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INDOOR AND OUTDOOR RELATIONSHIPS OF PARTICLES WITH DIFFERENT SIZES AT AN APARTMENT IN HA NOI: MASS CONCENTRATION AND RESPIRATORY DOSE ESTIMATION

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Abstract. This paper presents data on the size distribution and concentration of particulate matters ($PM_{0.1}$, $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_{10}, TSP) in indoor and outdoor air at a residential apartment in two seasons (winter and summer) in Ha Noi, Viet Nam. These particles with different sizes were taken by 5 stage impactors (Nano sampler 3182, KINOMAX). Daily average concentrations of coarse particles (PM_{10}) and fine particles ($PM_{2.5}$) indoors and outdoors exceeded the WHO recommended values. In winter, the concentrations of $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_{10} and TSP are higher than in summer. However, concentrations of $PM_{0.1}$ (NP) remains negligible change between two seasons. The indoor NP accounts about 8 % and 17 % of fine particles ($PM_{2.5}$) and 7 % and 12 % of coarse particles (PM_{10}) in winter and summer, respectively. The indoor fraction for fine particles ($PM_{0.5}$, PM_1 and $PM_{2.5}$) have better infiltration than coarse sizes ($PM_{2.5-10}$, PM_{10} and TSP), except for NP in summer. Moderate correlation between wind speed (Ws) and PM concentration is found, whereas precipitation (Pr), relative humidity (RH) and temperature (T) correlate with PM concentrations with different sizes weakly. Strong correlations between particles with different sizes are also found in indoors and outdoors (r = 0.73 - 0.98). Household activities like cooking, cleaning and smoking are attributable to elevate the indoor NP. The Monte Carlo simulation shows that highest estimated dose is observed in the age group (over 60 years) and age group (0 - 3 years) suffers the lowest dose, which has implications in the adverse health effects for sensitive groups. Sensitive analysis finds the concentration of particles to be the most influencing factor on inhalation dose estimation.

Keywords: particulate matter, dose estimation, I/O ratio, seasonal variation, Monte Carlo.

Classification numbers: 3.6.2, 3.4.5.

1. INTRODUCTION

Particulate matter was the fifth-ranking mortality risk factor in 2015 and has been known as

leading cause of global burden of disease [1]. In the modern life, most people spend roughly 80-90 % of our time in enclosed spaces, so assessing human exposure to particulate matter in indoor environment has become the important issue. It was reported that a population living in the tight buildings contracted upper respiratory diseases was at rates 46 to 50 % higher than group living in better ventilated houses [2] Viet Nam has recently gotten worse with the high PM concentration [3]. There were more than 60000 deaths from heart disease, stroke, lung cancer, chronic obstructive pulmonary diseases and pneumonia in Viet Nam in 2016 due to air pollution [4]. Compared to $PM_{2.5}$ and PM_{10}, which are primary factors of adverse health outcomes associated with respiratory disease from air pollution, health effects of nanoparticles (NP) could be even more harmful. NP may penetrate deep into the lung, which facilitates into blood stream, subsequently to other organs and their exposure linked to biomarkers of cardiovascular effects and excess mortality [5, 6]. A considerable amount of studies explored size segregated particulate matter (PM) and dose estimation in some indoor environment such as Sports Facility in Poland, Dwellings in Jordan also have done in the world [7, 8]. Recent studies in size resolved airborne particles in atmospheric environment have been conducted in Viet Nam. The number concentrations of NP were measured in indoor and outdoor six householders in Ha Noi [9], whereas, the mass concentration and carbonaceous compositions of PM in urban location were reported [10], the publication documented the elemental composition of indoor-outdoor ultrafine/fine/coarse particles in two preschools in Ha Noi [11]. To the best ofour knowledge, no studies have been found the relationship of indoor and outdoor of particles with different sizes and dose estimation in the residential indoor environment in Ha Noi, Viet Nam. The main objectives of this study are: (1) monitor the mass concentration of particles with different sizes by seasons; (2) analyze indoor – to - outdoor relationship of PM, and (3) estimate the inhalation dose of PM with different sizes.

