

The Contribution of Outdoor Fine Particulate Matter to Indoor Air Quality in Bangkok Metropolitan Region, Thailand – Are Indoor Dwellers Safe?

Mongkhon Sompornrattanaphan, M.D.*, Torpong Thongngarm, M.D. *, Pongsakorn Tantilipikorn, M.D., Ph.D.**, Piyawut Kreetapirom, M.D.***, Johnson Foo, B.E.****

*Department of Medicine, **Department of Otorhinolaryngology, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok 10700, ***Division of Pediatrics, Chaophya Hospital, Bangkok, Thailand, ****Mechanical Engineer, SD Trading and Distribution PTE., Ltd., Singapore.

ABSTRACT

Objective: This study aimed to analyze the relationship between indoor and outdoor fine particulate matter (PM_{2.5}) concentrations and to characterize factors that may contribute to domestic PM_{2.5} concentrations, including smoking, printer/copier, and cooking activities.

Methods: We measured the ambient and indoor PM_{2.5} concentrations from 7 sampling sites in Bangkok Metropolitan and vicinity area, Thailand by using PM_{2.5} concentrations sensor (SN-GCHA1, Panasonic Photo & Lighting Co., Ltd). Real-time PM_{2.5} concentrations, temperature, and relative humidity (RH) measurements were recorded hourly for two consecutive days during February 20th to March 2nd, 2018. We collected real-time indoor and outdoor PM_{2.5} mass concentrations at the same time. Factors influencing domestic PM_{2.5} production in the indoor environment were recorded.

Results: The mean indoor PM_{2.5} concentrations from each site ranged from 20.05-45.85 µg/m³ and the mean outdoor PM_{2.5} concentrations ranged from 9.42-56.56 µg/m³. The ambient and indoor PM_{2.5} mass concentrations curves tended to fluctuate in a similar trend. There was a significantly positive correlation between the average ambient and the average indoor PM_{2.5} mass concentrations in all studied places. The correlation coefficient (r) varied from 0.6 to 0.833. Five from seven sites demonstrated a strong correlation ($r \geq 0.7$), whereas, two from seven sites demonstrated a moderate correlation ($0.5 \leq r < 0.7$). The average indoor/ambient PM_{2.5} concentration ratio from each place ranged from 0.37 to 3.57.

Conclusion: The indoor PM_{2.5} concentrations are correlated with the ambient PM_{2.5} concentrations. The concentrations of PM_{2.5} in most sampling sites were higher than the recommended threshold. Hence, indoor dwellers are still at risk for health impacts from PM_{2.5}. Besides public management of the ambient PM_{2.5}, the interventions dealing with the indoor PM_{2.5} should be promoted concurrently.

Keywords: Particulate matter; PM_{2.5}; indoor air pollution; allergic rhinitis; asthma (Siriraj Med J 2018;70: 265-271)

INTRODUCTION

With fast urban development and modernization, air pollution is rapidly worsening globally, especially in low- and middle-income countries. Major air pollutants include gaseous pollutants (i.e. O₃, NO₂, SO₂) and particulate matters (i.e. PM₁₀, PM_{2.5}).¹ In Thailand, with growing

number of factories and combustion sources, the population-attributable fraction of the disease burden for all-causes mortality in adults due to PM_{2.5} was one of the highest among all air pollutants up to 7.5%.²

PM_{2.5} is fine particulate matter with aerodynamic diameter less than 2.5 micrometers. The primary

