FINE AND ULTRAFINE PARTICLE CONCENTRATIONS AT HANOI PRIMARY SCHOOLS

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Abstract: *Epidemiological studies have consistently shown that fine ($PM_{2,5}$ and PM_{10}) and ultrafine (UF) particles measured in terms of particle number (PN) concentrations are toxic to human health, especially to children, who are easier exposed to these pollutants. Studies on particle concentrations at primary schools have attracted worldwide scientists' attention. However, there is no related article in Vietnam published yet. Using two sets of instruments, the authors, for the first time, have simultaneously and continuously measured concentrations of UF, $PM_{2,5}$, and PM_{10} both indoor and outdoor of classrooms at ten Hanoi primary schools in order to quantify and primarily evaluate factors that affect particle concentrations. Mean concentrations of indoor and outdoor UF particles were 3846-8709 particle/cm^3 and 8519-33624 particle/cm^3, respectively. Mean indoor and outdoor $PM_{2,5}$ concentrations were 71-173 μg/m^3 and 80-355 μg/m^3, respectively; While average indoor and outdoor PM_{10} concentrations ranged from 81-188 μg/m^3 and 99-410 μg/m^3, respectively. Statistical analysis showed that indoor UF particle concentrations were strongly influenced by high outdoor vehicle PN sources, while indoor $PM_{2,5}$ and PM_{10} levels were influenced by both outdoor sources and indoor primary school students' activities.*

Keywords: *Ultrafine particle, fine particle $PM_{2,5}$ and PM_{10}.*

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1. Introduction

Recent epidemiological studies have consistently shown the relation between fine particle concentrations (presented by mass concentrations of $PM_{2.5}$ and PM_{10}) and increase in both morbidity and mortality in respiratory and cardiovascular [1-5]. Health effects of ultrafine (UF) particles (measured by number of particles in 1 cm^3 of air) are less well known, however, research to date indicates that they may be equally or even more dangerous than those of $PM_{2.5}$ and PM_{10} [6-9].

Air quality, specially fine and ultrafine particles at primary schools have drawn the interest of the scientists due to the fact that primary school pupils usually spend a long day time at school (up to 10 hours per day), and they are also very sensitive and easier influenced by air pollutants compared to adults [10]. Numerous of studies on fine and ultrafine particles at primary schools have been conducted worldwide [11-17].

Due to economic development and uncontrolled urbanization process, air pollution situation in major cities in Vietnam, such as Hanoi, Hochiminh city is increasing [18]. However, research on air pollutants in general, particles in particular is limited. Especially, no study on particle pollution at primary schools has been published yet in Vietnam. From this point of view, the study aims to quantify and primarily evaluate factors influenced fine and UF particle concentrations indoor and outdoor classrooms at primary schools in Hanoi.

2. Methods

2.1 Sample sites

Ten primary schools in Hanoi urban districts were participated in the study and coded as TH1 to TH10. Their locations were selected how to present various outdoor air pollution sources. Some are close to busy streets/roads. Some locate in residential areas with low traffic situation, and one is surrounded by

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construction sites. Selected sampled classrooms have different ventilation conditions, with number of pupils about 50 at each class. Detail information of school locations and their classroom conditions are presented in Table 1 and Fig. 1.

Table 1. *Location characteristics of selected primary schools and their classrooms' ventilation conditions*

No	Code	School location characteristic	Classroom ventilation condition
1	TH1	Closed to high traffic street, far from city center	Using air conditioners with sliding aluminium glass windows
2	TH2	Closed to a low traffic street, far from city center	Using air conditioners with sliding aluminium glass windows
3	TH3	Closed to a high traffic street, far from city center	Using ceiling fans with traditional wood windows
4	TH4	Closed to a high traffic street, in city center	Using air conditioners with sliding aluminium glass windows
5	TH5	Closed to a high traffic street, in city center	Using ceiling fans with traditional wood windows
6	TH6	Closed to a low traffic street, in city center	Using ceiling fans with traditional wood windows
7	TH7	Closed to a high traffic street, in city center	Using air conditioners with sliding aluminium glass windows
8	TH8	In the residential area at city center	Using ceiling fans with traditional wood windows
9	TH9	Far from city center and surrounding by construction sites	Using ceiling fans with traditional wood windows
10	TH10	Closed to a low trafic street, far from city center	Using ceiling fans with traditional wood windows