2. MATERIALS AND METHODOLOGY

2.1. Sampling site

The measurement was performed in a residential apartment (21^0.01N, 105^0.9E) located in the Hanoi capital in the Northern Viet Nam. The residential apartment was selected basing on the characteristics such as ventilation system, floor, wall and ceiling, window structure, building age. This high building was set up in 2004 and made of brick and cement, which is located in highly populated area and surrounded by many high residential, commercial buildings. It is approximately 100 m far from main road conjunction of the city, with high traffic density roads. The sampled apartment is on the 2^{nd} floor of this building, with total area of 120 m^2. The indoor aerosol sampling took place in the master room with 60 m^2 conjunction with kitchen area, in which people mainly spent on their time. Outdoor aerosol sampling took place on the corridor. Both indoor and outdoor inlets were placed approximately 1.5 m above the floor. The apartment is covered by laminate floor, ventilation system including natural and mechanical ventilation system, five regular occupants in the room, gas stove in use during the sampling period, the apartment windows/doors keep closed, doors only opened on getting out/in and on cleaning days.

2.2. Sampling and mass analysis

The sampling campaign was taken for two weeks in winter and two weeks in summer. Outdoor and Indoor samples were conducted successively from 13^{th} January to 25^{th} January and

22th April to 4th May, 2019 by two identical particle samplers (Five stage impactor - Nanosamper II, Model 3182, KINOMAX) to collect different size fractions of airborne particles. The particles with different sizes were taken simultaneously indoors and outdoors on quartz filters (55 mm - diameter) by five stage cascade impactors at a constant flowrate of 40 L/min. Before sampling, all samplers were calibrated to obtain recommended flowrate by a TSI mass flow meter (TSI Incorporation). Quartz filters were pre-baked at 900^0C for four hours to remove possible contaminants. The collected air borne particles were kept in clean Petri dishes and stored from 20 ^{o}C to 25 ^{o}C. The filters were put in the desiccator at the balance room where kept relative humidity at the range of 30 to 40 % within 48 hours before weighing according to the reference method (EN12341:2014). The mass concentrations of airborne particles are determined by the Electronic microbalance with an accuracy of 10^{-6} g (AX26 DeltaRange microbalance, Mettler Toledo company, Switzerland) and constant inonizing air blower (Model YIB01-ODR, Germany) to eliminate the charges. The meteorological data such as wind direction, wind speed, temperature, relative humidity, pressure was obtained from Lang station (in Ha Noi) during sampling period.

2.3. Indoor-outdoor relationship

Indoor/Outdoor (I/O) is the ratio between the indoor and outdoor concentration of PM, which has been used for quick establishment whether the indoor environment is enriched by PM or compounds from outdoor sources. I/O $\geq$ 1.2 or I/O $\leq$ 0.8, the possible indoor or outdoor source was dominant, respectively. Otherwise, there is equivalence between indoor and outdoor sources [12]. The correlation coefficient between indoor and outdoor samples is used as indicator of the infiltration factor of different fractions from outdoors to indoors [12, 13]. The infiltration factors are determined by the linear regression equations. A simple linear equation is applied to determine infiltration factor following the equation: $C_{in} = C_s + F_{in}\, C_{out}$. ($C_{out}$, C_{in}: Outdoor and indoor PM concentration, F_{in}: infiltration factor; C_s: indoor concentration contributed in indoor source).

2.4. Inhalation dose estimation

To assess the health effects associated with respiratory particles ($PM_{0.1}$, $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_{10}), daily respirable dose (ADD) was estimated following the US EPA model [14]. The ADD for respirable particles can be calculated by the following equation [1]:

$$\boldsymbol{ADD = \frac{C \times IR \times ET \times EF \times ED}{24 * BW * AT}} \quad (1)$$

C is particle concentration (μg/m^3), IR is inhalation rate (m^3/day), ET is exposure time (h/day), EF is exposure frequency (d/year), ED is exposure duration (year) and AT is the average time (day). BW is body weight (kg). The values of C, ET, EF, ED, BW were determined in the sampling campaign and questionnaires; IR and AT were based on exposure handbook of USEPA [14, 15]. IR were at 0.89, 10.1, 12, 16.3, 15.7 and 12.6 m^3/day for (0 - 3 years), (3 -6 years), (6 - 11 years), (11 - 21 years), (21 - 60 years) and (over 60 years), respectively; AT of 25550 days were assumed at 70 year lifetime [14, 15]. From 500 questionaires, ED was at 21.6; 15.6; 13; 12.5; 14.54; 20.95 hours/day; ED was at 3, 6, 11, 21, 60, 65 years and BW was at 10.6, 18.4, 25.4, 45.2, 55.3, 57.8 kg for corresponding age caterogies: (0 - 3 years), (3 - 6 years), (6 - 11 years), (11 – 21 years), (21 - 60 years) and (over 60 years), respectively.

