ISSN: 2710-0588

Chemical Compositions and Sources of Indoor Airborne $PM_{2.5}$ at a Middle School in China

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Abstract

To investigate the indoor air quality on middle school campus in China, $PM_{2.5}$ samples in a classroom and a laboratory during summer and winter at a y middle school in a coastal city of China were collected and analyzed for their chemical composition and sources. Our results showed that the average winter and summer $PM_{2.5}$ concentrations in the classroom and the laboratory ranged from 11–24 μg/m^3 during the observation periods, which is slightly higher than the WHO recommended value of 10 μg/m^3, suggesting a necessary for improving campus indoor air quality. Due to increased window ventilation, a greater outdoor air intrusion in summer led to $PM_{2.5}$ concentrations in both classroom and laboratory higher in summer than in winter. Moreover, we found that the proportions of Ca^{2+} and Na^+ in classroom and laboratory $PM_{2.5}$ were higher than outdoors due to an enhanced indoor dust resuspension. Moreover, the campus indoor $PM_{2.5}$ contained high levels of phthalate plasticizers, which are several times outdoors, indicating a plasticizer pollution in indoor campus air, which mainly originate from the volatilization of plastic flooring and wall coatings. Since these substances are reproductively toxic and teenagers are vulnerable, reducing the use of such plasticizers is necessary for improving indoor air quality.

Keywords

$PM_{2.5}$; Campus indoor air; Chemical composition; Organic compounds; Plasticizers.

1. Introduction

In the past decades air quality in China has significantly been improved. However, air pollution in the country is still serious [1][2][3]. In particular, the concentration of atmospheric fine particles ($PM_{2.5}$) in many Chinese cities still far exceeds the World Health Organization (WHO) recommended annual average value of 10 μg/m^3, making it the primary pollutant affecting urban air quality compliance in China [1][4][5]. $PM_{2.5}$ refers to particulate matter with an aerodynamic diameter equivalent or less than 2.5 μm. Compared to coarse particles, although $PM_{2.5}$ accounts for a smaller proportion of the total mass, its large specific surface area makes it an important media for atmospheric chemical reactions [6][7]. Furthermore, its large specific surface area allows it to adsorb toxic and hazardous substances such as polycyclic aromatic hydrocarbons (PAHs) [8][9], black carbon (BC) [10][11][12], and heavy metals (e.g., Pb, Hg) [11][13][14], which can then be absorbed through the respiratory tract, posing significant risks to human health.

Studies have shown that people spend approximately 90% of their daily working and living time indoors [15]. Therefore, indoor air quality has a substantial impact on human health. Since teenagers are more vulnerable than adults to airborne $PM_{2.5}$ and spend a large amount of time at school [16][17], understanding the composition and sources of indoor airborne $PM_{2.5}$ in schools is particularly important for safeguarding the physical and mental health of young

ISSN: 2710-0588

people [18][19][20][21]. In the past researches on school air quality have mostly focused on outdoor environments with few in-depth studies on indoor air pollution, especially in primary and secondary schools [22][23][24]. The limited available studies have only addressed a few organic pollutants such as PAHs in indoor airborne particles without systematic analysis of the chemical composition and sources of indoor $PM_{2.5}$ [25][26]. Over the past decade, although air pollution in China has been effectively mitigated, the associated improvements in air quality have targeted outdoor atmospheres, while indoor air quality—particularly in school settings—has not received sufficient attention. This study selected a secondary school in a coastal city of China as a case study for investigating the air quality. We first collected $PM_{2.5}$ samples from a classroom and a laboratory, then analyzed their chemical compositions, and identified their sources, along with a comparison with outdoor samples to evaluate the pollution levels in the campus indoor air. Our results thereby provided a scientific basis for further improving school air quality in China.

2. Experimental Section

2.1. $PM_{2.5}$ sample collection

The sampling was conducted in a classroom and a laboratory at a secondary school in a Chinese coastal city during the summer and winter of 2025, with six samples collected in each room in each season. The $PM_{2.5}$ sample was simultaneously collected in the classroom and the laboratory each for 24 hours by using two medium-flow samplers (TH-150F, Tianhong Company, China) with a flow rate of 100 L/min. $PM_{2.5}$ particles were collected onto quartz fiber filters, which were prebaked in a muffle furnace at 450°C for 6 hours to remove any adsorbed organic matter and sealed in aluminum foils prior to sampling [27][28][29].