2.2 Instruments and sampling procedures

Two sets of instruments, consisting of P-TRAK™ model 8525 and DUSTTRAK™ Aerosol Monitor Model 8520 (TSI-USA) were used to continuously measure UF particle number concentrations in the range 20-2000 nm and fine particle concentrations (PM_{10} and $PM_{2.5}$), respectively. Both instruments were setting up log interval of 1 minute.

One set of instruments was used to measure particle concentrations inside classrooms. These instruments were located on student desks, how to equal to the breath level of pupils when they sit down. Pupils nearby the instruments were requested to keep a distance and do not touch the instruments during their operation.

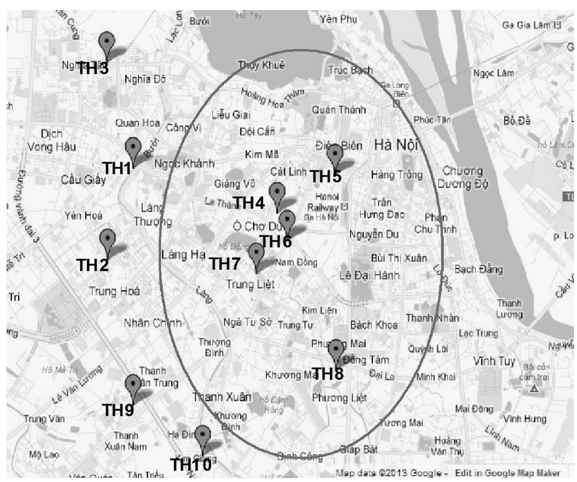

Figure 1. *Locations of TH1 - TH10 primary schools*

The other set of instrument were located at the front of the relevant school gate to simultaneously measure outdoor particle concentrations. The instruments were setting up at the height of 1.2 m, where equal to the breath level when pupils stand.

All instruments were calibrated by putting together to measure at a same sample before starting the camping. Then correlation between data sets of the pair instruments was set up for their data calibration after each school measurement.

Measuring periods were performed from 19/3/2013 to 11/4/2013. Sampling was conducted on one day from 9h to 12h or 14h to 17h for each school.

2.3 Data analysis

Data from each instrument was downloaded after each measuring period for each school, and then was calibrated for data quality control. Statistical analysis (including Student_test and One_way Anova) was performed with SPSS version 20 with a 5% level of significance.

3. Results and discussion

3.1 PM_{10} concentrations at outdoor and indoor Hanoi primary schools

Overall indoor and outdoor PM_{10} concentrations and their indoor and outdoor ratios (I/O) at ten primary schools in Hanoi are presented in Table 2. Mean indoor PM_{10} concentrations ranged from 81±8 to 188±52 μg/m^3. While average outdoor PM_{10} concentrations were from 99±19 to 410±53 μg/m^3. These concentrations were significantly higher than those regulated on the standards [10,19].

Mean outdoor PM_{10} concentration at school TH7 was highest compared to other schools. It could be understood as their outdoor samples were taken in the late afternoon (15h30 to 17h30) and closed to the very busy street. While the second highest concentrations at schools TH9 were able to influenced by surrounding construction sites. In contrast, the lowest PM_{10} concentrations at school TH2 was due to its location in the low traffic density area.

I/O ratios of PM_{10} concentrations were lower than 1 at almost schools. Especially, I/O ratios at school TH7 was lowest (0.33±0.05). Tightly closed sliding aluminum glass window to avoid outside noise during the measurement can explained for that. While mean I/O ratio at school TH8 was highest (1.47±0.46). The siginificant higher of indoor PM_{10} concentrations compared to those outside in this school could be greatly affected by the pupils' indoor activities during their art lesson.