2.5. Data analysis

@Risk software model version 8.0 was used for Monte Carlo simulation with 100.000 trials to minimize the uncertainties in the dose estimation and sensitive analysis to define the influence of input variables. Monte Carlo simulation is a statistical technique by which a quantity is calculated repeatedly, using randomly selected "what-if" scenarios for each calculation in risk assessment. In this study, instead of using single-point value of variables, the parameters such as particle concentrations, body weight, and exposure time are varied randomly with 100,000 values for each variable as inputs for Monte Carlo simulation to obtain a probabilistic model as expected outcomes.

3. RESULTS AND DISCUSSIONS

3.1. Seasonal variation of particles with different sizes

The seasonal variations of particles with different sizes for indoors and outdoors are listed in Figure 1. In winter, the average levels of indoor $PM_{0.1}$, $PM_{0.5}$, $PM_{1,}$ $PM_{2.5}$, PM_{10} and TSP are observed to be 8.08, 20.11, 47.63, 105.85, 135.01 and 143.37 µg/m^3, respectively. Those of outdoor $PM_{0.1}$, $PM_{0.5}$, $PM_{1,}$ $PM_{2.5}$, PM_{10} and TSP are seen to be 8.74, 21.67, 50.74, 117.87, 173.95 and 204.54 µg/m^3, respectively. In winter, the values of $PM_{2.5}$ in indoors and outdoors exceed the daily limit recommended by WHO of 25 µg/m^3 more than 4 folds, whilst those of PM_{10} exceed the WHO recommended values of 50 µg/m^3 daily from 3 to 5.5 folds. It is noted that there are no guidelines for indoor air in Viet Nam. In summer, the average mass concentrations of indoor $PM_{0.1}$, $PM_{0.5}$, $PM_{1,}$ $PM_{2.5}$, PM_{10} and TSP are 6.95, 13.03, 26.83, 43.38, 59.27 and 65.92 µg/m^3, respectively, whereas, those of outdoor $PM_{0.1}$, $PM_{0.5}$, $PM_{1,}$ $PM_{2.5}$, PM_{10} and TSP are 5.28, 10.43, 21.10, 43.30, 69.16 and 83.31 µg/m^3, respectively. The concentrations of $PM_{2.5}$ and PM_{10} are higher than WHO values in both indoor and outdoor samples. As interpreted, the daily mass concentrations of $PM_{0.1}$ in winter is negligibly higher than those in summer, whereas, the those of $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_{10} and TPS in winter are much higher than those in summer for both indoor and outdoor air. It can be explained that Ha Noi is strongly influenced by the North and Norther-East monsoon, which can bring dust pollution from long-range transport form Northern China Island during winter. In contrast, southeasterly winds blow towards to the Sea or to the North and frequent rains can wash out the particulate matter pollutants in summer. However, it is likely that the $PM_{0.1}$ seems to be negligible change. High fluctuations of fine particles ($PM_{1,}$ $PM_{2.5}$) and coarse particles (PM_{10} and TSP) are seen during two seasons. The seasonal stability of $PM_{0.1}$ (NP) can be due to removal mechanism of NPs, which can be the diffusion to the earth's surface, or diffusing and agglomerating with larger particles or growing out of NP size range through condensation of gases [16]. In addition, the higher concentrations of fine particles ($PM_{0.5}$, PM_1, $PM_{2.5}$) and coarse particles (PM_{10}, TSP) are observed in outdoors in comparison with those in indoors in winter. The concentrations of NP and fine particles in indoor are higher than in outdoor, whereas, only concentrations of coarse particles increase in outdoor in summer. The indoor PM concentrations are enriched in both seasons, which is attributable to indoor activities such as cooking, smoking and cleaning activities that can elevate the indoor fine particles [7 - 9], whereas resuspensions of coarse particles are contributed by occupant's moving and sweeping [11, 13]. It is fact that the investigated apartment often uses gas for cooking and microwave for heating foods daily. Smoking behavior can also be explained for increased indoor PM concentrations. Besides, the concentrations of indoor particles with different sizes are strongly influenced by outdoor particles. Higher outdoor levels are corresponding to the increased indoor particles. The causes may be due to penetrate through building gaps from ambient air and infiltrate from ventilation

systems.