Correspondence to: Mongkhon Sompornrattanaphan

E-mail: mongkhon.som@mahidol.ac.th

Received 11 May 2018 Revised 25 May 2018 Accepted 7 June 2018

doi:10.14456/smj.2018.43

contributors of PM_{2.5} are mainly from the traffic and industry, including fuel combustion from power plant, oil refinery, and automobiles. Due to its small size compared to larger particles, PM_{2.5} can reach the smallest airways and alveoli, causing serious effects on human health.³ Based on numerous epidemiological evidences, PM_{2.5} has been considered as the main culprit of the adverse cardiovascular effects of air pollution on human health. PM_{2.5} exposure was associated with increased risk of incident stroke.⁴ Higher long-term fine particulate matter concentrations are associated with increased carotid intima-media thickness (IMT) progression and that greater reduction in fine particulate matter concentrations are related to slower IMT progression.⁵ Some reports also suggested the potential relationship between air pollution and various cancers. Higher levels of ambient PM_{2.5} concentrations were associated with an increment in lung cancer mortality.⁶ PM_{2.5} concentrations was also correlated with increased risk of mortality for specific cause of cancer in upper digestive tract and in digestive accessory organs.⁷

A number of studies found the relationship of level of PM_{2.5} and allergic disease. In mouse model, mice with allergic rhinitis showed elevated levels of adhesion molecules and inflammatory cytokine expressions as well as nasal remodeling after exposure to PM_{2.5}.^{8,9} PM_{2.5} was found to adjunct the pollen in promoting allergic disease. The higher level of PM_{2.5}, the greater pollen effect was detected.¹⁰ The prevalence of allergic rhinitis was significantly associated with PM_{2.5} concentrations.^{11,12} Furthermore, increase in PM_{2.5} was correlated with emergency room visit due to acute exacerbation and other acute respiratory disease in patients with chronic respiratory disease, especially in children.¹³⁻¹⁵ Hence, management of PM_{2.5} should be considered to be crucial in treatment and prevention of allergic disease.

WHO Air quality guidelines (AQGs) in 2016 recommended the threshold level for PM_{2.5} concentrations at below 10 µg/m³ for annual mean and below 25 µg/m³ for the 24-hour mean. However, no threshold has been identified below which no damage to health is demonstrated. Therefore, the AQGs suggested achieving the lowest concentrations of PM as possible.¹

Most studies are limited only to ambient particulate matter concentrations, while most urban residents spend more than 80% of daily life indoors.¹⁴ Therefore, exposure to airborne particulate matter primarily occurs indoors. As ambient particulate matter penetrates from outdoor environment to indoors through ventilation systems and building leaks, research interest has been focused on the relationship between indoor and outdoor particulate matter

concentrations in various settings. In China, 24-hour real-time indoor and ambient PM_{2.5} concentrations and indoor/ambient PM_{2.5} ratio (I/A ratio) were measured. I/A ratio was used for evaluation of how easy the indoor environment can be influenced by outdoor PM_{2.5} and examined the impacts of indoor sources on indoor PM_{2.5} mass concentrations. Hourly ambient PM_{2.5} concentrations had a median of 58 microgram/m³ while hourly indoor PM_{2.5} had a median of 34 microgram/m³. The median I/A ratio was 0.62.¹³ There was a variation of I/A ratio from different studies. This could be due to the differences in the outdoor pollution, outdoor weather, indoor sources of pollution, the building envelope itself, and the air changes per hour.¹⁶ The I/A ratios for all air pollutants are lowest in buildings with closed windows, compared to ventilated environments.¹⁷

Although in Thailand, especially Bangkok Metropolitan Area, where serious air pollution problems have occurred for decades, no study has been conducted to study the relationship of indoor and ambient air pollution in different ventilation conditions. This study was designed to assess the indoor and ambient fine particulate matter (PM_{2.5}) concentrations in different ventilation conditions (open and closed ventilation systems) in different building categories, i.e. residential houses, hospital, office buildings, condominiums in Bangkok Metropolitan Area. Our objectives were to analyze the relationship between indoor and outdoor PM_{2.5} concentrations and to characterize factors that may contribute to endogenous PM_{2.5} concentrations, including smoking, printer/copier, and cooking activities.