Table 2. *PM_{10} concentrations (μg/m^3) at Hanoi primary schools*

School	TH1			TH2			TH3			TH4			TH5		
	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O
Mean	170	215	0.79	81	99	0.81	106	142	0.75	177	230	0.87	130	195	0.69
SD	15	12	0.08	8	19	0.13	11	13	0.12	21	106	0.31	9	28	0.12
Max	197	265	0.93	103	189	1.11	139	172	1.00	286	739	1.59	167	288	1.01
Min	147	194	0.57	68	77	0.42	86	115	0.54	148	133	0.23	118	154	0.42

School	TH6			TH7			TH8			TH9			TH10		
	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O
Mean	146	183	0.85	133	410	0.33	188	145	1.47	143	250	0.73	169	188	0.90
SD	13	27	0.15	16	53	0.05	52	39	0.46	19	124	0.32	13	28	0.15
Max	187	283	1.12	194	628	0.48	327	332	2.27	210	718	1.42	231	255	1.26
Min	118	137	0.51	113	328	0.23	113	108	0.44	117	116	0.21	149	132	0.63

3.2 $PM_{2.5}$ concentrations at outdoor and indoor Hanoi primary schools

Indoor and outdoor, and their I/O ratios of $PM_{2.5}$ concentrations at Hanoi primary schools are presented in Table 3. Mean indoor and outdoor $PM_{2.5}$ concentrations ranged from 71±4 μg/m^3 to 173±19 μg/m^3 and 80±4 μg/m^3 to 355±29 μg/m^3, respectively. $PM_{2.5}$ concentrations in our study were significantly higher than those at classrooms in Brisbane, Australia, where mean indoor and outdoor $PM_{2.5}$ were 6.7±0.2 μg/m^3 and 11.6 ±0.8 μg/m^3, respectively [20], as well as at classrooms in Southern of Texas, US with mean indoor and outdoor $PM_{2.5}$ concentrations were from 2.8±1.8 μg/m^3 to 7.8±1.3 μg/m^3 and from 2.7±1.3 μg/m^3 to 23.2±1.3 μg/m^3, respectively [17]. Compared to Hanoi ambient $PM_{2.5}$ (66±22 μg/m^3) [21], the mean outdoor $PM_{2.5}$ at all primary schools were also significantly higher.

I/O ratios of $PM_{2.5}$ concentrations at schools TH1, TH2, TH3, TH5, TH6, TH7, TH9 were lower than 1. As mentioned earlier, tightly closed classroom windows at school TH7 led to lowest I/O ratio (0.31±0.03). In contrast, mean I/O ratios at schools TH4, TH8, TH10 were higher than 1. Indoor students' activities may contribute to $PM_{2.5}$ concentrations as reviewed [13].

Table 3. *$PM_{2.5}$ concentrations (μg/m³) at Hanoi primary schools*

School	TH1			TH2			TH3			TH4			TH5		
	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O
Mean	173	213	0.82	71	80	0.88	97	137	0.71	159	164	1.04	132	195	0.68
SD	19	11	0.11	4	4	0.06	3	15	0.08	13	65	0.22	3	22	0.07
Max	218	280	1.04	77	96	0.97	105	170	0.84	177	602	1.34	141	276	0.84
Min	151	201	0.57	61	71	0.73	89	116	0.57	139	124	0.28	124	156	0.47
School	TH6			TH7			TH8			TH9			TH10		
	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O
Mean	144	159	0.95	111	355	0.31	143	123	1.20	139	171	0.94	142	141	1.02
SD	15	24	0.18	10	29	0.03	26	24	0.23	16	92	0.23	7	17	0.14
Max	166	285	1.25	143	450	0.36	190	299	1.64	221	713	1.35	160	201	1.32
Min	121	128	0.47	99	318	0.23	108	100	0.50	121	117	0.19	134	115	0.70

3.3 UF particle number concentrations at outdoor and indoor Hanoi primary schools

Table 4 presents indoor and outdoor, and their I/O ratios of UF particle number concentrations at Hanoi primary schools. Mean outdoor UF particle number concentrations at Hanoi primary schools ranged from 8519±3644 to 33624±10939 particle/cm³. The concentrations were relevant to those measured in developed countries schools, such as in Canada from 13000 to 14900 particle/cm³ [16], in California and Texas, US from 9000 to 26000 particle/cm³ [15] and 3400 to 9400 particle/cm³ [17], respectively. Outdoor school UF particle number concentrations were not significantly different compared to those measured outside households located in the Hanoi urban center; however, they were lower than those measured at the households closed to the ring roads or highway in Hanoi [21].

