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Microplastic Fallout in Different Indoor Environments

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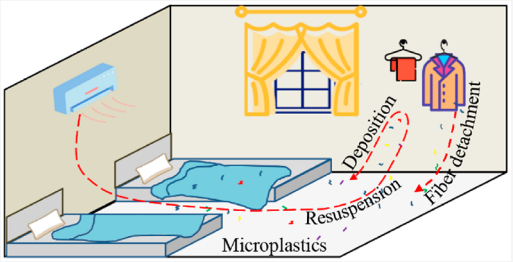
ABSTRACT: Microplastics in the air have gradually attracted our attention in recent years; however, temporal and spatial trends of microplastics in indoor air are rarely discussed. In the present study, we tracked microplastic fallout in a dormitory, an office, and a corridor on both workdays and weekends for three months. In addition, an air conditioner was used to understand airflow influence on microplastic resuspension in the dorm. Among the three sampling sites, the highest average microplastic abundance appeared in the dormitory (9.9×10^3 MPs/m^2/d), followed by the office (1.8×10^3 MPs/m^2/d) and the corridor (1.5×10^3 MPs/m^2/d). In the dormitory, the average MP abundance on weekends (1.4×10^4 MPs/m^2/d) was approximately three times of that on weekdays (5.8×10^3 MPs/m^2/d). In the office; however, the abundance on weekends (1.2×10^3 MPs/m^2/d) was 50% of that on weekdays (2.4×10^3 MPs/m^2/d). Microplastic fallout existed mostly in the form of fibers and showed similar polymer compositions to the textile products used in indoor environments. The airflow tests using an air conditioner suggested that airflow turbulence increased resuspension of microplastics. Taken together, we conclude that indoor environments are prone to serious microplastic pollution, but microplastic level varies greatly due to different characteristics of indoor setting. Our results also indicate that textile quantity is one of the main factors affecting microplastic abundance in indoor air, whereas air conditioner-induced airflow turbulence can cause microplastic migration in indoor environments.



1. INTRODUCTION

Microplastics (MPs) are generally defined as plastic particles smaller than 5 mm. They have been found to be widespread in environments and organisms.[1,2] Marine MP pollution has been well documented after this concept was first proposed in 2004,[3] and MP-related ecological effects and environmental consequences have been, and are continuously being explored.[4,5] Recently, human health risk is becoming a great concern due to MPs found in human related environmental media and food items.[6,7]

Recently, nine types of MPs were found in human stool, with a median of 20 MPs per 10 g of stool identified.[8] These MPs are likely to enter human digestive tract through food ingestion.[7,9] MPs have been found in various food items, including seafood, table salt, and drinking water.[6,10,11] In fact, exposure risk of MPs is not limited to ingestion of contaminated foods due to the widespread of MPs in terrestrial environments. Other routes may also contribute to human exposure. During the whole process from food harvest, production, packaging, and transport to food intake, extra MPs may be introduced in any stage.[12−14] For instance, plastic bottles and caps have been speculated to be one of the MP sources in bottled water.[12] It has been demonstrated that cap-bottleneck friction of plastic bottles will increase the number of MPs in a bottle.[13] Steeping a plastic tea bag in 95 °C water for 5 min releases billions of MPs and nanoplastics.[14] Another important source for human exposure is atmospheric MPs, which have the ability to contaminate other media.[15] Air is indispensable for human survival; however, less attention has been paid to MPs in the air, compared to the MPs in the other environmental compartments. MPs in atmospheric fallout were first reported by Dris et al.[16] using data collected in Paris in 2015. Subsequently, different levels of atmospheric MP pollution were detected in many other countries and regions, in both indoor and outdoor environments.[17,18] The diversity of MP forms in the air (i.e., suspended and deposited) leads to distinction of sampling methods. Dry and wet deposition, as well as dust collection, was used to detect deposited MPs, while air sampling is an effective way to collect suspended MPs.[17−20]

Modern human activities are often conducted under indoor environments, with relative residence proportion of 89%.[21] The air quality of indoor space thus has great impacts on human health.[22] Moreover, both suspended and deposited MPs have been reported in higher abundance in the indoor space than outdoors.[20,23] MP intake through ingestion of atmospheric fallout cannot be ignored, because it may even be more frequent compared with that through ingestion of MP-contaminated food.[24] It has been estimated that incidental

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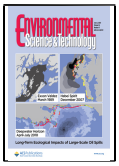

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human ingestion of MP fallout during dinner could be (1.4−6.8) × 10^4 MPs/y/person, which was much higher than MP intake via mussels consumption (1.2 × 10^2−4.6 × 10^3 MPs/y/person).[24] Recently, mass of polyethylene terephthalate (PET) particles in dust was estimated, demonstrating dust as another source of human exposure to MPs.[23] At the same time, children are facing higher exposure risks via consuming dust, in both indoor and outdoor environments.[19,23] Abbasi et al.[19] calculated that street dust exposure may lead to higher intake of 1.6 × 10^3 MPs/y per child in a normal exposure scenario (200 mg/d), compared to 0.8 × 10^3 MPs/y per adult. Although there is still no direct evidence that MPs are toxic to human beings, the results of toxicological tests on aquatic animals, mammals and cells may have some implications for human health effects from MPs. Ingestion of MPs induced inflammatory responses in the digestive system of *Mytilus*.[25] In vitro experiments showed that polystyrene (PS) could be internalized in a variety of cells, causing damages to intracellular structures.[26,27] Also, PS particles have been reported to cause cytotoxic and inflammatory effects in human lung epithelial (BEAS-2B) cells.[28] After being ingested, MPs are capable of translocating and accumulating in different organs and tissues. Mouse-model-based experiment showed that MPs can accumulate in gut, liver, and kidney.[29] Moreover, the chemical additives used for plastic manufacture can also threaten human health, such as terephthalic acid and bisphenol A.[23] All these findings call for urgent attention on atmospheric MP pollution, especially for indoor air.