2.2. $PM_{2.5}$ sample analysis

2.2.1. Water-soluble inorganic ions in $PM_{2.5}$

About 0.5–6 cm^2 of the filter sample was cut into pieces, and put it into a centrifuge tube. Then, 15 mL of ultrapure water was added and ultrasonically extracted for 1 hour. Afterwards, the water solution inside the tube was filtered by using a 0.20 μm aqueous-phase polyethersulfone filter to remove any insoluble materials, and the filtrate was transferred to a 15 mL glass vial. Inorganic ions in the samples were measured using an ion chromatographer (940 Professional IC Vario, Metrohm, Switzerland). A total of 10 anions and cations were determined (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, F^-, Cl^-, NO_2^-, NO_3^-, and SO_4^{2-}). The details of the method can be found elsewhere [30][31]

2.2.2. Organic Compounds in $PM_{2.5}$

About 5–10 cm^2 of the filter sample was cut into pieces and placed into a 20 mL glass vial. Approximately 5 mL of a dichloromethane:methanol (2:1, v/v) mixture was added into the vial and ultrasonically extracted three times each for 15 minutes. Afterwards, the extract was filtered through silylanized glass wool and concentrated into about 1mL using a rotary evaporator. The concentrate was transferred to a 2 mL gas chromatography (GC) vial and further concentrated to near dryness under a stream of high-purity nitrogen (purity > 99.999%). Then, 60 μL of a BSTFA (bis(trimethylsilyl)trifluoroacetamide):pyridine (5:1, v/v) mixture was added into the vial , and heated 70°C for 3 hours. After the reaction, the vial was cooled down to room temperature, and 40 μL *n*-hexane containing 1ppm *n*-tridecane (internal standard) was added to bring the final volume to 100 μL. Finally, organic compounds in the derivatized sample were analyzed using a gas chromatography-mass spectrometry (GC-MS) system (7890B-5977B, Agilent Technologies, USA). The GC inlet temperature was set at 280°C to ensure complete vaporization of the liquid samples. The temperature program for the column oven was as follows: (1) Hold at 50°C for 2 min; (2) Ramp from 50°C to 120°C at

ISSN: 2710-0588

15°C/min; (3) Ramp from 120°C to 300°C at 5°C/min and hold at 300°C for 20 min. The carrier gas was high-purity helium (purity > 99.999%) supplied by Air Liquide (France). During the program, the carrier gas pressure was 7.65 psi, and the flow rate was 3 mL/min [32][33][34].

3. Results and Discussion

3.1. Comparison of indoor and outdoor $PM_{2.5}$

During our observation period, concentrations of outdoor pollutants (PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, and CO) were collected from a national air quality monitoring station near the campus. The temporal variations in concentrations of these six pollutants are shown in Figure 1 and summarized in Table 1. The shaded areas in the figure indicate the periods of the indoor campus $PM_{2.5}$ sampling. As seen in Table 1, the averaged concentrations of PM_{10} and $PM_{2.5}$ in the outdoor atmosphere near the campus were 37±25μg/m^3 and 18±11μg/m^3 in summer and 59 ±39μg/m^3 and 35±29μg/m^3 in winter, respectively, which are higher than the 1st rank of the National Ambient Air Quality Standard (annual value 15μg/m^3) of China especially in winter[35][36], while all the gaseous pollutants on the campus are less than the 1st rank of the National Ambient Air Quality Standards, indicating that atmospheric particle pollution in the city is still serious while gas pollution is alleviated enough. As shown in Figure 1 haze pollution episodes with a daily $PM_{2.5}$ exceeding 100μg/m^3 frequently occurred in the city, while O_3 pollution with a daily level exceeding 160μg/m^3, the 2nd rank of the National Ambient Air Quality Standard, only occurred in summer, suggesting that particle pollution is more serious in the cold season while O_3 pollution only happens in the hot season[1][2][3][36].