MATERIALS AND METHODS

Sampling sites and sampling period

The study was conducted in 7 sampling sites in Bangkok Metropolitan and vicinity area, Thailand – including Bangkok, Nonthaburi, Nakhon Pathom, Samutprakarn provinces (Fig 1). Sampling sites were divided into 4 categories, which were offices, residential houses, hospitals, and high-rise accommodations (i.e. hotels/condominiums). Hourly real-time PM_{2.5} concentrations, temperature, and relative humidity (RH) measurements were recorded for two consecutive days during February 20th to March 2nd, 2018. We collected real-time indoor and outdoor PM_{2.5} mass concentrations at the same time. We excluded the days on which raining occurred because this might affect the PM_{2.5} mass concentration level, RH, temperature, and the comparisons of data.

There were three different ventilation conditions for each site. Sensors were located at the ambient environment, indoor environment with a closed ventilation system,

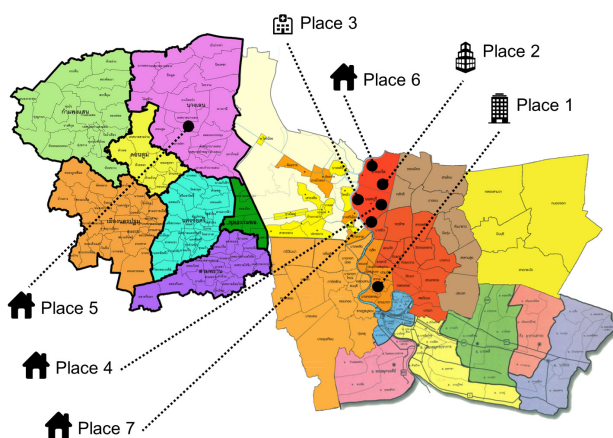


Fig 1. Map of sampling sites.

where all doors and windows were tightly closed all day, and indoor environment with an open ventilation system, all doors are closed, but windows were kept partially opened for the entire sampling period. We also calculated I/A ratio which was defined as a ratio between indoor PM_{2.5} mass concentrations compared with ambient PM_{2.5} mass concentrations. In order to reflect the real situation for office indwellers in Bangkok, we used the indoor PM_{2.5} concentrations measured in the closed ventilation setting to calculate I/A ratio.

For the ambient environment, sensors were placed on the ground 1.5 meters away from the building. For the indoor environment, sensors were placed in the middle of the room, at the level of the breathing zone of a sitting person (1.5 meters above the floor). Factors influencing PM_{2.5} endogenous production in the indoor environment were recorded. These include smoking activities, printer and/or copier, cooking activities, and proximity to traffic area.

Instrumentation and data collection

All sensors, including PM_{2.5} concentrations sensor (SN-GCHA1, Panasonic Photo & Lighting Co., Ltd), a temperature sensor (RHHI-112A, Shinyei Technology Co, Ltd), and RH sensor (RHHI-112A, Shinyei Technology Co, Ltd), were placed within one control box (9 cm x 16 cm x 11 cm). The measurement complied with Federal Reference Method (FRM) according to the recommendation from US. EPA. Data recorded by these sensors at each measurement site were transferred through Wi-Fi connection to the local router, and from the local router to cloud server through 4G internet connection. Hourly real-time data of indoor and ambient PM_{2.5} concentrations, temperature, and RH were exported in Excel files for statistical assessment.

Statistical analysis

All statistics were analyzed by using SPSS version 18.0. Ambient and indoor PM_{2.5} concentrations were shown as mean, median, SD, and 25th and 75th percentile. The correlation between ambient and indoor PM_{2.5} concentrations was demonstrated by simple linear regression analysis. Comparison of PM_{2.5} concentrations and I/A ratios in multiple places with different factors which influenced endogenous PM_{2.5} production in indoor environment (i.e. whether smoking was allowed or prohibited, having printer or not, and cooking activities was allowed or not) was performed by t-test or Mann Whitney U Test. P values of less than 0.05 ($p < 0.05$) were considered as statistically significant.