In outdoors, wind is one of the key factors affecting MP movement. Once entering the air, outdoor MPs can be transferred to remote areas through wind.[16,30,31] Likewise, there is also airflow in indoor environments, say via air conditioner (a/c). An a/c can produce airflow with various intensities under different operating modes. Previous studies suggested that airflow can cause resuspension of particles in indoor space.[32] Considering the common use of a/c in daily life in modern-day cities, we speculate that the turbulence thus induced may influence MP movement.

Both spatial and temporal variations of MP abundance have been found in outdoor air, but are rarely discussed in terms of indoor air.[16,17] In particular, long-term observation and analysis of MPs in the same indoor environment has not been carried out. For a better understanding of these issues, we monitored MPs in different indoor environments. The spatial and temporal trends of MPs in atmospheric fallout were detected. The sources of these MPs and the factors affecting MP abundance were explored, in terms of the characteristics of each space. Airflow turbulence tests were conducted to detect the influence of a/c-induced airflow on MP resuspension in indoor space.

2. MATERIALS AND METHODS

2.1. Study Area. Three indoor environments of the East China Normal University, Shanghai, China were selected, including a students' dormitory room, a students' office, and a corridor of a lecture building. The dormitory space is 25 m^2, occupied by two students; and the office space is 40 m^2, used by 12 people. The sampling spot of the corridor is near a window opened a little. Central air conditioner is used in the office and the corridor while split hanging air conditioner is used in the dormitory.

2.2. Passive Sampling of Indoor Microplastic Fallout. Indoor microplastic fallouts were collected on Tuesdays (weekday) and Saturdays (weekend) from 26 February to 26 May 2019, over 13 weeks in total. The duration of sample collection was 24 h. The activities in the dormitory and office were normal during the sampling period. In the corridor, remodeling was conducted from 6 to 9 April; so human activities in the corridor increased during those days. In the present study, we tended to obtain data closer to reality. Therefore, we did not do additional house cleaning deliberately during the sampling, but cleaned the dormitory twice a week and the office once a week as usual.

Samples were collected using stainless steel basins with an open area of 0.08 m^2 (D = 0.32 m, H = 0.11 m) (Figure 1).

Figure 1. Collection and extraction methods of microplastic fallout in indoor environment.

The passive sampler was adapted from previous studies.[20,24] Before taking samples, the basins were washed with ultrapure water. Then, they were sealed with aluminized paper and transported to the sampling sites; they were placed on the desks at the height of 1.2 m. Three replicates and three controls were conducted at each site. The treatment of the controls was consistent with that of the replicates but covered with aluminized paper during sampling. After 24 h dry deposition, the basins were covered with aluminized paper and then transported to the laboratory. Atmospheric fallouts were rinsed from basins with 3 × 0.5 L of ultrapure water, and filtered onto 5 μm cellulose filter membranes (Whatman GF/B). Pilot experiments showed that the number of MPs in the fourth rinse was similar to that of the controls. After filtration, membranes were quickly placed into glass dishes and dried for follow-up analysis. All operating procedures, such as wearing cotton lab coat and setting blank controls, were conducted according to strict standards to minimize experimental contamination.[33] The whole process of sample treatment excluded digestion and flotation to reduce loss of particles or MP contamination during too many steps.

2.3. Visual Observation and μ-FTIR Analysis. A total of 234 samples and 234 blanks were collected. Particles on filter membranes were observed using stereomicroscope (Micro-Imaging GmbH, Göttingen, Germany).[34] Their colors and shapes were determined according to the criterions of Hartmann et al.[35] The software image J allowed particle size to be measured. Since there were too many particles on membranes, eight equal slices were marked from the center of each circle filter membrane, and two of the slices were