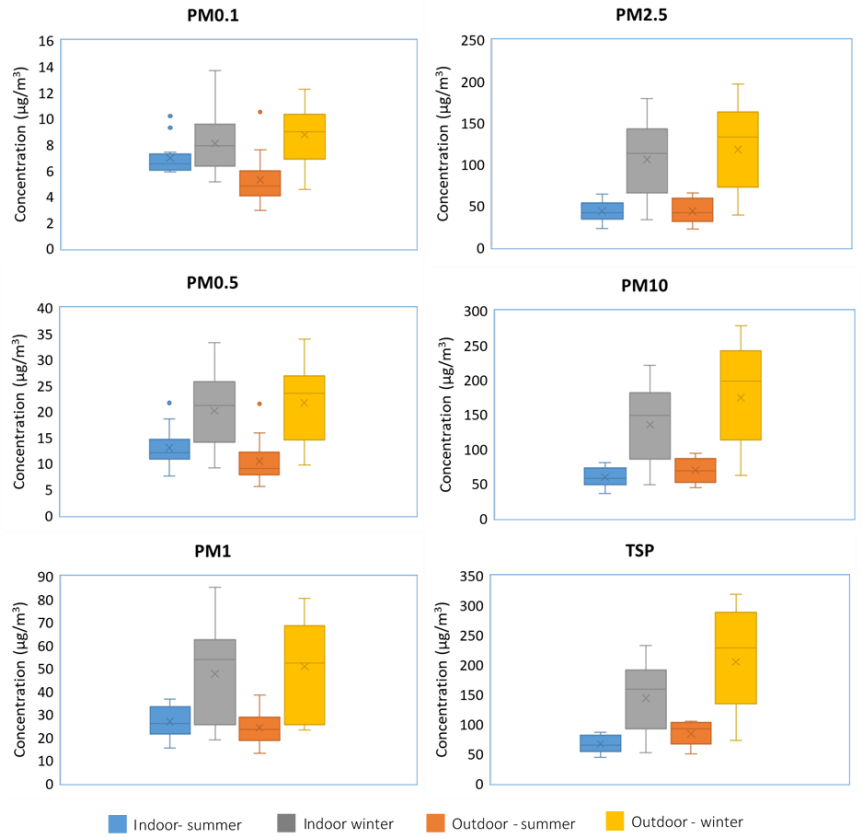

Figure 1. Seasonal variations of concentrations of $PM_{0.1}$; $PM_{0.5}$; PM_1; $PM_{2.5}$; PM_{10} and TSP in indoors and outdoors

3.2. Particle mass size distribution

There are positive correlations among different size fractions (NP; $PM_{0.1\text{-}0.5}$; $PM_{0.5\text{-}1}$; $PM_{1\text{-}2.5}$; $PM_{2.5\text{-}10}$, $PM_{>10}$) indoors and outdoors. The similar trend of correlations among different sizes was observed in indoor and outdoor. There are very good correlations between fine particles ($PM_{0.1\text{-}0.5}$, $PM_{0.5\text{-}1}$; $PM_{1\text{-}2.5}$) and coarse particles ($PM_{2.5\text{-}10}$, PM_{10}) with correlation coefficients in range of 0.81 to 0.93. It may be attributable that these airborne particles may be derived from the same sources. The lower correlation coefficients of NP with higher size fractions are also seen in comparison with those of other size fractions in indoor and outdoor samples, respectively. It can be suggested that the origin of $PM_{0.1}$ may be somewhat unlike to the sources of other particles. The contribution of NP on other different sizes are also investigated in this study. The indoor NP contributes on 55 %, 42 % in $PM_{0.5}$; 27 %, 19 % in PM_1; 17 %, 8 % in $PM_{2.5}$; 12 %, 7 % in PM_{10}, 11 %, 6 % in TSP whilst, average outdoor NP contributes on 51 %, 42 % in $PM_{0.5}$; 22 %, 19 % in PM_1; 12 %, 8 % in $PM_{2.5}$; 8 %, 5 % in PM_{10}, 6 %, 8 % in TSP in summer and winter, respectively. It is a fact that, the proportions of NP contribution on other different sizes are lessen with increased particle sizes. The same trend on the NP's contributions on other sizes is observed in indoor and outdoor samples. In the summer, proportions of NP contributions on other different sizers are higher than those in winter and proportions of indoor

NP increase in comparison with those in outdoor NP. It may be understood that, indoor sources such as cooking, smoking, cleaning activities can release more NP, that were reported in previous studies [8, 11, 12]. The higher indoor proportions of coarse particles are explained by occupants' activities contributing mainly by the resuspension [11, 13]. The average contributions of fine particles ($PM_{2.5}$) to coarse particles (PM_{10}) in indoors are about 73.14 % and 74.08 %, those in outdoors are 57.56 % and 61.85 % during winter and summer, respectively. Thus, fine particles ($PM_{2.5}$) accounts for the major proportions of indoor PM_{10} mass concentrations, and higher contributions of indoor fine particles on coarse particles are found in comparison with those of outdoor particles, that are agreed with previous study [11].

