Topic 4: Indoor Environment and Health

Indoor and Outdoor PM2.5 and Ozone Levels: A Case Study in a College Student Dormitory in Summer

Jialei Shen, and Zhi Gao*

School of Architecture and Urban Planning, Nanjing University, 22 Hankou Road, Nanjing, Jiangsu Province, 210093, China

*Corresponding email: zhgao@nju.edu.cn

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ABSTRACT

Indoor and outdoor $PM_{2.5}$ and ozone concentrations are monitored in a student dormitory in Nanjing University for a period of 37 days in 2015 summer. The results show that the indoor concentrations of $PM_{2.5}$ and ozone are generally lower than the outdoor concentrations, and the indoor concentrations are closely following the outdoor concentrations. The I/O ratios for $PM_{2.5}$ and ozone are 0.42-0.79, and 0.21-1.00, respectively. The I/O ratios for $PM_{2.5}$ and ozone are 0.49(±0.05) and 0.26(±0.05) in the case of window closed (ACH is 0.66/h), and the I/O ratios for $PM_{2.5}$ and ozone are 0.65(±0.08) and 0.50(±0.15) in the case of window opened (ACH is 1.32/h). Therefore, it would be an effective method to control the indoor ozone concentration by closing the window when the outdoor concentration is high. However, this method may not be effective for controlling indoor $PM_{2.5}$ concentrations, due to the high I/O ratio of $PM_{2.5}$.

INTRODUCTION

People usually spend on average almost 90% of their lives indoors (Klepeis et al. 2001; deCastro et al. 2007; Schweizer et al. 2007; Hussein et al. 2012). Indoor pollutants such as $PM_{2.5}$ and ozone could adversely affect human health, particularly in relation to impaired lung function (Lucas 2000; Bell et al. 2004; Triche et al. 2006). The outdoor pollutants, e.g. particulate matter and ozone, can be a significant source of indoor pollutants and will influence the indoor air quality (Gao and Zhang 2012). Indoor/outdoor (I/O) ratio, affected by permeability of building envelope, air exchange rate, and decay rate of pollutants, indicates the relationship of indoor and outdoor particulate matter and ozone concentrations. Weschler (2000) revealed that the I/O ratios of ozone for most buildings in the United States were in the range of 0.2-0.7. Monn et al. reported that the I/O ratios of PM_{10} in non-smoking room were 0.7-1.2, while the I/O ratios reported by Funasaka et al. were in the range of 0.62-0.96. Zhao et al. (2015) reported that the I/O ratios of $PM_{2.5}$ during winter in Beijing were mainly distributed between 0.4 and 0.9.

Student dormitory is the typical residential building in the vast majority of high schools and colleges in China, with highly similar indoor layout and materials as shown in Figure 1(a). Air quality in dormitory is therefore closely related to students' health owing to their long-term residence, usually 7 years or even more. However, few of the previous investigations have studied the air quality in the student dormitories. In this paper, indoor and outdoor $PM_{2.5}$ and ozone concentrations are monitored in a student dormitory in Nanjing University for a period of 37 days in 2015 summer. The I/O ratios of $PM_{2.5}$ and ozone in the cases of window opened and closed are analyzed.

METHODS

Field measurements were conducted for a period of 37 days (July 15, 2015 to August 31, 2015) in a college student dormitory without any indoor ozone or $PM_{2.5}$ source, which located in Nanjing University, Nanjing, China (Figure 1(b)). The volume of the research room was $45m^3$ (3m*5m*3m). There was an openable sliding window on one side of the room, with openable area $0.84m^2$ (Figure 1(c)). Indoor and outdoor ozone concentrations were sampled by 2B Technologies Model 202 and POM, respectively. Two TSI DUSTTRAK II-Model 8532 were used to monitor the indoor and outdoor $PM_{2.5}$ concentrations. The concentrations of ozone and $PM_{2.5}$ were sampled at 1min interval during the study period. The indoor monitor point was set at the center of the room with a vertical height of 1.5m, i.e. breathing zone height, while the outdoor monitor point was set at the outside of the window. Air exchange rate (ACH) of the room was evaluated according to the concentration decay SF_6, which monitored by Innova 1412i Lumasense gas monitor.