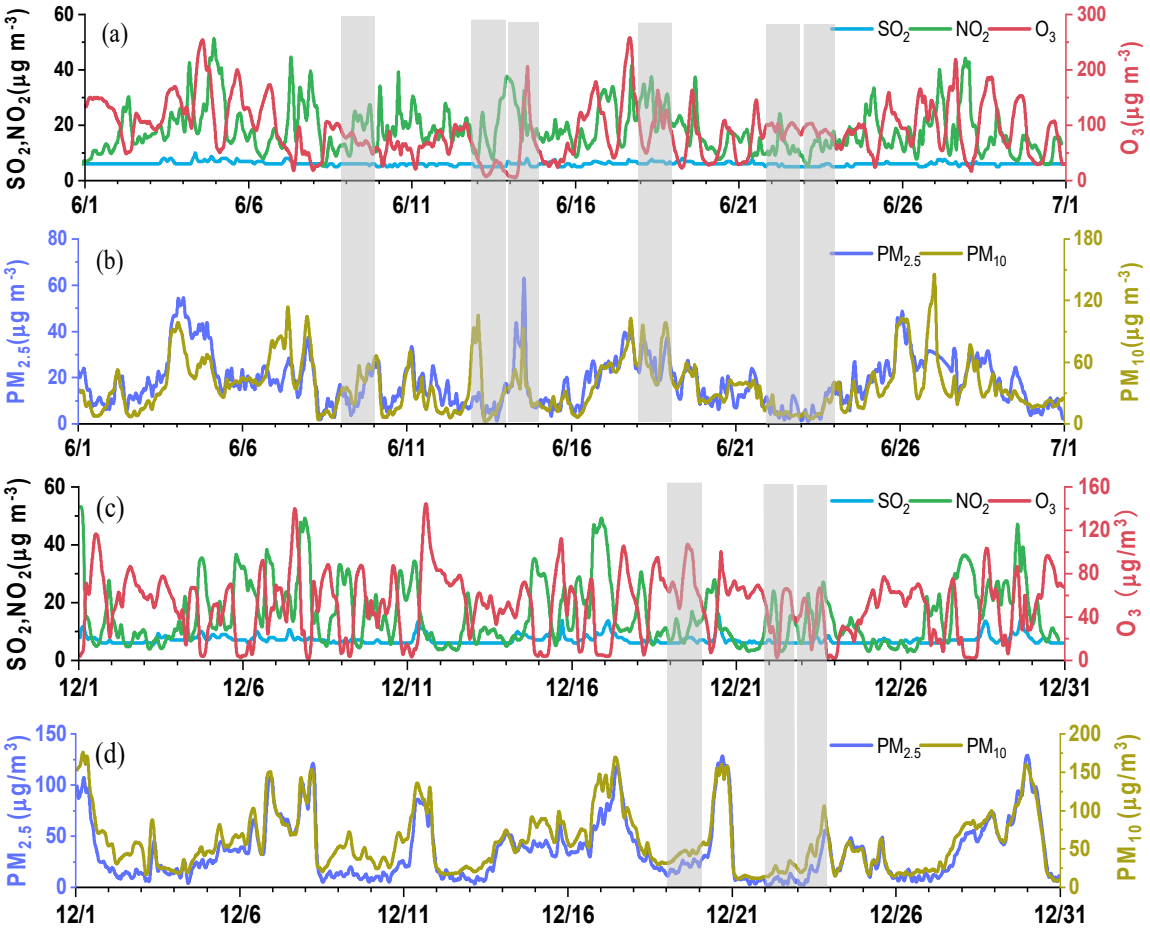

Figure 1. Temporal variations of SO_2, NO_2, PM_{10} and $PM_{2.5}$ in the outdoor air on the campus during the summer and winter

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Table 1. Concentration (μg/m^3) of air pollutants in the campus atmosphere

	Summer			Winter		
	Min	Max	Mean	Min	Max	Mean
PM_{10}	2.0	154	37 ± 25	9.0	177	59 ± 39
$PM_{2.5}$	1.0	65	18 ± 11	2.0	131	35 ± 29
SO_2	5.0	11	6.1 ± 0.7	5.0	17	7 .0± 2.0
NO_2	5.0	56	19 ± 9	8.0	124	39 ± 25
O_3	4.0	261	91 ± 48	1.0	146	52 ± 29
CO	600	1600	1000 ± 200	100	1600	600 ±300

Table 2 shows the comparison of indoor $PM_{2.5}$ concentrations and their chemical compositions on the campus during summer and winter. It can be seen that the summer $PM_{2.5}$ concentrations in the classroom and laboratory were 16 ± 5.0 and 24 ± 10 μg/m^3, respectively, which are 1.3 and 2.2 times higher than those in winter, indicating that indoor $PM_{2.5}$ pollution on the campus was more severe in summer than in winter. The ratios of indoor to outdoor $PM_{2.5}$ in the classroom and laboratory were 0.57 and 0.86 in summer, respectively, while both were around 0.3 in winter, suggesting a smaller indoor-outdoor difference in summer and a larger difference in winter. As shown in Table 1, the outdoor summer $PM_{2.5}$ during the observation period was 28 ± 14 μg/m^3, only 65% of the winter concentration. Therefore, we infer that the higher indoor $PM_{2.5}$ concentration in summer compared to winter may be related to the influence of outdoor air intrusion due to open windows. In contrast, although the outdoor winter concentration was much higher than in summer, due to the cold weather, windows were opened less frequently, making the indoor environment relatively more sealed. Under the same ventilation conditions, the indoor air in winter was less affected by outdoor air, resulting in better air purification. This led to the aforementioned situation where summer indoor $PM_{2.5}$ concentrations were higher, indicating that keeping doors and windows closed to reduce outdoor air inflow while enhancing ventilation filtration and purification is key to reducing indoor $PM_{2.5}$ pollution. Compared with the safety standard of 15 μg/m^3 in the WHO 2021 Global Air Quality Guidelines, the summer $PM_{2.5}$ concentration in the classroom basically met the standard, but that in the laboratory exceeded the standard by 60%. In contrast, in winter, both classroom and laboratory had concentrations below the WHO standard. This further suggests that summer laboratory was more affected by outdoor air intrusion, possibly due to longer window ventilation times, indicating that enhancing the purification function of the air conditioning system in summer laboratory and reducing window ventilation time are key to further improving campus air quality.