RESULTS

Data from 7 sampling sites were systematically collected. Factors influencing indoor PM_{2.5} concentrations were recorded and summarized in Table 1. Five from seven sampling sites (71%) included at least one printer and/or copier in the room. Four from seven sites (57%) had cooking activities present in indoor environment, and two from seven sites (28%) had smoking activities present inside the building.

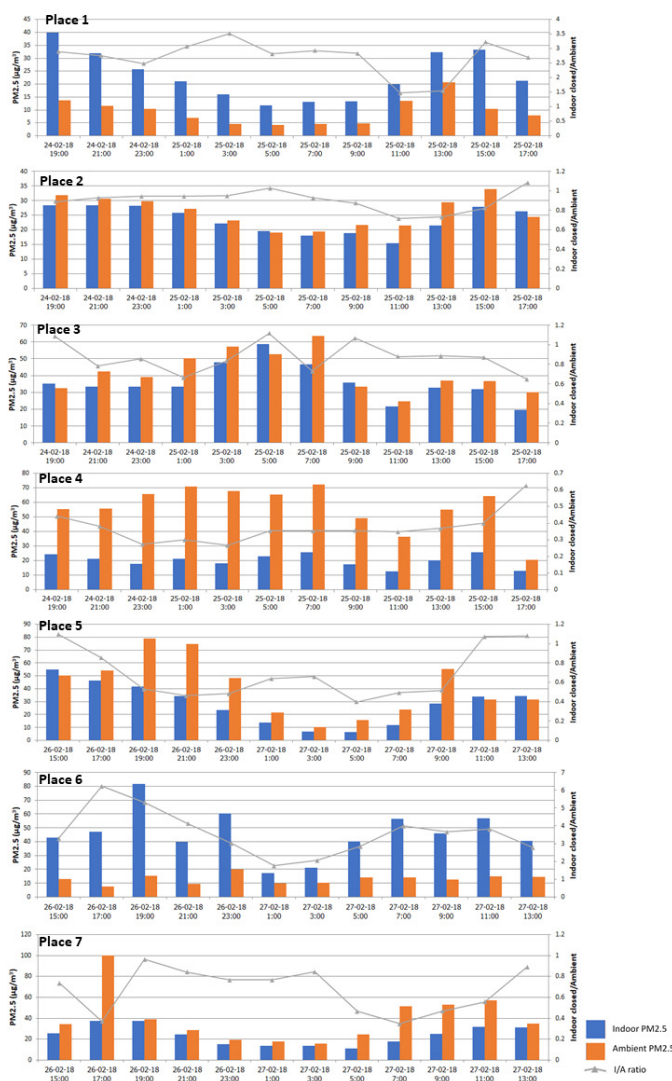
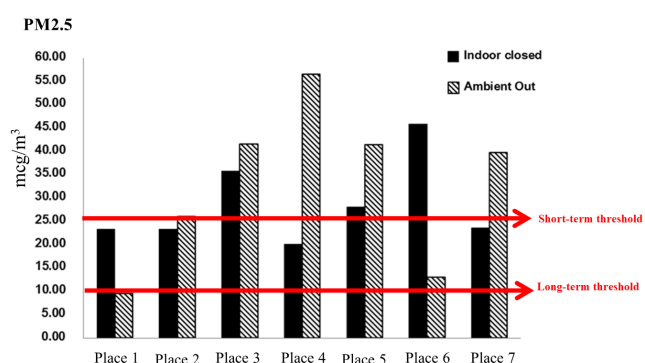
The Concentrations of Ambient and Indoor PM_{2.5}

The distribution of PM_{2.5} mass concentrations from seven sampling sites during two consecutive days was demonstrated in Fig 2. During data collection, the hourly mean ambient temperatures were 28.8-35.2°C. The minimal and maximal ambient temperatures were 24.8°C and 41.6°C, respectively. The hourly indoor temperatures were in the range of 25.4-31.3°C, whereas the minimal and maximal indoor temperatures were 23.3°C and 35.3°C, respectively. The mean RH was 55.2-63.1% for indoor, and 60.2-72.6% for outdoor.