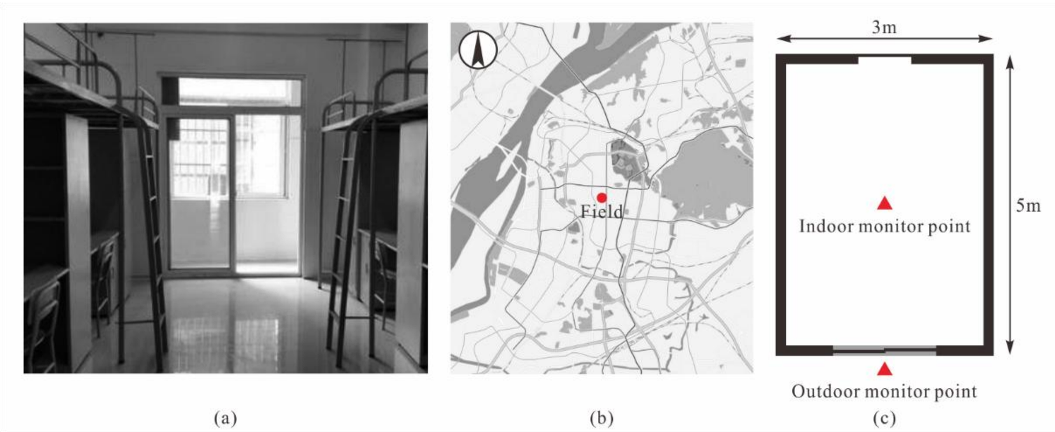

Figure. 1. (a) A typical student dormitory in China; (b) Location of field measurement; (c) The researched student dormitory.

RESULTS

Indoor and outdoor concentrations of $PM_{2.5}$ and ozone during 7 days (August 22-28, 2015) in the case of window opened are shown in Figure 2(a) and 2(b), respectively. The indoor concentrations of $PM_{2.5}$ and ozone are generally lower than the outdoor concentrations, and the indoor concentrations are closely following the outdoor concentrations. Figure 2(a) shows that the indoor $PM_{2.5}$ concentrations vary with the outdoor concentrations almost simultaneously, although the indoor levels are always lower than the outdoor levels. The outdoor ozone concentrations show significant diurnal periodic variations, i.e. rapid increasing of concentrations in everyday morning, and reaching the peak at noon or afternoon, then continuing to decline throughout the evening until reaching a low point at midnight, which have been reported by literatures. The indoor ozone concentrations in the case of window opened also show diurnal periodic variations varied with the outdoor concentrations. However, the $PM_{2.5}$ concentrations don't show significant periodic variations during the study period.

Figure 2(c) and 2(d) illustrate indoor and outdoor concentrations of $PM_{2.5}$ and ozone during 3 days (July 15-17, 2015) in the case of window closed. In this case, the indoor concentrations still vary with the outdoor concentrations. However, the indoor concentrations of $PM_{2.5}$ and ozone show more moderate variations than the case of window opened, which leads to general lower indoor concentrations. Therefore, the diurnal periodic variations of indoor ozone concentrations are not as significant as the case of window opened.