Mean indoor UF particle number concentrations in Hanoi primary schools were from 3846±834 to 8709±943 particle/cm³. The concentrations were similar to those reported in developed countries. Fromme, et al. measures UF particle number concentrations in 75 classrooms in Munich, Germany, their concentrations ranged from 2600 to 12100 particle/cm³ [11]. UF particle number concentrations inside classrooms in Canada were from 4600 to 5400 particle/cm³ [16]. Guo et al. repeated indoor UF particle number concentrations at one primary school in Queensland, Australia from 2100 to 2900 particle/cm³ [12]. Average UF particle number concentrations in six classrooms in Northern California, US were from 5200 to 16500 particle/cm³ [15]. Zhang and Zhu reported UF particle number concentrations in five classrooms in the Southern Texas, US ranged from 1600 to 16000 particle/cm³ [17].

Table 4. *PN concentrations (particle/cm³) at Hanoi primary schools*

School	TH1			TH2			TH3			TH4			TH5		
	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O
Mean	8401	23087	0.42	4005	7065	0.62	8709	25558	0.60	5435	15177	0.38	7505	13194	0.59
SD	1437	11903	0.15	412	1845	0.16	943	13446	0.56	511	4052	0.10	894	2431	0.12
Max	11841	60113	0.81	5044	13705	1.06	11070	51595	2.28	6665	26731	0.67	9236	20026	0.99
Min	6251	11493	0.14	3335	4502	0.34	6928	4848	0.17	4492	7996	0.18	5892	9069	0.34
School	TH6			TH7			TH8			TH9			TH10		
	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O	In	Out	I/O
Mean	5456	12915	0.45	7487	33624	0.18	4997	13362	0.48	4780	19256	0.27	3846	8519	0.41
SD	526	2879	0.13	3111	10,939	0.07	880	5157	0.28	1212	6244	0.09	834	3644	0.17
Max	6434	20096	0.86	14508	59,393	0.36	6490	23526	1.55	11218	32688	0.45	6400	13462	0.66
Min	4496	7462	0.26	4645	13,773	0.09	3241	3571	0.18	3369	11085	0.13	2765	4195	0.24

In general, mean outdoor UF particle number concentrations at primary schools closed to busy treets (TH1, TH7), or nearby construction site (TH9) were significantly higher than those nearby low trafic streets (TH6, TH10), or within residential areas (TH8). In additional, I/O ratios of UF particle number concentrations at schools were significantly lower than 1. It means that outdoor particle number concentrations at primary schools were strongly influenced by vehicle emissions as denoted by previous research [22-25].

4. Conclusions

For the first time, both indoor and outdoor ultrafine and fine particle concentrations at 10 Hanoi primary schools were quantified and their influenced factors were primarily evaluated. Indoor ultrafine particle concentrations were strongly influenced by outdoor sources. While fine particle concentrations were effected not only by outdoor sources but also from indoor student activities. Both indoor and outdoor ultrafine particle concentrations at Hanoi primary schools were relevant to those at primary schools in developed counties. While their fine particle concentrations were significantly higher than those in developed countries. As denoted in [21], this study also find that the ultrafine and fine particle concentrations in Hanoi are not consistently correlated. Therefore, it is recommended to continue the monitoring of UFPs and related pollutants (e.g., $PM_{2.5}$, CO) to better characterize air quality trends and potential exposures, and consequently to separate the effects of ultrafine particles from those of $PM_{2.5}$. It is noted that the findings of this study were based on short term monitoring and should be extended to confirm all the hypotheses.

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