All places had diurnal changes of PM_{2.5} mass concentrations. However, the ambient and indoor PM_{2.5} mass concentrations curves tended to fluctuate in the similar trend. Ambient PM_{2.5} mass concentrations were higher than the indoor PM_{2.5} mass concentrations in most sampling sites, except place 1 and place 6. The mean indoor PM_{2.5} mass concentrations from each site ranged from 20.05-45.85 µg/m³ and the mean outdoor PM_{2.5} mass concentrations ranged from 9.42-56.56 µg/m³. In contrast, the average PM_{2.5} mass concentrations from all sites was 28.6 µg/m³ for indoor and 32.5 µg/m³ for outdoor. We demonstrated the mean PM_{2.5} mass concentrations from seven sampling sites in Fig 3.

TABLE 1. Factors influencing indoor PM_{2.5} concentrations in sampling sites.

Place No.	Area	Building Category	Smoking		Printer and/or Copier		Cooking	
			Yes	No	Yes	No	Yes	No
1	Silom - Bangkok	High-rise accommodation	✓		✓		✓	
2	Chaengwatta - Nonthaburi	Office building	✓		✓		✓	
3	Sanambin Nam - Nonthaburi	Hospital		✓	✓			✓
4	Ngamwongwan - Nonthaburi	Residential house		✓		✓		✓
5	Bang Len - Nakhon Pathom	Residential house		✓		✓	✓	
6	Bang Phut - Nonthaburi	Residential house		✓	✓		✓	
7	Talat Kwan - Nonthaburi	Residential house		✓	✓		✓	

**Fig 2.** Daytime diurnal variation of PM_{2.5} mass concentrations from 7 different places in Bangkok Metropolitan Area.**Fig 3.** Average PM_{2.5} concentrations from 7 different places in Bangkok. The horizontal line indicates WHO threshold of PM_{2.5} concentrations for short-term exposure (25 µg/m³) and long-term exposure (10 µg/m³).

Ambient and indoor PM_{2.5} mass concentration relationship

We summarized the descriptive statistics of outdoor and indoor PM_{2.5} mass concentrations in Table 2. The average I/A ratio from each place ranged from 0.37 to 3.57. There was a significantly positive correlation between the average ambient and average indoor PM_{2.5} mass concentrations in all measurable places. The correlation coefficient (*r*) varied from 0.6 to 0.833. Five from seven sites demonstrated a strong correlation ($r \geq 0.7$), whereas, two from seven sites demonstrated a moderate correlation ($0.5 \leq r < 0.7$).

Stratification by Factors Influencing Endogenous PM_{2.5} Production

Each sampling site had different factors which were involved in the endogenous production of indoor PM_{2.5}. The presence or absence of such factors was stratified to

TABLE 2. Correlation of indoor (closed ventilation system) and ambient PM2.5 concentrations using simple linear regression (r, correlation coefficient; beta, regression coefficient; SE, standard error; R², Coefficient of determination), analyzed by simple linear regression.

Place	Indoor PM2.5 concentrations (µg/m ³)					Ambient PM2.5 concentrations (µg/m ³)					r	Beta	SE	R ²	P-value
	Mean	SD	Median	P25	P75	Mean	SD	Median	P25	P75					
1	23.30	9.28	25.68	18.30	35.01	9.42	5.02	29.18	14.65	50.32	0.77	1.41	0.376	0.586	0.004
2	23.37	4.67	21.15	14.67	32.12	26.02	5.11	9.09	4.63	12.53	0.83	0.76	0.160	0.694	0.001
3	35.78	10.86	23.94	19.23	27.99	41.58	11.92	25.82	21.55	30.23	0.80	0.73	0.174	0.634	0.002
4	20.05	4.43	33.36	32.33	41.08	56.56	15.29	37.98	32.90	51.45	0.75	0.22	0.061	0.556	0.005
5	28.04	15.93	20.81	17.66	23.74	41.40	22.41	60.04	52.10	66.80	0.73	0.52	0.155	0.527	0.008
6	45.85	17.23	31.32	12.77	38.07	12.99	3.31	40.15	22.72	54.71	0.60	3.13	1.319	0.360	0.039
7	23.64	9.41	44.36	39.98	56.69	39.70	23.64	13.54	10.05	14.74	0.68	0.27	0.091	0.473	0.013