The SO_4^{2-}concentrations in $PM_{2.5}$ in summer classroom and laboratory are comparable, which were about half of the outdoor concentration, indicating no significant indoor source of SO_4^{2-} pollution. The NO_3^- concentration in the classroom was lower than that in laboratory, about one-third of the latter, and both were 20-50% of the outdoor NO_3^- concentration, again indicating that laboratory was more affected by outdoor air pollution input. However, as can be seen from Table 2, the NH_4^+ concentration in classroom $PM_{2.5}$ was higher than in laboratory, while they were comparable in winter. This may be related to more students in classroom and consequently more significant ammonia emissions from the human body compared to laboratory in summer. In winter, the SO_4^{2-} concentrations in both classrooms and laboratory were lower than outdoor, but the concentration in the classroom was still 1.5 times that in the laboratory, suggesting an unknown pollution source in classrooms.

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Table 2. Concentrations of chemical components of $PM_{2.5}$ in summer and winter

	summer			winter		
	Classroom	Laboratory	Outdoor	Classroom	Laboratory	Outdoor
(I) Inorganic ions (μg/m³)						
$PM_{2.5}$ μg/m³	16 ± 5.0	24 ± 10	28 ± 14	12 ± 6.0	11 ± 3.0	43 ± 28
SO_4^{2-}	2.06 ± 1.35	1.95 ± 1.02	5.4 ± 3.4	3.93 ± 2.93	2.63 ± 1.17	5.4 ±3.1
NO_3^-	0.52 ± 0.04	1.47 ± 1.38	3.1 ± 4.2	0.97 ± 0.56	2.84 ± 1.82	13 ± 12
NH_4^+	0.39 ± 0.29	0.03 ± 0.02	2.6 ± 1.6	0.95 ± 1.09	1.21 ± 0.98	5.2 ± 4.2
Other-IC[a]	2.38 ± 0.49	2.96 ± 0.83	4.2 ± 4.0	4.56 ± 0.42	4.18 ± 1.13	2.9 ± 1.1
(II) Organic compounds (ng/m³)						
Levoglucosan	3.9 ± 1.2	28 ± 41	Nd[b]	26 ± 26	36 ± 22	46 ± 38
Sugars	13 ± 3.7	39 ± 39	Nd[b]	45 ± 38	56 ± 30	67 ± 53
n-Alkanes	62 ± 16	122 ± 123	Nd[b]	78 ± 51	76 ± 26	83 ± 37
PAHs	1.6 ± 0.4	0.9 ± 0.6	0.9 ± 0.5	3.3 ± 2.9	2.5 ± 0.9	6.9 ± 5.5
Phthalic acids	37 ± 9.0	38 ± 25	Nd[b]	40 ± 35	38 ± 20	Nd[b]
Fatty acids	385 ± 109	259 ± 51	Nd[b]	276 ± 105	198 ± 61	Nd[b]
Phthalates	796 ± 222	478 ± 40	93 ± 31	872 ± 221	173 ± 79	54 ± 26
Other-Org[c]	101 ± 39	81 ± 67	Nd[b]	77± 79	62± 36	Nd[b]

[a]Other-IC: Na^+, K^+, Mg^{2+}, Ca^{2+}, F^-, Cl^- and NO_2^-; [b]Nd: not detected; [c]Other-Org: alcohols and nitrophenols.

Levoglucosan is a tracert of biomass burning emissions [32][33][37]. In summer, the concentration of levoglucosan in classrooms was only one-seventh of that in laboratory. This is because cellulose combustion processes occur in laboratory. For example, students use alcohol lamps whose wicks are made of cotton fibers, releasing levoglucosan during combustion. The difference between the two was smaller in winter, mainly due to fewer student experimental activities. The *n*-alkane concentration in summer classroom was about half of that in laboratory, while the concentrations were comparable in winter. PAHs mainly come from the incomplete combustion of carbonaceous materials such as fossil fuels and biomass and undergo photochemical degradation in the atmosphere [38][39]. As can be seen from Table 1, both indoor and outdoor PAHs concentrations in summer were much lower than in winter. This is because, on one hand, emissions from heating and fossil fuel combustion increase in the city and its surrounding areas during winter; on the other hand, weaker sunlight in winter leads to slower photochemical decomposition of PAHs in the air, resulting in higher PAHs concentrations in winter [40][41]. Phthalic acids mainly originate from the photooxidation of PAHs and the combustion of plastic products [42][43][44]; their concentrations in the classroom and the laboratory were comparable. Fatty acids mainly come from the volatilization of oils and fats [45][46][47]. Fatty acid concentrations in the classroom were higher than in the laboratory in both summer and winter, due to the fact that food can be brought into classrooms, and oils from food surfaces volatilize into the air. Phthalates are plasticizers widely used in plastic products [48][49][50]. As seen in Table 1, phthalate concentrations in the classroom and the laboratory were much higher than outdoors in both seasons, especially in winter classroom where they were more than 20 times the outdoor concentration. Moreover, phthalate concentrations were much higher in the classroom than in the laboratory in both seasons (Table 2), indicating that a large number of plastic products (e.g., plastic flooring, paints, and other decorations) exist in both classroom and laboratory, volatilizing substantial amounts of plasticizers, and that more plastic products are used in the classroom, leading to higher plasticizer concentrations in classroom air. The relative chemical composition of indoor PM2.5 is shown in Figure 2.