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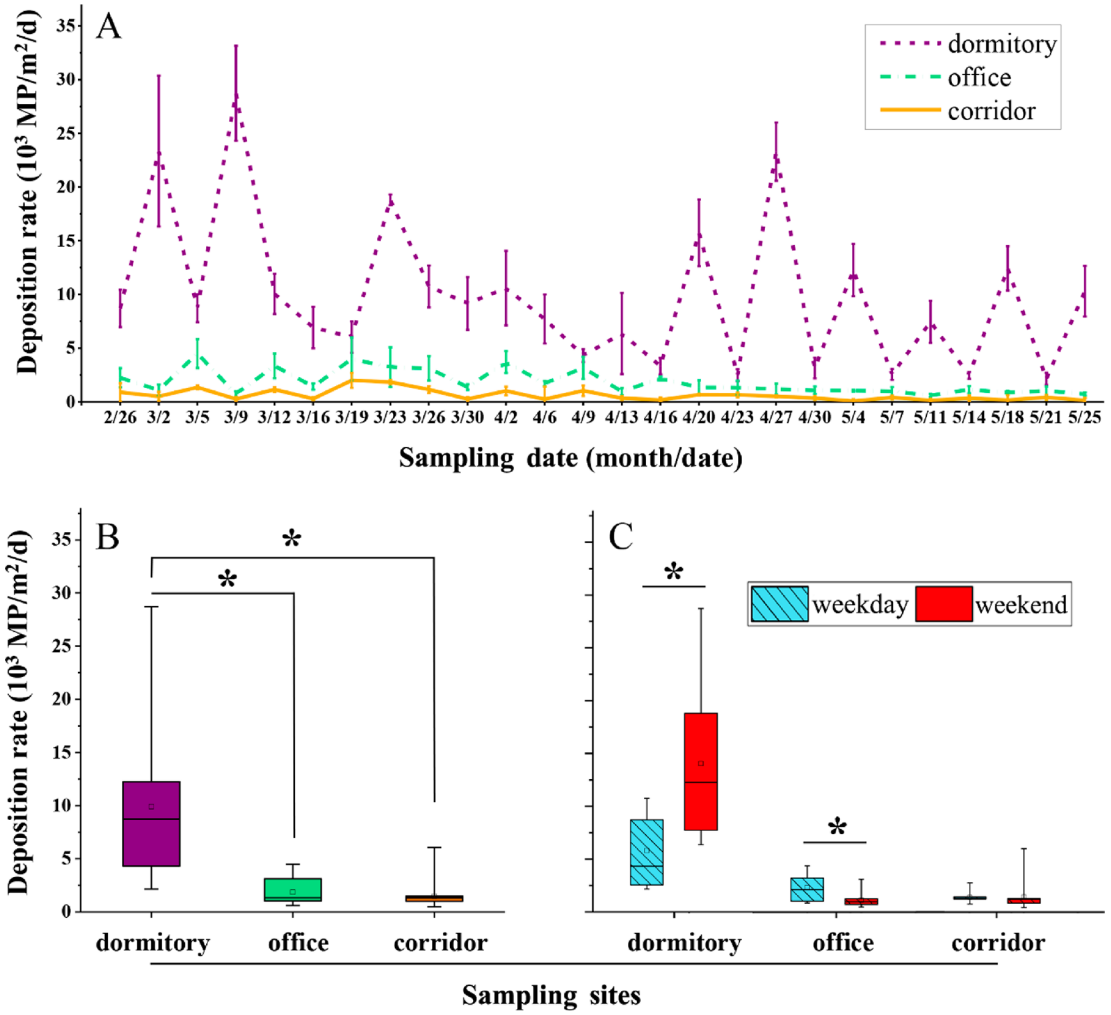

Figure 2. (A) Microplastic deposition rates in the dormitory, office and corridor during 13-week period. Results are presented as means ± SD (B) Spatial distribution of microplastics at the three sampling sites. (C) Temporal trends in microplastic abundance. Whiskers represent the maximum or minimum value. The upper and lower boundaries of each box represent the 75th and 25th percentiles, respectively. The horizontal line represents the median value, and the small white square represents the mean value. *: $p < 0.05$.

randomly picked and then observed. MP fallout was expressed in terms of MPs per square meter per day.

To make further identification, μ-FTIR technology (Thermo Nicolet iN10 MX, Thermo Scientific, Waltham, MA) was adopted.[34] Signals were obtained in transmittance mode, with the spectral range from 4000 to 650 cm^{-1}. Each spectrum was scanned 16 times and compared with the database. The matching degrees which referred to the spectral similarity between samples and database were obtained in OMNIC software.[36] A material was identified as plastic with matching degree >70%.[21] Rayon and cellophane are classified as plastics since they are manufactured by transformation of natural polymers. As it is hard to distinguish the obtained spectra of natural and artificial particles, the method for identifying semisynthetic and natural celluloses was adopted.[36] The particles on the filter membranes were picked onto the microcompression cell II with diamond window using a tweezer for identification through FTIR instrument. Considering that large amounts of fibers were the dominant shape of our samples, 50 fibers on each Tuesday from each sampling site were randomly chosen and identified, while the other nonfibrous particles were all analyzed. In total, 1950 fibrous and 136 nonfibrous particles were identified. The detection limit was 50 μm due to the magnification of microscope and identification method.

2.4. Collection and Identification of Textile Products. To confirm the sources of MP fallout in the dormitory, we collected all textile products used or worn by the two students who lived there. These products included clothes, curtain, bedding, towels, plush toys, hats, scarves, etc. Labels were checked to determine the content. A few fibers were detached from these textiles so their compositions can be identified by infrared microscopy.