compare the median I/A ratio (Fig 4). The places where indoor smoking was allowed had statistically significant higher I/A ratio than where smoking was prohibited ($p = 0.001$). The places where printers were present had significantly higher I/A ratio than where a printer was not present ($p < 0.001$). I/A ratio was also found to be significantly higher in the places where cooking was allowed, compared with the places where cooking was not allowed ($p < 0.001$).

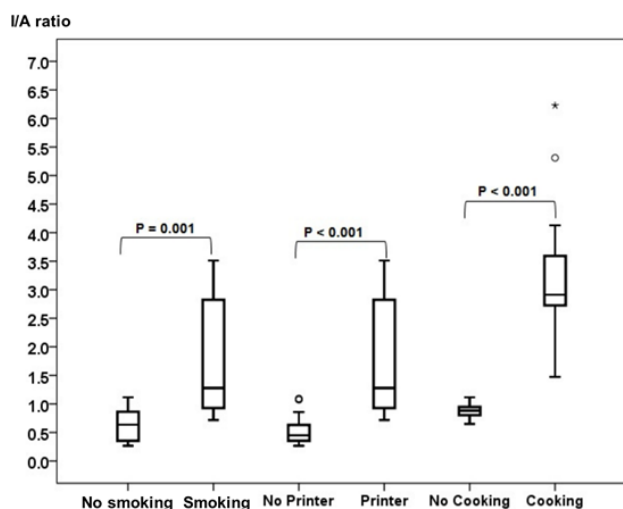


Fig 4. Median I/A ratio stratified by various factors influencing the endogenous production of PM_{2.5}.

DISCUSSION

Air pollution has become a major concern in the past decade, with a raising number of acute air pollution occurrences in many cities worldwide. It accounted for 5.5 million premature deaths globally in 2013.¹⁸ We have illustrated the ambient and indoor fine particulate matter in Bangkok Metropolitan Region, Thailand during February 20th to March 2nd, 2018. The median ambient PM_{2.5} mass concentrations during the study period (2018) was 29.18 µg/m³, which was lower than reported annual median PM_{2.5} concentrations (55 µg/m³) from South-East Asia in 2014. However, it is important to note that the trend of PM_{2.5} concentrations in South-East Asia during a five-year period (2008-2013) has been increasing more than 5% change.¹

We measured the indoor PM_{2.5} concentrations in the closed ventilation settings to calculate I/A ratios because we hypothesized that this could reflect the real situation for indoor indwellers in Bangkok. Our data revealed that, the ambient PM_{2.5} concentrations dominate the indoor PM_{2.5} concentrations in most of the sampling sites. We found that there was a moderate to strong correlation between the ambient and indoor PM_{2.5}

concentrations in all sites, reflecting the contribution of outdoor fine particulate matter to indoor air quality. Despite the closed ventilation system, the average I/A ratio from each place ranged from 0.37 to 3.57. It was clear that the outdoor PM_{2.5} can enter the buildings through three main ways, including natural ventilation, mechanical ventilation (air conditioning system), and infiltration. The I/A ratios could vary greatly because of the differences in indoor particle emission rates, the geometry of the cracks in building envelopes, and the air exchange rates. Penetration factor is an important factor for the penetration mechanism through cracks in the building envelope.¹⁹

According to the WHO Air Quality Guidelines (AQG) 2016, we compared the mean values of ambient and indoor PM_{2.5} mass concentrations with the AQG threshold level which was demonstrated in Fig 3. By using annual mean threshold (10 µg/m³), all of the sampling sites (7 from 7 sites) exceeded the threshold level in both ambient and indoor PM_{2.5}. When considering the short-term threshold (25 µg/m³), the ambient PM_{2.5} concentrations of five from seven sites (71%) exceeded the threshold level and the indoor PM_{2.5} concentrations of three from seven sites (43%) exceeded the threshold level. The interventions to solve this problem should be launched and prioritized because a higher level of ambient PM_{2.5} concentrations are associated with the risk of various diseases, including cancers, cardiovascular diseases, and allergic diseases.