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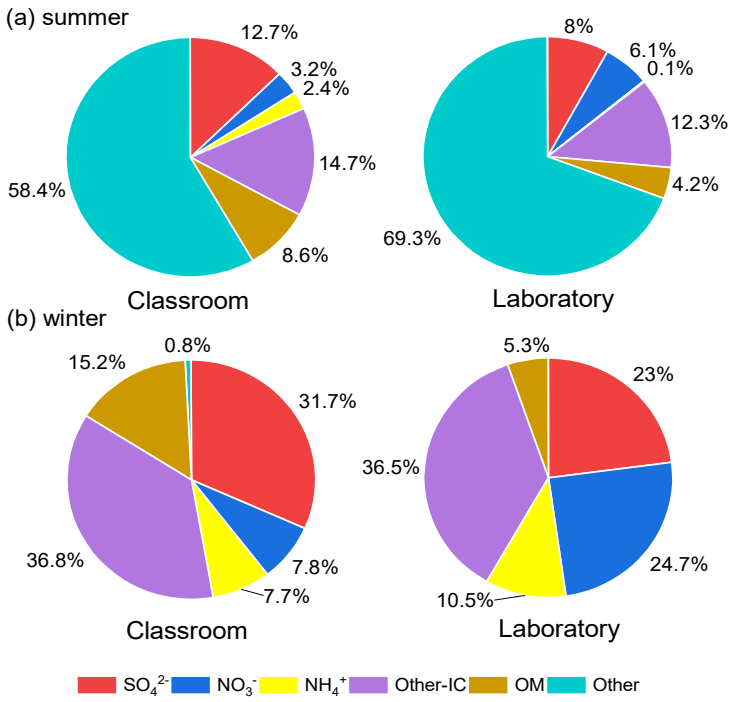

Figure 2. Chemical composition of indoor $PM_{2.5}$ during the summer and winter.

3.2. Chemical composition of indoor $PM_{2.5}$

3.2.1. Inorganic ions in $PM_{2.5}$

To further understand the sources of indoor $PM_{2.5}$ on campus, we analyzed the chemical composition of $PM_{2.5}$ in the classroom and the laboratory. In terms of inorganic ion composition (Figure 3), SO_4^{2-} had the highest proportion in summer, mainly due to outdoor air input. The second-highest ions differed: in classrooms it was Na^+, while in laboratory and outdoors it was NO_3^-. The third-highest ion in the classroom was Ca^{2+}, in laboratory it was Na^+, and outdoors it was NH_4^+. Compared to outdoors, both classroom and laboratory showed higher proportions of Na^+ and Ca^{2+} than NH_4^+, possibly due to denser indoor persons and more resuspended dust from the floor. Additionally, the higher Cl^- concentration in laboratory was mainly attributed to the volatilization of hydrochloric acid used during experimental procedures. This study also employed the equivalent balance of anions and cations to estimate the acidity/alkalinity of aerosol particles [51], in order to further investigate the pollution characteristics of indoor $PM_{2.5}$. The formulas for calculating cation equivalents (CE) and anion equivalents (AE) are as follows:

$$CE = \frac{[Na^+]}{23} + \frac{[NH_4^+]}{18} + \frac{[K^+]}{39} + 2\times\frac{[Mg^{2+}]}{24} + 2\times\frac{[Ca^{2+}]}{40}$$

$$AE = \frac{[F^-]}{19} + \frac{[Cl^-]}{35.5} + \frac{[NO_2^-]}{46} + \frac{[NO_3^-]}{62} + 2\times\frac{[SO_4^{2-}]}{96}$$

Where $[i]$ represents the mass concentration of inorganic ion i in $PM_{2.5}$ ($\mu g/m^3$).

The cation-to-anion equivalent ratios (C/A) of $PM_{2.5}$ were 2.48 in the classroom, 1.44 in the laboratory, and 1.88 outdoors, indicating that indoor and outdoor $PM_{2.5}$ were alkaline in the city. The stronger alkalinity of indoor particulate matter in the classroom was attributed to Ca^{2+} and Mg^{2+} from increased dust resuspension, whereas in laboratory, the use and volatilization of chemical reagents such as hydrochloric acid resulted in the lowest pH value for $PM_{2.5}$, making it relatively more acidic. In winter, NO_3^- accounted for the highest proportion outdoors,

ISSN: 2710-0588

approximately 2.5 times that of SO_4^{2-}. Compared to outdoors, NO_3^- and SO_4^{2-} concentrations in the laboratory were comparable; however, in the classroom, SO_4^{2-} was much higher than NO_3^-, with the former concentration being four times that of the latter, suggesting the presence of an indoor source of SO_4^{2-} in the classroom.