2.5. Airflow Turbulence Test. To detect the effect of airflow turbulence on indoor MP distribution, simple tests were conducted in the dormitory. At 07:00, windows and door were closed; the experiment started at 08:00 (so most suspended particles settled down by then), and MPs were collected for 1, 2, 3, ..., 6 h' time. At 14:00, the a/c was turned on, and MPs were again collected for 1, 2, 3, ..., 6 h' time until 20:00. Another experiment was carried out to explore MP deposition rates under different a/c operating modes, including off, sleep, low (wind speed), medium (wind speed), and high (wind speed). MP fallouts were collected for 1 h under each mode. To make the results unaffected by human activity during airflow turbulence test, there was almost no human activity

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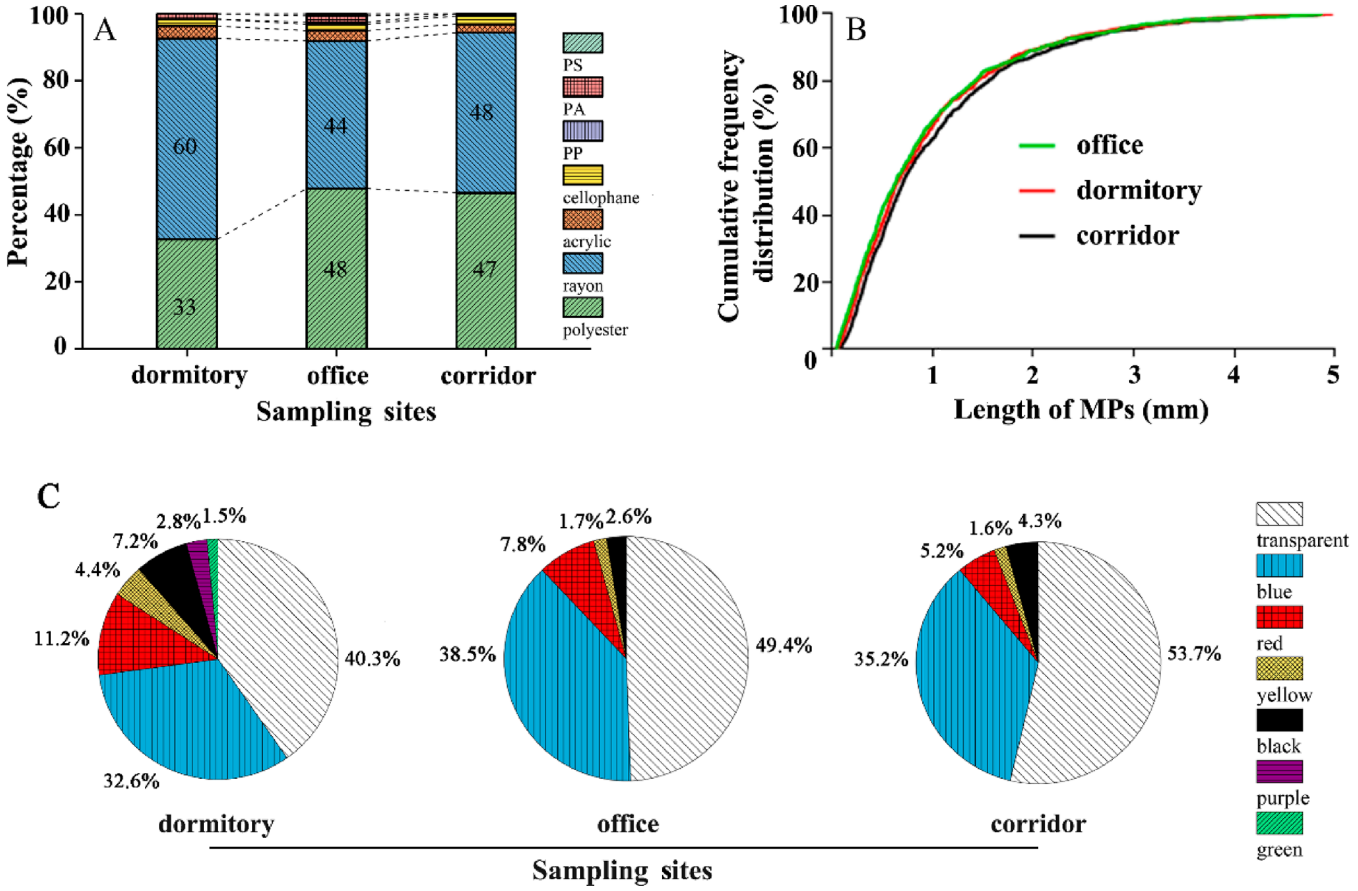

Figure 3. Characteristics of microplastics in the dormitory, office and corridor. (A) Composition, (B) Size and (C) Color. PS: polystyrene; PA: polyamide; PP: polypropylene.

during the sampling hours except for the gentle operation of covering and uncovering the aluminized paper.

2.6. Data Analysis. Statistical analysis was performed using software SPSS 17.0. Normality of the data was tested by the Shapiro-Wilk's test. Difference in MP abundance between weekdays and weekends at each sampling site was determined with a *t*-test. Data of different sites and of different a/c operating modes were analyzed using one-way ANOVA, followed by Tukey's posthoc test for paired comparison. $P < 0.05$ was considered to be statistically significant.