The prevalence of allergic airway diseases has increased significantly worldwide with the highest increase observed in industrialized nations.²⁰ The impact of particles on the human respiratory system is an issue of concern. In some countries, the morbidity for chronic respiratory diseases is much higher than other non-communicable diseases and the mortality from lung diseases is second to the accident.²¹ Recent evidence has demonstrated the association between PM_{2.5} and asthma, respiratory inflammation, and impairment of lung functions. The pathomechanism of PM_{2.5} is determined by size, composition, origin, solubility, and ability for reactive oxygen species production.

We have demonstrated that indoor dwellers are still at risk to exposure to fine particulate matter, so this should be concerned. This emphasizes the need for indoor dwellers protection from PM_{2.5}. Its impact on the human respiratory system should not be dismissed, especially the sensitive individuals such as asthmatic patients, children, and the elderly. Elderly individuals >65 years of age are more likely to spend a greater proportion of their time indoors and have multiple co-morbidities

which affect the overall morbidity. The environmental control strategies to reduce particle concentrations might improve the respiratory outcomes. The interventions reported to reduce the indoor PM_{2.5} concentrations included: reduction of the endogenous PM_{2.5} sources, sealing of cracks in the building envelope, a combination of the air conditioner, and air filter with efficient PM_{2.5} purification function.¹⁶

However, this study has some limitations. First, we did not measure some ambient air pollutants, such as O₃, NO₂, and SO₂ concentration data. As a result, our study could not extrapolate to the overall air pollution status. However, we measured PM_{2.5} which is the air pollutant that has been most closely studied and is most commonly used as a proxy indicator of exposure to air pollution more generally. Second, our study had the limited number of sampling sites and duration of data sampling. Therefore, our data may not be reflective of the overall pollution situation in Thailand.

In conclusion, the indoor PM_{2.5} concentrations were correlated with the ambient PM_{2.5} concentrations. The concentrations of PM_{2.5} in most sampling sites were higher than the limited threshold. Hence, indoor dwellers are still at risk for health impacts from PM_{2.5}. Besides public management of the ambient PM_{2.5}, the interventions dealing with the indoor PM_{2.5} should be concurrently promoted.

ACKNOWLEDGMENTS

We would like to acknowledge our research assistants for the measurements of PM_{2.5} concentrations.