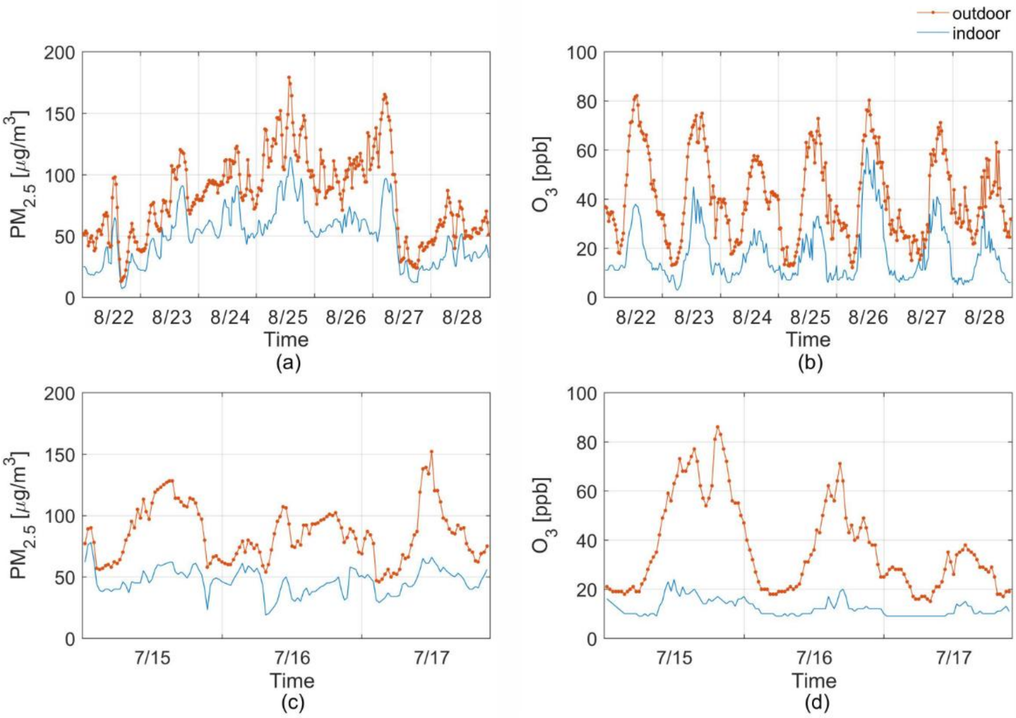

Figure. 2. Indoor and outdoor concentrations of (a) $PM_{2.5}$ and (b) ozone during 7 days (August 22-28, 2015) in the case of window opened. Indoor and outdoor concentrations of (c) $PM_{2.5}$ and (d) ozone during 3 days (July 15-17, 2015) in the case of window closed.

Table 1 reveals that the measured I/O ratios of $PM_{2.5}$ and ozone during the 37 days are in the range of 0.42-0.79 and 0.21-1.00, respectively. Among them, the mean values of I/O ratio of $PM_{2.5}$ and ozone are lowest in the case of window closed, while the mean values are highest in the case of window opened. The I/O ratio is closely associated with the value of ACH in the cases of different window states. The value of ACH measured in the case of window opened is 1.32, and the value is 0.66 in the case of window closed. The I/O ratios of $PM_{2.5}$ are generally higher than the I/O ratios of ozone, even in the case of window closed. The high I/O ratio of $PM_{2.5}$ in the case of window closed (0.49) indicates stronger penetration ability of $PM_{2.5}$ through the building envelope structures (cracks and wall cavities). The I/O ratios measured in this paper are generally consistent with the previous studies (Thompson et al. 1973; Tu and Knutson 1988; Hayes 1991; Koponen et al. 2001).

Table 1. I/O ratio of $PM_{2.5}$ and ozone concentrations in the cases of window opened and closed.

	$PM_{2.5}$			Ozone		
	Window opened	Window closed	Total	Window opened	Window closed	Total
Mean (±SD)	0.65(±0.08)	0.49(±0.05)	0.60(±0.10)	0.50(±0.15)	0.26(±0.05)	0.43(±0.17)
Mid-value	0.66	0.49	0.62	0.47	0.25	0.42
Range	0.45-0.79	0.42-0.69	0.42-0.79	0.23-1.00	0.21-0.39	0.21-1.00

Figure 3 revealed the indoor and outdoor concentrations of $PM_{2.5}$ and ozone in the cases of different window states, including window opened and closed. Linear regressions are conducted to analyze the linear correlation of measured indoor and outdoor concentrations in each case. Generally, the I/O ratio in the case of window opened is highest among the different cases, while the I/O ratio in the case of window closed is lowest, as analyzed above. The correlation coefficient (R) of each case shows that indoor $PM_{2.5}$ concentrations have high degrees of correlation with outdoor concentrations in any case, but indoor ozone concentrations have relatively low degrees of correlation, particularly in the case of window closed.