3. RESULTS

3.1. Microplastic Abundance in Indoor Environment. The total MP fallouts collected at the three sites were counted for each sampling day. The deposition rates of total particles (including plastic and nonplastic) were 5.7×10^3–7.7×10^4 particles/m^2/d in the dormitory, 1.7×10^3–1.3×10^4 particles/m^2/d in the office and 1.4×10^3–1.7×10^4 particles/m^2/d in the corridor. Only 1–5 fibers per filter were observed on each blank filter. Among the 650 fibers randomly selected from each site and identified via μ-FTIR, 37.5% (dormitory), 35% (office) and 35% (corridor) were identified as MPs, while natural fibers were the majority. The deposition rates of MPs were calculated according to the number of total particles and the percentage of MPs. The ranges of MP deposition rates were 2.1×10^3–2.9×10^4 MPs/m^2/d in the dormitory, 6.0×10^2–4.5×10^3 MPs/m^2/d in the office, and 5.0×10^2–6.0×10^3 MPs/m^2/d in the corridor (Figure 2A). The highest level occurred in the dormitory (Figure 2B). In both dormitory and office, MP abundance showed clear differences between weekdays and weekends (Figure 2C). In the dormitory, the average MP abundance on weekends (1.4×10^4 MPs/m^2/d) was almost three times of that on weekdays (5.8×10^3 MPs/m^2/d). The opposite trend occurred in the office, with MP abundance increasing on weekdays (2.4×10^3 MPs/m^2/d) and decreasing on weekends (1.2×10^3 MPs/m^2/d). The data of the corridor tended to be stable except for the period of decoration (6–9 April), during which the MP abundance has reached to 6.0×10^3 MPs/m^2/d.

3.2. Characteristics of Indoor Microplastics. Chemical compositions of the collected particles were identified using μ-FTIR. Similar percentages (35–37.5%) of MPs were found at the three sites (Figure 3A). Almost all the nonfibrous particles and more than 60% of the fibers were nonplastics, including, cotton, cellulose, protein, and inorganic substance. Seven types of synthetic or semisynthetic polymers were identified, including polyester, rayon, acrylic, cellophane, polypropylene (PP), polystyrene (PS), and polyamide (PA). Among them, polyester and rayon accounted for >90%.

Fiber was the most prevalent shape of the MPs we collected, and only one PS fragment was discovered in the office. The size distribution of the MPs showed a similar pattern among the three sites (Figure 3B). MPs of 50–2000 μm represented the majority, accounting for 80% of the total number of collected MPs. The dominant colors of the MPs were transparent, followed by blue, red, black, yellow, purple, and green (Figure 3C), which were similar to the colors of the textile products.

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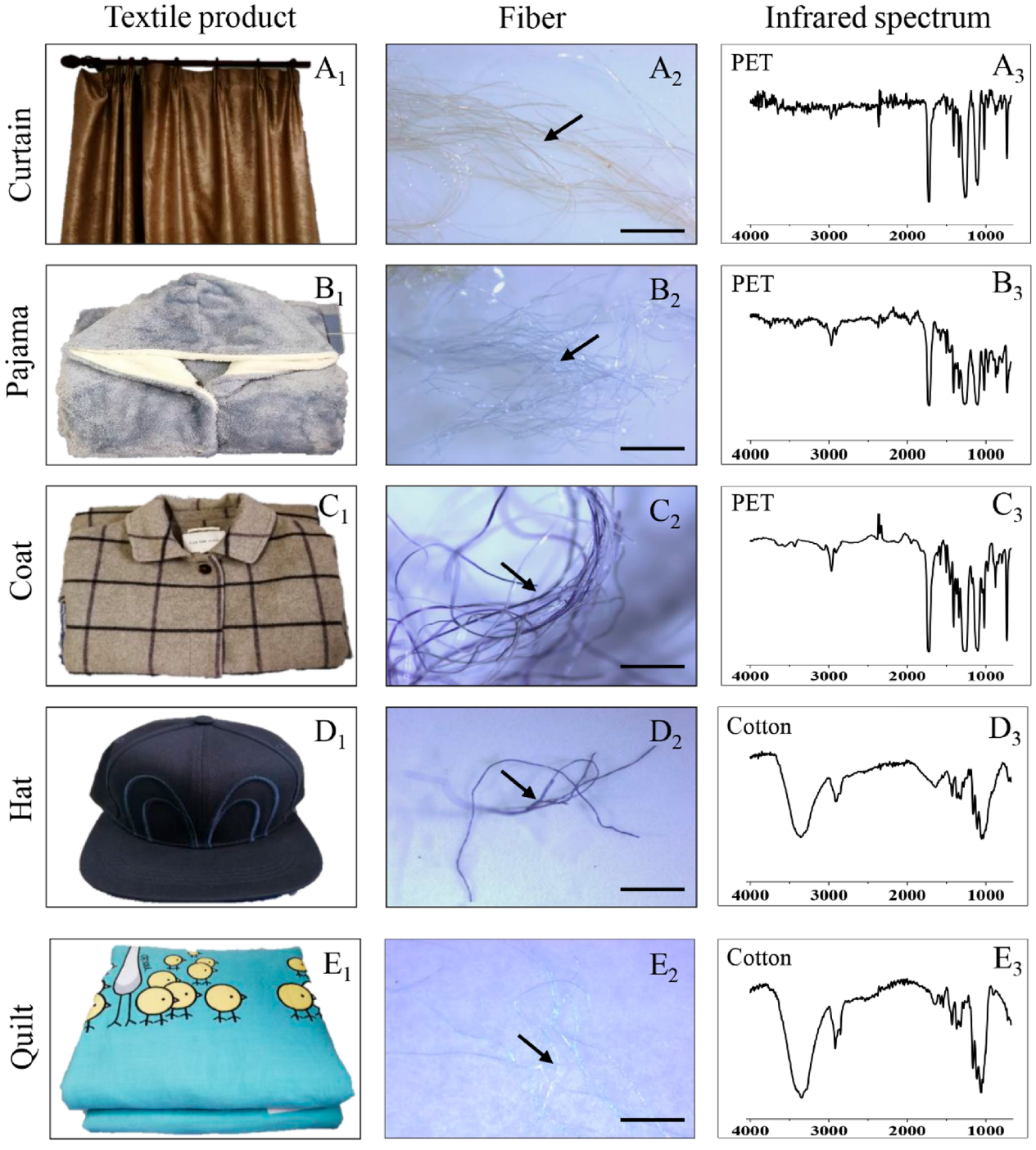