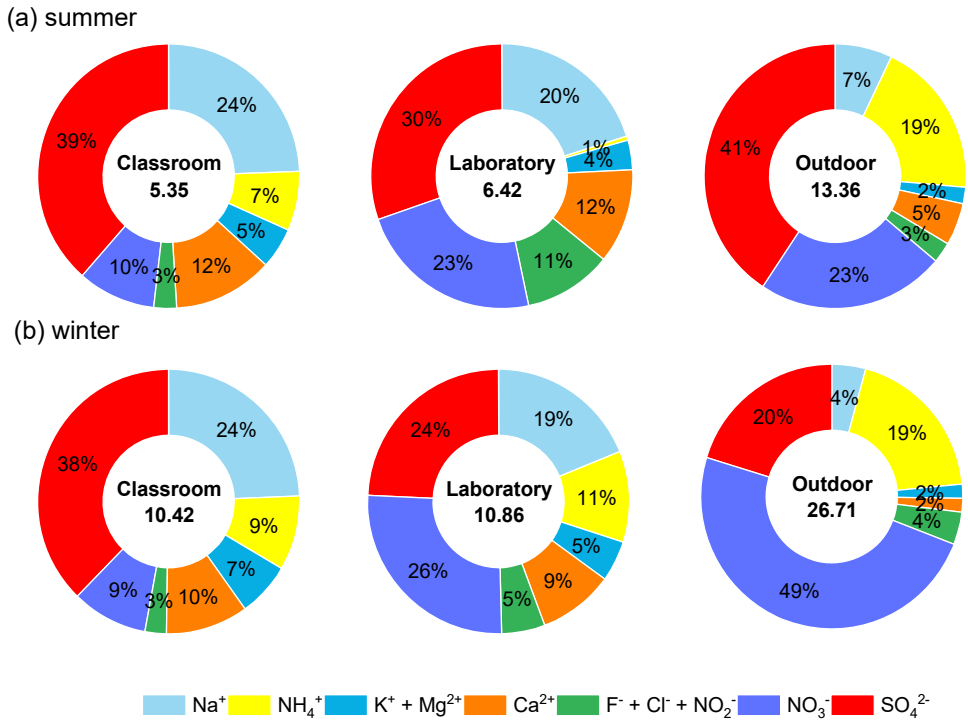

Figure 3. Chemical composition of inorganic ions in the indoor $PM_{2.5}$ during the summer and winter.

3.2.2. Organic matter in $PM_{2.5}$

In addition to inorganic ions, organic matter is a major component of $PM_{2.5}$ in the air. As shown in Figure 4, phthalates were the most abundant organic pollutants in $PM_{2.5}$, accounting for as much as 73% in winter classroom, with significantly higher concentrations in the classroom than in the laboratory, indicating that the greater use of plastic products and wall coatings in the classroom is a key factor. Hsu. et al. showed that excessive phthalate concentrations can increase the incidence of allergies and asthma in children[52] and affect children's reproductive health. Fatty acids were the second most abundant organic compounds in $PM_{2.5}$. Weschler et al. found that human sebum contains large amounts of free fatty acids (palmitic acid, stearic acid, etc.), which are the primary sources of organic aerosols and saturated fatty acids in enclosed spaces [53] . Therefore, high occupant density indoors, especially in the classroom, is the main source of indoor fatty acids. Furthermore, the proportion of *n*-alkanes in the laboratory was significantly higher than in the classroom. The main sources of *n*-alkanes are fossil fuel combustion and plant emissions [40][48], but there are no such sources in laboratory; this is mainly related to the intrusion of outdoor air pollutants due to window ventilation during student experiments. For the same reason, higher concentrations of phthalic acids and sugars in laboratory compared to classroom are also caused by greater outdoor air input, as the former are products of photochemical oxidation and waste incineration, while the latter are mainly products of biomass burning.