3.3. Correlation of particles concentrations with outdoor meteorological factor

The outdoor meteorological factors are examined in this study including precipitation (Pr), wind speed (Ws), temperature (T), relative humidity (RH). The inter correlations between PM concentrations and outdoor meteorological factors are shown in Table 1.

Table 1. Correlation between mass concentrations of PM and outdoor meteorological factors.

	Indoor				Outdoor			
	Pr	RH	T	Ws	Pr	RH	T	Ws
$PM_{0.1}$	-0.22	-0.22	-0.22	-0.42	-0.29	-0.32	-0.33	-0.58
$PM_{0.5}$	-0.23	-0.26	-0.22	-0.52	-0.27	-0.4	-0.38	-0.64
PM_1	-0.22	-0.26	-0.24	-0.6	-0.24	-0.42	-0.32	-0.65
$PM_{2.5}$	-0.24	-0.14	-0.37	-0.59	-0.24	-0.19	-0.42	-0.65
PM_{10}	-0.25	-0.16	-0.36	-0.5	-0.27	-0.2	-0.39	-0.67
TSP	-0.26	-0.17	-0.36	-0.6	-0.28	-0.22	-0.38	-0.67

The negative correlations between Ws and Pr and mass concentration suggest that increasing of wind speed and rainfall can decrease the mass concentration of particles with different sizes. Strong wind generally blows out the pollutants, leading to reduce the level of PM in ambient air and indoor air. Besides, precipitation also plays an important role in washing of pollutants from the atmosphere. The concentrations of particles vary significantly in rainy and windy conditions, which presents in Table 2. In winter, the concentrations of $PM_{0.5}$, PM_1, $PM_{2.5}$ PM_{10} and TSP decrease substantially in days with rain and wind (Ws > 3 m/s) in comparison with those in days with no-rain and calm wind (Ws < 1 m/s), whilst the negligible difference on NP concentration is observed in two periods in indoors and outdoors, respectively. The somehow different trend is found in summer. In days with rain and wind (Ws > 3 m/s), the levels of NP, $PM_{0.5}$, PM_1, $PM_{2.5}$ and PM_{10}, TSP are lower than those in days with no rain and wind (Ws > 2 m/s) and those in days with scattering rain and calm wind (Ws < 1 m/s). Weak correlations are also found in between RH and T with PM concentrations. Negative correlations with these parameters indicate their inverse relationship. As RH increases, the PM concentrations are decreasing. As increased outdoor humidity is associated with rainy days, which may wash out or absorb pollutants and lower the outdoor concentration, consequently, decreasing indoor PM concentration from filtration and infiltration. Apart from this, outdoor high relative humidity can cause growth of atmospheric particles, then, agglomerate the smaller particles to larger size, enhancing their deposition [17]. Like humidity, low temperature can lower height mixing, which obstructs on dispersion, leading to increasing the PM accumulation whereas low temperature is not comfortable to force air out of building [18]. These inter correlations between fine particles ($PM_{1,}$ $PM_{2.5}$), coarse particles ($PM_{10,}$ TSP) and meteorological factors in this study are consistent with previous findings [17, 18].

Table 2. Seasonal indoor and outdoor concentrations of PM with different sizes (μg/m^3).

			$PM_{0.1}$	$PM_{0.5}$	PM_1	$PM_{2.5}$	PM_{10}	TSP
(Rainy & windy) (Ws ≥ 3 m/s) *(n = 4)*	Winter	Indoor	6.57	14.43	31.19	61.64	79.27	78.82
		Outdoor	7.98	17.10	34.61	69.67	101.25	119.37
No rainy & calm wind (Ws < 1m/s) (*n = 9)*		Indoor	8.75	22.64	54.93	125.50	159.78	160.38
		Outdoor	9.08	23.70	57.91	139.29	206.26	242.35
Rainy &windy) (Ws > 3 m/s) (*n = 4)*	Summer	Indoor	5.94	9.68	19.85	31.47	43.78	49.56
		Outdoor	3.56	7.18	17.56	31.33	51.10	62.23
No rainy & windy (Ws > 2 m/s) *(n = 6)*		Indoor	7.33	14.24	28.60	43.86	61.39	85.58
		Outdoor	6.24	11.91	25.83	42.19	71.91	87.76
Scattering rain& calm wind (Ws < 1 m/s) (n = 3)		Indoor	7.51	15.06	32.61	58.31	75.67	82.10
		Outdoor	5.65	11.82	29.34	61.46	87.72	102.53

