x10^{-6}

"-" no data available, a USDOE (2011), b USEPA (2011)

The concentrations of trace metals in both PM_{10} and indoor dust were seen to be dominated by Zn, followed by Pb, Cu and Cd, probably due to the use of Zn-containing building materials and paint in the study buildings. The concentrations of trace metals in PM_{10} were found to be higher than those found in previous research with the exception of Cd, which had a relatively low concentration compared to that found in other studies. However, the concentration of trace metals in indoor dust was found to be lower than that found in previous studies. For the non-carcinogenic, overall *HI* of each metal estimated from the exposure routes of inhalation, ingestion and dermal shows that there is no hazardous effect due to the exposure of PM_{10} and indoor dust in both buildings UR and AR. Further, the overall carcinogenic cancer risk due to the exposure of indoor dust and PM_{10} via the three possible exposure routes for both the UR and AR sites shows no threat to human health.

This study suggests that barriers can give a significant difference in the trace metal concentrations of PM_{10} and indoor dust in buildings under renovation and that the concentration of trace metals in indoor environments should be monitored even after the completion of renovation. Future research with high number of buildings and sampling points need to be conducted to determine the impact of renovation on the level of indoor air pollutants to human health.

Acknowledgements

The authors would like to thank Ministry of Education, Malaysia for Fundamental Research Grant FRGS/1/2013/STWN01/UKM/02/2 and Universiti Kebangsaan Malysia for Research University Grant (DIP-2016-015). Thanks to Mrs Alena Sanusi, Dr Rose Norman and Ms K Alexander for assistance with the proofreading of this manuscript.

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