Figure 4. Main types of textile products (A_1–E_1), fibers taken from the textile products (A_2–E_2), and their corresponding spectra (A_3–E_3) in the dormitory. The black arrows in the photographs (A_2–E_2) indicate the particles that were detached and identified. Scale bar = 0.5 mm.

3.3. Compositions of Indoor Textile Products. The compositions of 131 pieces of textile products commonly used in the dormitory were identified (Figure 4A_1–E_1). According to their labels, 73 pieces were made of pure cotton, 22 pieces were made of pure polyester, and the rest were made of more than two materials. Of all the fibers taken from the textiles (Figure 4A_2–E_2), cotton fibers accounted for the majority, and the rest were MP fibers (Figure 4A_3–E_3). Overall, the information on the labels of the textiles and their compositions matched well.

3.4. Influence of Airflow on Microplastic Resuspension. Airflow turbulence tests were performed using the a/c in the dormitory. The MPs collected increased as the sampling time increased (Figure 5A). Under the same sampling duration, MP abundance was relatively low when the a/c was off, and increased significantly when the a/c was turned on. As for the effect of operating mode, all operating modes increased MP deposition rate compared with the off mode (58 MPs/m^2/d) (Figure 5B). Sleep mode had the least impact on MP deposition (179 MPs/m^2/d) compared with the other operating modes, whereas no significant difference was found under different wind speeds (i.e., 350 MPs/m^2/d under low wind speed, 333 MPs/m^2/d under medium wind speed and 383 MPs/m^2/d under high wind speed).

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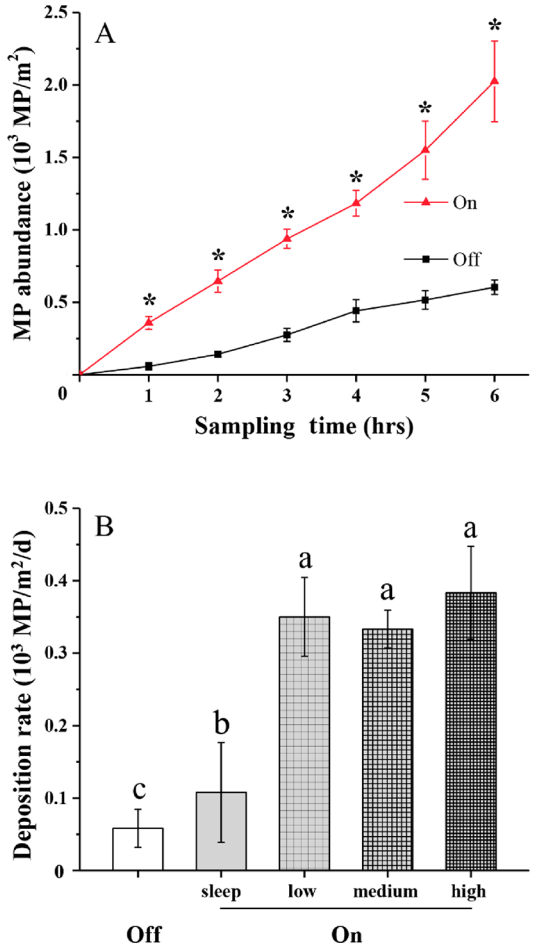

Figure 5. (A) Microplastic abundance under on and off modes of air conditioner. * presents significant difference between data of the two modes during the same sampling duration ($p < 0.05$). (B) Microplastic deposition rates under different air conditioner operating modes. Letters a, b, and c represent significant difference ($p < 0.05$).

4. DISCUSSION

4.1. Spatial Variation of Microplastics in Different Indoor Environments. Microplastics have been detected in atmospheric fallout in previous studies.[17,30,37] However, none of the study focused on MPs in different indoor environments over a long period. In the present study, we collected MPs from different indoor environments over 13 weeks. Not only temporal and spatial variations of MPs were observed, but also the influencing factors of MP abundance were identified according to different characteristics of indoor spaces.

Among the three sampling sites, the highest MP abundance occurred in the dormitory, about 4.4−50 times of that in the office and corridor. The characteristics were unique at each site. In the dormitory, there were rich textile products such as clothes and bedding; in the office, clothes were still the major textile products; in the corridor, the sampling spot was near a window opened a little, with very few people passing by. The biggest difference among the three sites lies in the quantity of textile products. Having collected this information, we deduced that the markedly spatial variation of MPs was likely caused by different textile quantities at different sites.