3.4. The relationship of indoor and outdoor PM concentrations with different size fractions

Generally, the I/O ratios and regression lines were used to evaluate the I/O relationships of particles with different sizes in winter and summer. The Table 3 describes the I/O values and regression equation for indoor and outdoor PM. It is found that, I/O ratio ranges from 0.53 to 0.96 in winter and 0.63 to 1.4 in summer. Higher I/O ratios are observed in NP and fine particles indicating additional sources in indoor environment. In addition, NP and fine particles show higher I/O ratios than coarse particles suggesting more effective infiltration of fine particles than coarse particles from outdoors into the apartment that are consistent with the homes in India [19]. In general, the outdoor particles with different sizes can enter the indoor air in two ways. One is via direct penetration through gaps in the buildings between indoors and outdoors, and the other way is via access through the ventilation system. These findings imply that the indoor NP, fine particles are greatly influenced by indoor sources in summer, whereas, the indoor coarser particles ($PM_{2.5-10}$, $PM_{>10,}$ PM_{10}, TSP) are strongly influenced from outdoor sources in two seasons. The indoor sources could be seen in residential apartments such as daily cooking activities, cleaning action, electronic equipment usage, tobacco smoking, moving actions etc. Outdoor sources may include traffic emissions, industrial and construction activities, etc. In this study, levels of indoor NP and fine particles are transiently higher than outdoors, which were similar in previous publications in the schools and residential homes [11, 19]. Otherwise, our I/O values are in good agreement with the other studies [11, 12, 20]. These indicate that the high concentration of indoor particles with different sizes can be attributable to outdoor sources and indoor activities. Strong correlations of indoor and outdoor particles with different fractions are also observed in our study, except for $PM_{>10}$. The high values of correlation coefficients imply that the particles with different sizes in indoors and outdoors can be derived from the same sources.

The similar results also are recorded and infiltration factors are presented in Table 3. There is a negligible discrepancy on infiltration factor (F_{in}) for all sizes except for $PM_{0.1}$ between winter and summer. The indoor fraction for small size intervals: 0.1 - 0.5 μm and 0.5 - 1 μm has better infiltration than bigger size intervals: 1 - 2.5 μm and 2.5 - 10 μm. The values of F_{in} ranges from 0.87 to 0.95 in small intervals and those vary from 0.48 to 0.84 in bigger size intervals in winter, whereas F_{in} values range from 0.92 to 0.99 in smaller particles and from 0.42 to 0.66 in bigger particles in summer, respectively. The results imply that infiltration of smaller size particles is more effective than the bigger sizes that particles are able to penetrate easily into the indoor environment. The lower infiltration factor of $PM_{0.1}$ in summer can relate with different removal mechanism and mechanical ventilation. During summer, the apartment was

mechanically ventilated by using air conditioning and keeping the doors and windows closed during sampling period, where acted daily domestic activities (cooking, smoking, cleaning etc.) as indoor sources and increased occupant's' activities in summer holidays. Whereas, in winters, doors/windows are opened more often, that increase natural ventilation system, suggesting the strength of outdoor sources. These findings strongly agree with previous researches [12, 13].

Table 3. Indoor/Outdoor relationships of particles with different sizes in sampling campaign.

	Winter				Summer			
	Regression equation (n = 13)	r	I/O	Fin	Regression equation (n = 13)	r	I/O	Fin
$PM_{0.1}$	$C_{in} = 0.05 + 0.92 \times C_{out}$	0.79	0.93	0.92	$C_{in} = 3.6 + 0.64 \times C_{out}$	0.9	1.4	0.64
$PM_{0.1-0.5}$	$C_{in} = 1.72 + 0.87 \times C_{out}$	0.82	0.93	0.87	$C_{in} = 0.99 + 0.99 \times C_{out}$	0.85	1.2	0.99
$PM_{0.5-1}$	$C_{in} = 1.59 + 0.89 \times C_{out}$	0.9	0.96	0.89	$C_{in} = 1.3 + 0.92 \times C_{out}$	0.7	1.02	0.92
$PM_{1-2.5}$	$C_{in} = 1.49 + 0.84 \times C_{out}$	0.97	0.87	0.84	$C_{in} = 3.8 + 0.66 \times C_{out}$	0.8	0.9	0.66
$PM_{2.5-10}$	$C_{in} = 2.64 + 0.48 \times C_{out}$	0.95	0.53	0.48	$C_{out} = 4.9 + 0.42 \times C_{out}$	0.76	0.63	0.42
$PM_{0.5}$	$C_{in} = -0.53 + 0.95 \times C_{out}$	0.9	0.93	0.95	$C_{in} = 4.5 + 0.86 \times C_{out}$	0.95	1.29	0.86
PM_{1}	$C_{in} = 0.86 + 0.92 \times C_{out}$	0.91	0.94	0.99	$C_{in} = 4.8 + 0.91 \times C_{out}$	0.88	1.13	0.8
$PM_{2.5}$	$C_{in} = -2 + 0.92 \times C_{out}$	0.97	0.9	0.92	$C_{in} = 8.5 + 0.8 \times C_{out}$	0.89	1.02	0.8
PM_{10}	$C_{in} = -1.32 + 0.78 \times C_{out}$	0.98	0.78	0.78	$C_{in} = 7.2 + 0.75 \times C_{out}$	0.89	0.86	0.75
TSP	$C_{in} = 2.2 + 0.69 \times C_{out}$	0.98	0.71	0.69	$C_{in} = 7.17 + 0.7 \times C_{out}$	0.84	0.8	0.7