References

1. WHO. Ambient air pollution: A global assessment of exposure and burden of disease. World Health Organization. 2016.
2. Pinichka C, Makka N, Sukkumnoed D, Chariyalertsak S, Inchai P, Bundhamcharoen K. Burden of disease attributed to ambient air pollution in Thailand: A GIS-based approach. *PLoS One*. 2017;12(12):e0189909.
3. Du Y, Xu X, Chu M, Guo Y, Wang J. Air particulate matter and cardiovascular disease: the epidemiological, biomedical and clinical evidence. *J Thorac Dis*. 2016;8(1):E8-E19.
4. Stafoggia M, Cesaroni G, Peters A, Andersen ZJ, Badaloni C, Beelen R, et al. Long-term exposure to ambient air pollution and incidence of cerebrovascular events: results from 11 European cohorts within the ESCAPE project. *Environ Health Perspect*. 2014;122(9):919-25.
5. Adar SD, Sheppard L, Vedal S, Polak JF, Sampson PD, Diez Roux AV, et al. Fine particulate air pollution and the progression of carotid intima-medial thickness: a prospective cohort study from the multi-ethnic study of atherosclerosis and air pollution. *PLoS Med*. 2013;10(4):e1001430.
6. Turner MC, Krewski D, Pope CA, 3rd, Chen Y, Gapstur SM, Thun MJ. Long-term ambient fine particulate matter air pollution and lung cancer in a large cohort of never-smokers. *Am J Respir Crit Care Med*. 2011;184(12):1374-81.
7. Wong CM, Tsang H, Lai HK, Thomas GN, Lam KB, Chan KP, et al. Cancer Mortality Risks from Long-term Exposure to Ambient Fine Particle. *Cancer Epidemiol Biomarkers Prev*. 2016;25(5):839-45.
8. Guo ZQ, Dong WY, Xu J, Hong ZC, Zhao RW, Deng CR, et al. T-helper type 1-T-helper type 2 shift and nasal remodeling after fine particulate matter exposure in a rat model of allergic rhinitis. *Am J Rhinol Allergy*. 2017;31(3):148-55.
9. Wang YL, Gao W, Li Y, Wang YF. Concentration-dependent effects of PM_{2.5} mass on expressions of adhesion molecules and inflammatory cytokines in nasal mucosa of rats with allergic rhinitis. *Eur Arch Otorhinolaryngol*. 2017;274(8):3221-9.
10. Konishi S, Ng CF, Stickley A, Nishihata S, Shinsugi C, Ueda K, et al. Particulate matter modifies the association between airborne pollen and daily medical consultations for pollinosis in Tokyo. *Sci Total Environ*. 2014;499:125-32.
11. Teng B, Zhang X, Yi C, Zhang Y, Ye S, Wang Y, et al. The Association between Ambient Air Pollution and Allergic Rhinitis: Further Epidemiological Evidence from Changchun, Northeastern China. *Int J Environ Res Public Health*. 2017;14(3):1-18.
12. Higgins TS, Reh DD. Environmental pollutants and allergic rhinitis. *Curr Opin Otolaryngol Head Neck Surg*. 2012;20(3):209-14.
13. Huang L, Pu Z, Li M, Sundell J. Characterizing the Indoor-Outdoor Relationship of Fine Particulate Matter in Non-Heating Season for Urban Residences in Beijing. *PLoS One*. 2015;10(9):e0138559.
14. McCormack MC, Breyse PN, Matsui EC, Hansel NN, Peng RD, Curtin-Brosnan J, et al. Indoor particulate matter increases asthma morbidity in children with non-atopic and atopic asthma. *Ann Allergy Asthma Immunol*. 2011;106(4):308-15.
15. Zhang F, Wang W, Lv J, Krafft T, Xu J. Time-series studies on air pollution and daily outpatient visits for allergic rhinitis in Beijing, China. *Sci Total Environ*. 2011;409(13):2486-92.
16. Lin Y, Zou J, Yang W, Li CQ. A Review of Recent Advances in Research on PM_{2.5} in China. *Int J Environ Res Public Health*. 2018;15(3):1-29.
17. Cyrus J, Pitz M, Bischof W, Wichmann HE, Heinrich J. Relationship between indoor and outdoor levels of fine particle mass, particle number concentrations and black smoke under different ventilation conditions. *J Expo Anal Environ Epidemiol*. 2004;14(4):275-83.
18. World Bank and Institute for Health Metrics and Evaluation. 2016. The Cost of Air Pollution: Strengthening the Economic Case for Action. Washington, DC: World Bank. License: Creative Commons Attribution CC BY 3.0 IGO.
19. Chen CZ, B. Review of relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor. *Atmos Environ*. 2011;45(2):275-88.
20. Brozek G, Lawson J, Szumilas D, Zejda J. Increasing prevalence of asthma, respiratory symptoms, and allergic diseases: Four repeated surveys from 1993-2014. *Respir Med*. 2015;109(8):982-90.
21. Paramesh H. Air Pollution and Allergic Airway Diseases: Social Determinants and Sustainability in the Control and Prevention. *Indian J Pediatr*. 2018;85(4):284-94.