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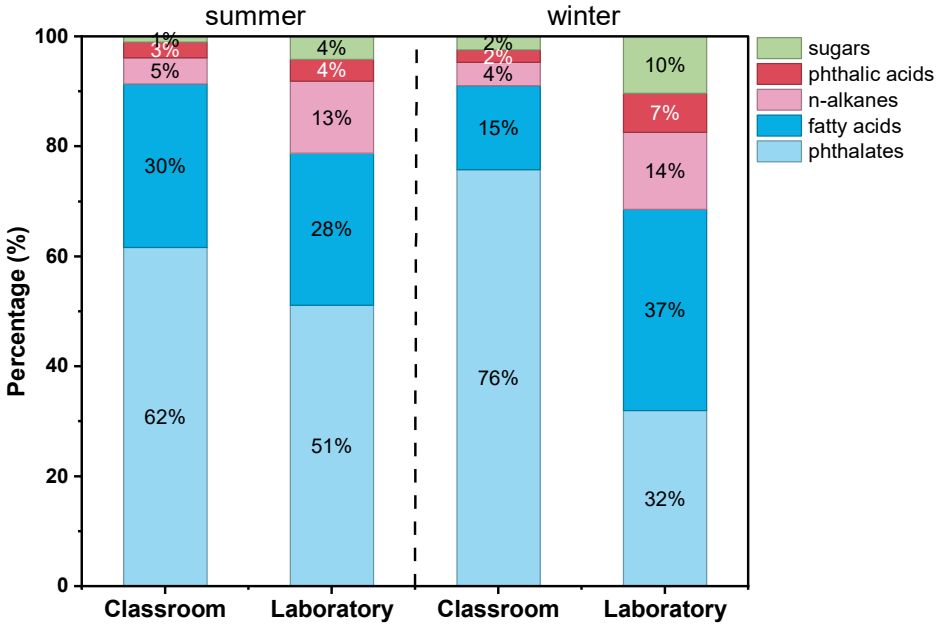

Figure 4. Chemical composition of organic matter in the indoor $PM_{2.5}$ during the summer and winter.

Figure 5 shows a comparison of the composition of indoor PAHs in summer and winter. It can be observed that the proportion of low-molecular-weight 3-ring PAHs in the classroom and the laboratory is significantly higher than outdoors, reaching as high as 70% in summer, while lower in winter. This finding is consistent with the results of Xu et al. [54], whose study also showed that the proportion of 3-ring PAHs in classroom air is higher than outdoors, where 4-ring PAHs dominate. This is because indoor temperatures are significantly lower than outdoor temperatures in summer, making the relatively more volatile low-molecular-weight gaseous 3-ring PAHs more likely to be enriched in the particulate phase, thus leading to a higher proportion of 3-ring PAHs in indoor $PM_{2.5}$. In contrast, indoor temperatures are significantly higher than outdoor temperatures in winter, causing 3-ring PAHs to partition more into the gas phase, thereby reducing their proportion in the particulate-phase PAHs indoors and resulting in a relatively higher proportion of high-molecular-weight PAHs with 4 or more rings.

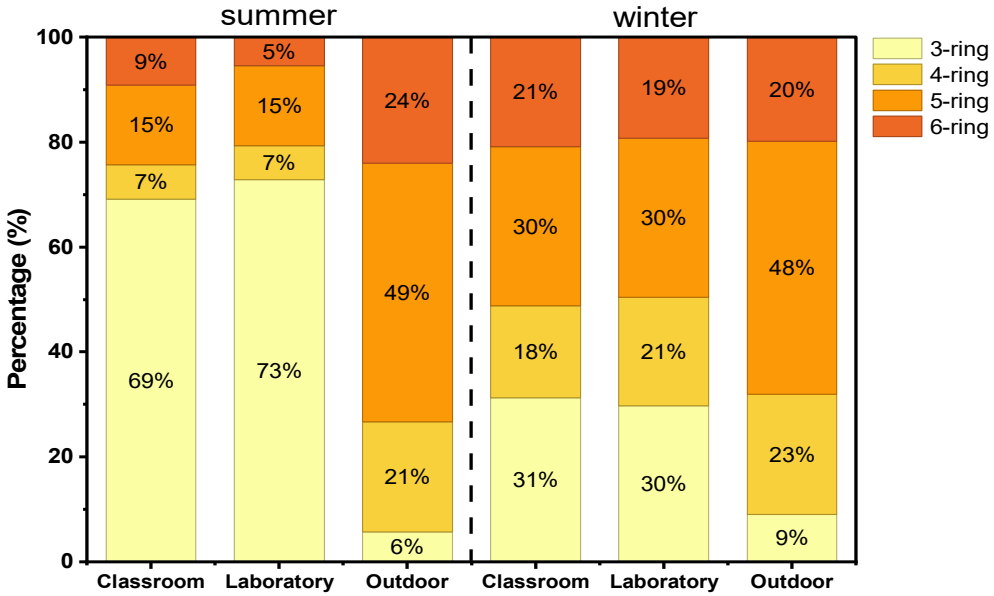

Figure 5. Molecular composition of PAHs in the indoor $PM_{2.5}$ during the summer and winter.