Note: r: correlation coefficient;I/O: ratios of concentration of indoor PM to outdoor PM;F_{in}: Infiltration factor.

Table 4. Summary of exposure dose to PM via inhalation derived from the Monte Carlo simulation.

		$PM_{0.1}$	$PM_{0.5}$	PM_{1}	$PM_{2.5}$	PM_{10}
0 - 3 year	5 %	0.14	0.18	0.23	0.48	0.14
	95 %	0.36	0.93	2.23	4.5	6.35
3 - 6 year	5 %	0.13	0.17	0.20	0.45	0.13
	95 %	0.35	0.89	2.19	4.32	6.09
6 - 11 year	5 %	0.17	0.22	0.23	0.66	0.18
	95 %	0.46	1.16	2.82	5.57	7.94
11 - 21 year	5 %	0.18	0.24	0.3	0.54	0.19
	95 %	0.48	1.22	2.95	5.90	8.32
21 - 60 year	5 %	0.49	0.75	0.93	1.97	0.58
	95 %	1.93	4.52	11.44	22.88	31.95
> 60 year	5 %	0.54	0.99	1.27	5.43	0.78
	95 %	1.94	5.12	12.43	24.66	35.18

Furthermore, indoor-generated particle concentrations (C_s) are also estimated from the regression lines. During the winter and summer, the concentrations of indoor generated particles with all size are positive, except for $PM_{2.5}$ and PM_{10} in winter. The values of C_s are negative might be attributed to some species' decomposition in indoor $PM_{2.5}$ and PM_{10}. The contributions of indoor sources on particle with different sizes are not same in two seasons. The proportions of contribution are 0.5 % and 51.85 % for $PM_{0.1}$; 2.48 % and 34.54 % for $PM_{0.5}$; 1.81 % and

1.68 % for PM_1 whistle those are 1.53 % and 10.88 % for TSP in winter and summer, respectively. Indoor generated particles in summer are prevailing than in winter. It should be noted that during summer, windows/doors were kept closed during campaign, causing to prevent the air exchange between indoor and outdoor. In addition, more indoor activities are attributable to accumulate particles with different sizes in the residential apartment, which are consistent with the previous studies in which particles could be originated sharply from indoor activities (food cooking, smoking or cleaning acitivities) [8, 9, 12].

3.5. Estimation of exposure dose by particle with different sizes

In this study, the daily doses (ADD) estimated basing upon the levels of particles with different sizes in a residential aparment are shown in the Table 4. It is found that the daily dose increases with the increasing size of particles for all age caterogies. There are neligible disimilarities on daily dose intake among (0 - 3 years) and (3 - 6 years); among (6 - 11 years) and (11 - 21 years); among (21 - 60 years) and (over 60 years). However, significant differences on daily doses are observed between age groups (from birth to 21 years) with age group (over 21 years) ($P < 0.05$). The mean $PM_{0.1}$ inhalation doses are seen at 0.24, 0.23, 0.3, 0.32, 1.03 and 1.32 µg/kg.day, respectively; those of $PM_{0.5}$ are 0.54, 0.51, 0.67, 0.71, 2.47 and 2.98 µg/kg.day, respectively; those of PM_1 was 1.22, 1.13, 1.48, 1.58, 5.08 and 6.64 µg/kg.day, respectively; those of $PM_{2.5}$ are 2.44, 2.27, 2.97, 3.18, 10.22 and 13.55 µg/kg.day, respectively; those of PM_{10} are 3.15, 2.95, 3.87, 4.13, 13.26 and 17.44 µg/kg.day for age caterogies: 0 - 3 years, 3 - 6 years, 6 - 11 years, 11 - 21 years, 21 - 60 years and over 60 years, respectively. These results are partly consistent with previous study in Poland, in which the PM daily dose for children and adults varied from 1.8 to 6.7 µg/kg.day in the sport facilities [7]. The sensitive group (0-3 year) exposes the lowest dose, whereas the sensitive group (over 60 years) suffers the highest dose. These different doses are due to the differences on inhalation rate, exposure time, exposure duration, body weight among the age caterogies. The inhalation doses of PM_{10} are the highest, those of NP are the lowest.