The spatial variation of MPs in the air exists not only in indoor environments, but also in outdoor environments. For instance, MP deposition rate was reported to be 53 MP/m^2/d in suburban area and 110 MP/m^2/d in urban area (most MPs > 200 μm) of Paris, which may be associated with different population density or pollution degree.[17] The abundance of MPs was 275 MPs/m^2/d (most MPs < 63 μm) in Hamburg, Germany,[37] while it was 36 MPs/m^2/d (most MPs > 200 μm) in Dongguan City, China.[18] The different detection limits induced by methodologies may be one of the factors resulting in such difference. Moreover, MP pollution levels differ between indoor and outdoor environments. Liu et al.[23] collected dust from 39 cities and found that both PET and PC abundance at home (PET: 2.7 × 10^4 mg/kg dust; PC: 4.6 mg/kg dust) were much higher than that outdoors (PET: 2.8 × 10^3 mg/kg dust; PC: 2.0 mg/kg dust). Note that the remarkably high MP abundance in the dormitory in our study has not been reported previously. Such result lies in the large number of textile products and relatively small space of the dormitory. This finding calls for urgent attention to indoor environments with similar characteristics, such as shopping malls, markest, and textile factories.

4.2. Temporal Trend in Indoor Microplastic Abundance. Our results clearly show that MP abundance is not a constant even at the same site and can fluctuate a lot over time. In both dormitory and office, the fluctuation of MPs coincided with students' work schedules. On weekdays, most students do not stay in the dormitory during daytime; they work in the office instead. On weekends, however, human activities decrease in the office and increase in the dormitory. Our results illustrate that more human activities can result in higher abundance of MPs. Besides, the significant increase of MPs in the corridor during remodeling (6−9 April) confirms this effect, considering there were more human activities than usual throughout this period.

Human activities have been demonstrated to have important effects on MP pollution, not only in indoor air but also in other environmental compartments. More MPs were found in outdoor air at the site with higher population density, which is considered as a proxy for human activity.[17] In marine environments, coastal zones with human activities are more likely to be polluted by MPs compared to pelagic zones.[38,39] Human activities such as fishing and recreation generate a large amount of plastic waste, an important pollution source of MPs in coastal zones.[40] Since the use of plastic products is inevitable in factory production and daily life, human activities have made and are making great contributions to MP pollution in various ways.

4.3. Sources of Indoor Microplastic Fallout. Fibers were found at all three sampling sites. Polyester and rayon were major types of the collected MP fibers, which showed similar polymer compositions to the textile products made of synthetic fibers used in the dormitory. Therefore, we deduce that textile products are the main MP sources in indoor environments. However, textile may not cover all MP sources due to the discovery of one PS fragment in the office. This fragment might be adhered to cloth and carried into indoor environment or blown into the room by wind since no PS material was used during our experiments.

Indoor MPs are often single-sourced, compared with outdoor MPs. In addition to MPs from textile products, there are MPs from weathering and fragmentation of plastic products such as plastic bags and bottles in outdoor environments.[18] As a result, MPs reported in outdoor atmospheric fallout have more diverse shapes and compositions.[23,41] For instance, fibers, foams, films, and fragments have

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been found in outdoor atmospheric fallout, with their compositions consisting of PP, PE, PS, etc.[18]

Fibers can be shed easily from textile products. Effluent of washing machine and emission of textile factories have been found to be important sources of MPs, especially fibrous MPs.[42−46] These particles can enter rivers, lakes, and seas.[47] Likewise, fibers in the air can also be transferred to remote areas through wind and rain.[16,30,31] The mobility of air is stronger compared with other environmental media. Therefore, air is not only suffering from MP pollution but also act as a vector of MPs, contaminating other environmental compartments, organisms, and food items. Indoor MP fallouts have the same source with laundry wastewater and textile factory sewage, which is textile products. Notably, plastic fibers have already entered the air during production, packaging, selling, and wearing before entering laundry wastewater. Fibers can also be shed from textiles during drying, sorting, and storage. Besides, a large portion of MPs in effluent can be removed by wastewater treatment technology,[48] whereas atmospheric MPs cannot be effectively reduced through filtration. Note also that while shedding plastic fibers, textile products also shed natural fibers such as cotton and cellulose ones, which are the majority (>60%) in the present study. However, the role of natural fibers on the anthropogenic pollution issue has been neglected in scientific studies.[49,50] Natural fibers have been proposed to hold environmental concerns like synthetic fibers do, considering their ability to sorb chemical pollutants.[49] Additionally, additives in cotton fibers may also cause effluent pollution.[51] Therefore, a more comprehensive understanding of microfibers, including synthetic and natural fibers, is needed when discussing environmental and health risks.