ISSN: 2710-0588

This study also analyzed the relative compositional variations of three major phthalate components: diisobutyl phthalate (DiBP), di-*n*-butyl phthalate (DnBP), and bis(2-ethylhexyl) phthalate (DEHP). As shown in Figure 6, indoor DEHP in summer was significantly higher than outdoors, accounting for 68% of the total, while DiBP and DnBP dominated outdoors. In contrast, in winter, low-molecular-weight DiBP and DnBP dominated the phthalates in both classroom and laboratory, while the higher-molecular-weight DEHP accounted for only 17–26%. Since the boiling points of DiBP, DnBP, and DEHP are 275°C, 340°C, and 384°C, respectively, DiBP partitions more readily into the gas phase in summer, causing its proportion in the particulate phase to decrease significantly, while DnBP and DEHP, being less volatile, tend to remain in the particulate phase. In winter, due to lower temperatures, DiBP partitions more into the particulate phase, thus increasing its proportion [55]. Kong et al. [56] found that DEHP accounts for a higher proportion in the particulate phase in winter, while DiBP and DnBP account for higher proportions in the gas phase in summer, consistent with the results of this study, indicating that the seasonal variation of indoor and outdoor phthalate pollution is mainly driven by temperature-dependent gas–particle partitioning. These phthalates, widely used as plasticizers in daily indoor decoration materials such as plastic flooring, paints, and inks, are endocrine disruptors with significant reproductive toxicity [57][58][59]. Therefore, the high concentrations of plasticizer pollutants indoors, especially in classrooms, indicate severe plasticizer pollution in the indoor air of middle school campuses, which needs to be addressed.

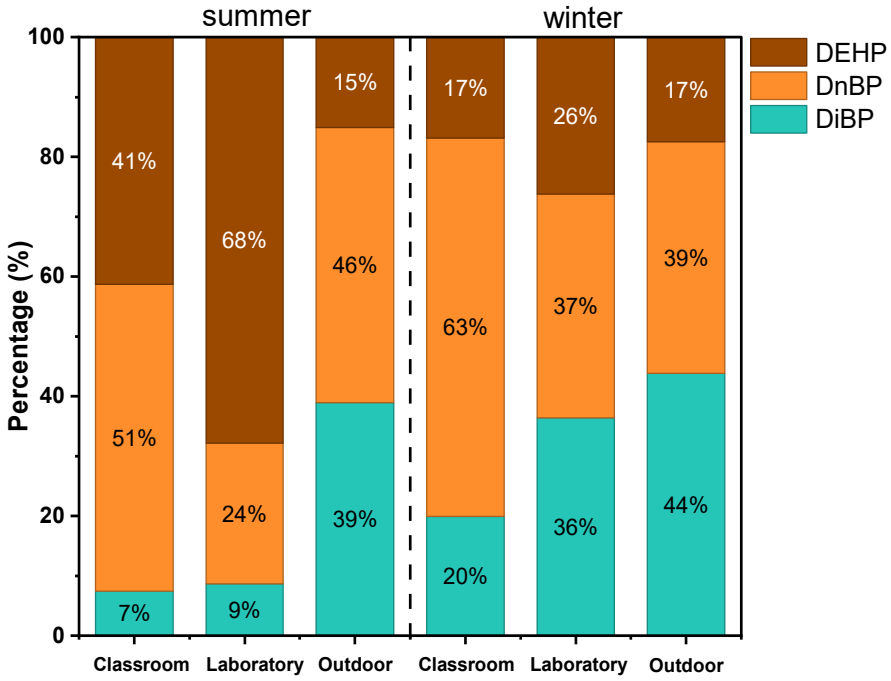

Figure 6. Molecular compositions of phthalates in the indoor $PM_{2.5}$ during the summer and winter.

4. Summary and Conclusion

In this study, $PM_{2.5}$ samples were simultaneously collected from classroom and laboratory air at a secondary school in a coastal city of China. Their chemical composition and concentrations were quantitatively analyzed and compared with outdoor environments. The main findings are summarized as follows:

(1) The average winter and summer $PM_{2.5}$ concentrations in the classroom and the laboratory ranged from 11–24 μg/m^3, which exceed the WHO recommended annual mean guideline value

ISSN: 2710-0588

of 10 μg/m^3, indicating that current indoor air quality in middle school of China requires further improvement.

(2) Due to increased window ventilation leading to greater outdoor air intrusion in summer, $PM_{2.5}$ concentrations in both classroom and laboratory were higher in summer than in winter. Notably, summer $PM_{2.5}$ concentrations in laboratory were comparable to outdoor levels, indicating that enhancing air conditioning ventilation in laboratory during summer is an effective means of improving indoor $PM_{2.5}$ pollution on campus.

(3) In terms of inorganic ion composition, the proportions of cations such as Ca^{2+} and Na^+ in classroom and laboratory $PM_{2.5}$ were higher than outdoors, suggesting that indoor dust resuspension is an important contributing factor. This indicates that further strengthening indoor floor cleaning would help reduce $PM_{2.5}$ pollution.

(4) The campus indoor $PM_{2.5}$ contained high levels of phthalate plasticizers, with concentrations more than one order of magnitude higher than outdoors, reaching as high as 872 ± 221 ng/m^3 in winter, indicating severe plasticizer pollution in indoor campus air, which mainly originate from the volatilization of plastic flooring and wall coatings. Because these substances are reproductively toxic, reducing the use of such plasticizers is of great significance for protecting student health.

Declaration section:

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors

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