The application of Monte Carlo simulations are applied to avoid the uncertanties in calculation. In this part, some single point value of input variables vary random with 100.000 trials for simulation using @Risk model version 8.0. The sensitive analysis also is conducted to define the influence of input variables to the outcomes basing on the rank correlation coefficients. The simulation results show that probability of daily inhalation doses by NP and $PM_{0.5}$ are relatively lower in the indoor environment in comparison with fine particle (PM_1, $PM_{2.5}$) and coarse particle (PM_{10}). The results of simulation for all fractions are summarized in Table 4. Taking of 95^{th} percentage, dose values range from 0.35 to 1.94 µg/kg.day for $PM_{0.1}$; 0.89 to 5.12 µg/kg.day for $PM_{0.5}$; 2.19 to 12.43 µg/kg.day for PM_1; 4.32 to 24.66 µg/kg.day for $PM_{2.5}$ and 6.09 to 35.18 µg/kg.day for PM_{10}, respectively for corresponding age caterogies. The rank correlation coefficients of input variable of PM concentration range from 0.67 to 0.91, meaning that the PM concentration influenced the most the inhalation dose for indoor air in comparson with ET and BW. The coefficients of ET vary from 0.006 to 0.26. Besides, values of BW present negative correlation with dose, ranging from 0.006 to 0.06, while other factors are ignored of the influences. These findings in study are consistent with previous publication [11]. The limitations of this study are likely that the small number of samples and the assumptions contained in US EPA methodology to estimate dose for protecting the human health can underestimate exposure dose. However, to minimize the uncertainties in the outcomes associated with health risk assesment, this study has applied Monte Carlos simulation and obtained a probabilistic model, which has been widely used in the previous study [11]. Notwithstanding

these limations, this study offers valuable insighs into exposure dose esimation associated with the indoor particles with different sizes.

4. CONCLUSIONS

This is first study on seasonal variation on mass concentration of particles with different sizes and inhalation dose estimation in a typical residential apartment in Ha Noi, Viet Nam, which can provide insight into the context of indoor air quality in Ha Noi. High concentrations of $PM_{0.1,}$ $PM_{0.5}$, PM_1, $PM_{2.5}$ and PM_{10} are found in both seasons. The mean concentrations of PM vary from 8.08 to 143.37 µg/m^3 in indoor and 8.74 to 204.54 µg/m^3 in outdoor in winter, whereas, those range from 6.95 to 65.9 µg/m^3 in indoor and 5.28 to 83.31 µg/m^3 in outdoor in summer. The sustainable variations on mass concentration of $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_{10} and TSP are observed, except for NP by the season. The results obtained suggested that outdoor sources as well as indoor activities influence on the concentrations of particles with different sizes, especially in NP during two seasons. Our results for $PM_{2.5}$ and PM_{10} in indoors and outdoors exceeded the WHO standards, whereas, the standards for NP, $PM_{0.5}$, PM_1 have not been proposed by any agencies. The concentrations of fine particles and coarse particles decrease significantly in rainy&windy days, except for NP in two seasons. For instances, the concentrations of PM_1, $PM_{2.5}$, PM_{10}, TSP in rainy&windy days (Ws>3 m/s) decrease in approximately 50 % in winter, in comparison with those in no rainy& calm windy days (Ws < 1 m/s) in the winter. Otherwise, those in rainy&windy days (Ws > 3 m/s) decrease in approximately 40 % in summer. The indoor fraction for small size intervals has better infiltration than bigger sizer intervals. The filtration factors increased during winter in comparison with summer for all sizes. The higher infiltration is found for NP, fine particles in comparison with coarse particles in winter and the same trend is also seen in summer except for NP. The sensitive groups comprise (0-3 year) and (over 60 years) expose the lowest to highest dose, implying great potential health risk assocated with particulate matter in indoor environment.

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