4.4. Factors Influencing Indoor Microplastic Fallout. According to the spatial variation of the MPs collected in the present study, we conclude that MP abundance in indoor environments mainly depends on textile quantity and proportion of synthetic materials. If the textiles made of synthetic fibers are predominant, MPs will account for a majority of the total atmospheric fallout. The characteristics of MPs including size, color, and type depend on the characteristics of the textiles used. For example, the discovery of PP particles was consistent with the PP carpet in the living room in one study.[20]

In outdoor environments, the key role of wind erosion has been confirmed in the transport of MPs.[31,52] As an important transport pathway of MPs, wind can carry environmental MP pollution a far distance from the original source. This has been reflected by the MPs found in a remote, pristine mountain catchment (French Pyrenees).[30] Similarly, our results suggest that airflow can induce migration of MPs in an indoor space. We find that the amount of collected MPs increased in the dormitory when the a/c was on. In fact, the airflow did not increase the total amount of MPs but induced the resuspension of the settled particles. After being resuspended, these particles redeposited into the sampling vessels from their settled locations. As a result, airflow turbulence changed the spatial distribution of indoor MPs. In addition to a/c, human activities such as walking and shutting doors have been reported to induce airflow inside a room.[46] MPs settled at corners or other places may drift onto food and drinking water without a lid as long as air turbulence exists, increasing the risk of human ingestion of MPs. Late-winter and early spring days were included in our sampling period, covering February, March, and April. During those months, heavy clothes increased MP sources; the increased use of a/c heater led to more air turbulence. At the same time, closed windows prevented indoor MPs from escaping. As such, MPs continuously deposited and suspended in the enclosed space. An effective way to reduce indoor MP fallout is to wipe off the deposited MPs on the floor and tables. As a result, the total quantity of MPs will decrease and the resuspension of MPs will also be reduced. However, such mitigation is temporary because fibers will be continuously shed from textile products and deposit into the air.

Based on our results, the temporal variation of MPs in indoor environments clearly reflects the influence of human activities. However, human activities are not the only factor; they combine with textiles (clothes) used and airflow turbulence. Therefore, increased human activities mean more MP sources and MP resuspension. In addition, the degree of fiber shedding from the textile itself affects indoor MP abundance. Various factors including the material, knitting technique, and aging of clothes have been demonstrated to have effects on fiber shedding.[46] It has been found that aged garments shed more fibers than newer ones.[46] As for textile construction, tightly constructed yarns are the preferred choice for reduced fiber shedding compared with fleece fabrics.[46]

The dynamic nature of MPs and the ways in which MPs interact with the surrounding environment in marine system have been extensively elaborated.[53] These all have influence on MP movement/transport in seawater and sediment. To date, the mechanism of MP movement/transport in the air is still unclear. Aerodynamic characteristics of MPs are not just affected by airflow. Many other factors may be involved. For instance, the physic-chemical characteristics of MPs themselves may affect the agglomeration, suspension duration, and the aerodynamic force required for resuspension. Temperature and humidity have been shown to influence particle resuspension as well.[54−56] Moreover, interactions between MPs and other atmospheric particles likely exist. These complicated issues need to be investigated in the future to have a deeper understanding of MP movement/transport in the air.

4.5. Human Exposure Risk of Indoor Microplastics. Dry deposition was adopted in the present study, followed by microscope and μ-FTIR analysis; this resulted in MPs smaller than 50 μm undetectable. The plastic fibers we identified (>50 μm) are likely to deposit after being shed from textiles. In a previous study conducted in household environment, one fiber was expected to deposit on a surface area of 4.32 cm^2 in 20 min.[24] If converted to the unit of the present study based on the MP proportion of 35%, MP deposition rate in household is equivalent to 5.8×10^4 MPs/m^2/d. This value is much higher than our data and highlights the severity of indoor MP pollution. Meanwhile, the deposited fibers also act as an important source of indoor dust MP contamination, being demonstrated as a non-negligible exposure pathway of humans, especially for children.[23] Researchers found that fiber was the main shape of MPs, and polyester was identified as an important component in MPs from dust, which is similar to our results.[23] Indoor dust has been estimated to cause a geomean daily intake of 1.7×10^4 ng/kg-bw of PET MPs in children.[23] In general, whether deposited onto food or dust, these fibers may cause digestive system exposure. Moreover, airflow is present as long as there are human activities.[46] The iterative deposition and resuspension of MPs induced by airflow in an indoor space raise risks for human MP exposure through MP migration onto food or into uncovered drinking

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water. In previous studies, smaller MPs were collected using air sampler in indoor and outdoor environments. The follow-up dyeing, SEM-EDX, fluorescence, or FPA-μFTIR-Imaging method allowed smaller MPs to be identified.[57−59] The smallest MPs detected were 5 μm so far.[58] Such MPs tend to suspend in the air and may enter human body through the respiratory tract. Similar with deposited MPs, suspended MPs also showed higher abundance in indoor environments (1.1−59.4 MPs/m^3) than outdoors (0.3−1.5 MPs/m^3).[20] Different from contaminated food causing digestive system exposure, atmospheric MPs may induce both digestive and respiratory exposure, accompanied by more serious MP levels in indoor environments. Consumption of some food products such as seafood, honey, and beer can be intentionally minimized or avoided, but potential exposure to MP-contaminated air is inevitable. Beyond that, the intake of atmospheric MPs through inhalation is believed to be the most significant among the pathways leading to human body burdens of MPs.[21] Overall, our knowledge on indoor MP fallout, as well as on the factors influencing indoor MP movement/transport, is still lacking. There is an urgent need for more studies focusing on these issues, which is of significance when assessing potential human health risk of MPs.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.0c00087.

Analysis of microplastics in indoor samples with μ-FTIR (Figure S1) (PDF)

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Notes

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