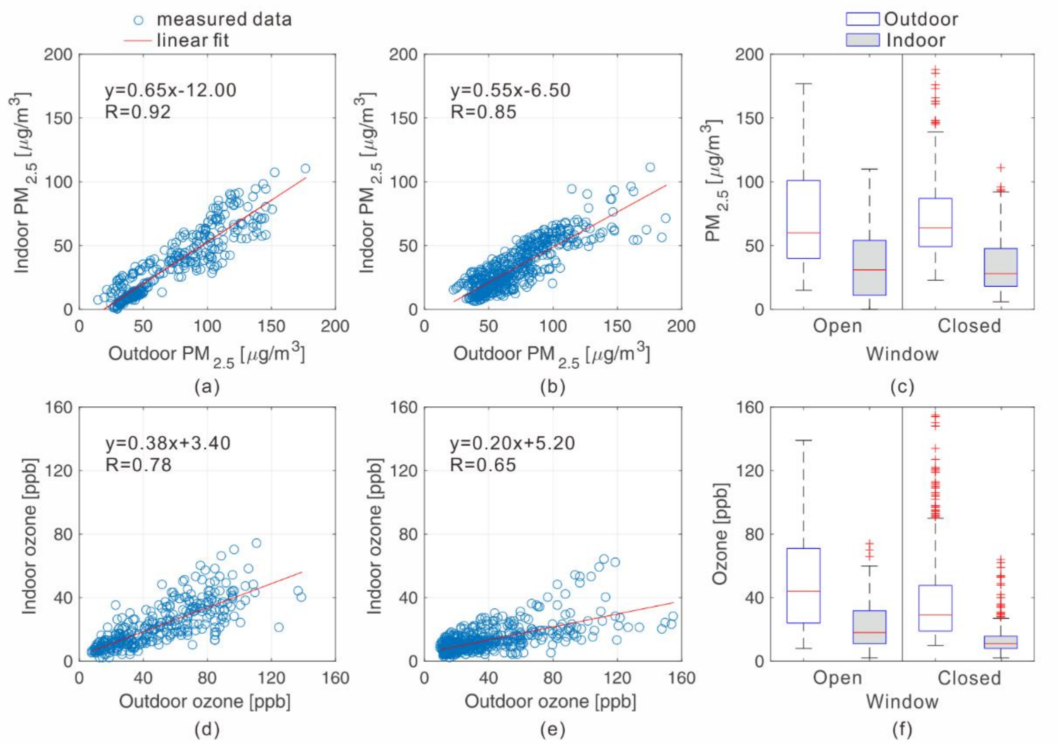

Figure.3. Indoor and outdoor concentrations of $PM_{2.5}$ in the cases of window (a) opened and (b) closed, (c) boxplots of measured $PM_{2.5}$ concentrations. Indoor and outdoor concentrations of ozone in the cases of window (d) opened and (e) closed, (f) boxplots of measured ozone concentrations. In each box, the mid-line shows the median value, the top and bottom of the boxes show the upper and lower quartiles (the 75th and 25th percentiles), and the top and bottom of the whiskers represent the 90th and 10th percentiles. The extreme values farther from the median than 1.25 times the whisker end are drawn with markers.

Figure 4 reveals the boxplots of measured outdoor and indoor $PM_{2.5}$ and ozone levels during 24h. Indoor levels are generally lower than the outdoor levels. The outdoor and indoor ozone levels during the daytime are significantly higher than the levels during the night, which is consistent with literatures. However, the outdoor and indoor $PM_{2.5}$ levels do not show significant differences between daytime and night.

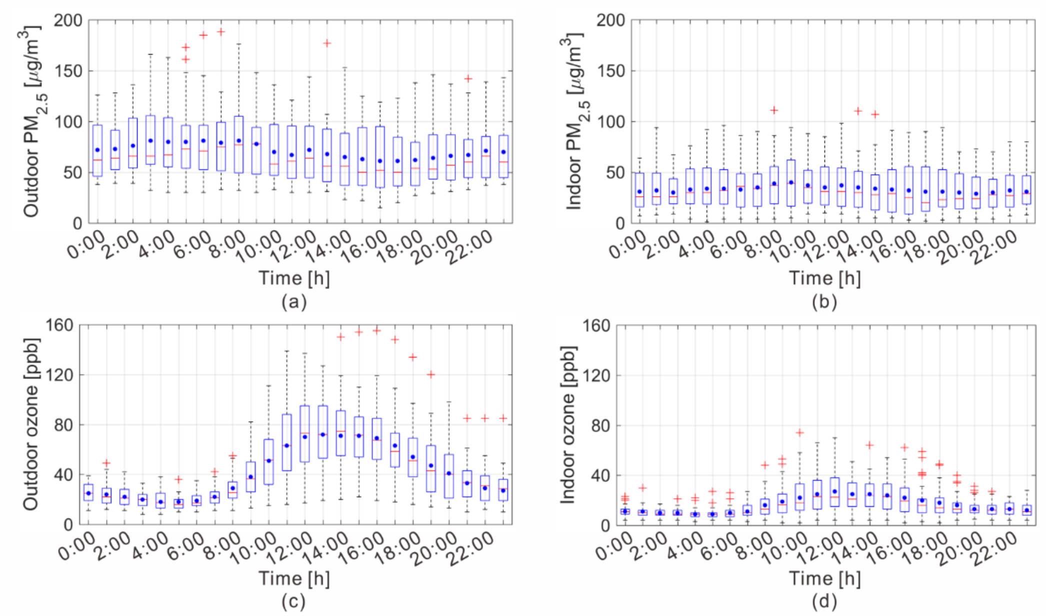

Figure. 4. Boxplots of (a) outdoor and (b) indoor $PM_{2.5}$ levels during 24h, and boxplots of (c) outdoor and (d) indoor ozone levels during 24h. In each box, the mid-line shows the median value, the top and bottom of the boxes show the upper and lower quartiles (the 75th and 25th percentiles), and the top and bottom of the whiskers represent the 90th and 10th percentiles. The extreme values farther from the median than 1.25 times the whisker end are drawn with markers, and point indicates the mean value.

DISCUSSION

Field measurements in this investigation show that the I/O ratios for $PM_{2.5}$ and ozone are 0.42-0.79, and 0.21-1.00, respectively. The I/O ratios for $PM_{2.5}$ and ozone are 0.49($\pm$0.05) and 0.26($\pm$0.05) in the case of window closed (ACH is 0.66/h), and the I/O ratios for $PM_{2.5}$ and ozone are 0.65($\pm$0.08) and 0.50($\pm$0.15) in the case of window opened (ACH is 1.32/h). Therefore, it would be an effective method to control the indoor ozone concentration by closing the window when the outdoor ozone concentration is high. However, this method may not be effective for controlling indoor $PM_{2.5}$ concentrations, because indoor concentration will be still quite high (approximately 50% of outdoor concentrations) even if the window is closed due to the penetration through the envelope structures. In that case, some additional measures are recommended to be taken to control the indoor $PM_{2.5}$ concentrations, e.g. using air cleaners.

Outdoor ozone concentrations are generally higher during the daytime in summer. However, in China, people tend to open the windows for better indoor natural ventilation in summer, which may lead to higher indoor ozone concentrations. According to the results in this paper, occupants should try not to open the window when the outdoor ozone concentration is high, if there is no material with high ozone reaction probability indoors.

CONCLUSIONS

Field measurements were conducted in a student dormitory in Nanjing University. Indoor and outdoor $PM_{2.5}$ and ozone concentrations are monitored for a period of 37 days in summer of 2015. The measured data show that the indoor concentrations of $PM_{2.5}$ and ozone are generally lower than the outdoor concentrations, and the indoor concentrations are closely following the outdoor concentrations. Significant diurnal periodic variations are observed for indoor ozone concentrations in the case of window opened. The I/O ratios for $PM_{2.5}$ and ozone are 0.42-0.79, and 0.21-1.00, respectively. The I/O ratios for $PM_{2.5}$ and ozone are 0.49($\pm$0.05) and 0.26($\pm$0.05) in the case of window closed (ACH is 0.66/h), and the I/O ratios for $PM_{2.5}$ and ozone are 0.65($\pm$0.08) and 0.50($\pm$0.15) in the case of window opened (ACH is 1.32/h). Indoor $PM_{2.5}$ concentrations have high degrees of correlation with outdoor concentrations in any case, but indoor ozone concentrations have relatively low degrees of correlation, particularly in the case of window closed. It would be an effective method to control the indoor ozone concentration by closing the window when the outdoor ozone concentration is high. However, this method may not be effective for controlling indoor $PM_{2.5}$ concentrations, because indoor concentration will be still quite high (approximately 50% of outdoor concentrations) even if the window is closed due to the penetration through the envelope structures. In that case, some additional measures are recommended to be taken to control the indoor $PM_{2.5}$ concentrations, e.g. using air cleaners.

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