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Environmental Influences on Microplastics and Particulate Matter Resuspension in Indoor Air: A Study of Office Settings with Air Conditioning

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ABSTRACT

This study investigates airborne microplastics (MPs) in office environments, with a particular focus on spaces with air conditioning (AC), due to increasing health concerns. The research aims to analyze the physical characteristics, sources, distribution, and potential health risks of MPs. Despite growing awareness of MP pollution, comprehensive data on their specifics in office settings such as shape, composition, and size remain limited. Between November 2023 and January 2024, 42 air samples were collected under controlled conditions, both with and without AC, at the Air Resource Research Laboratory, Universiti Teknologi Malaysia Kuala Lumpur Campus. Stereomicroscopy was employed to identify the MPs' physical properties, revealing a dominance of bead-shaped MPs in air-conditioned spaces, with smaller particles (<50µm), often transparent or black, being the most prevalent. Environmental factors like wind speed and humidity were found to influence MPs' abundance. The study also noted a potential correlation between atmospheric MPs and particulate matter (PM) emissions, suggesting shared sources or accumulation mechanisms. Estimates of daily MPs intake through dust ingestion highlighted associated health risks. This research provides insights into the dynamics of MPs and PM in air-conditioned offices, emphasizing the need for further investigation into their environmental and health impacts. Effective mitigation strategies are crucial for reducing MP and PM exposure, thereby improving indoor air quality and protecting human health.

Keywords: microplastics, pollution, particulate matter

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1. INTRODUCTION

Microplastic particles (MPs) are raising significant concern due to their potential adverse effects on human health and the environment. These particles formed through the breakdown of larger plastic objects and deliberate production for different purposes. They can vary in size, ranging from nanometers to millimeters [1]. Indoor environments, such as residences and workplaces, are especially vulnerable to contamination by microplastics (MPs) originating from sources such as synthetic fabrics and consumer goods [2]. A critical issue arises from the re-suspension of MPs into the air, complicating the situation by increasing the risk of human exposure via inhalation [3].

Current research emphasizes the need to comprehend the origins and consequences of indoor microplastic (MPs) pollution for human health and the management of indoor air quality [4]. In response to this gap, the present study aims to investigate the environmental factors that influence the resuspension of MPs and particulate matter, in indoor air. By examining these environmental conditions, such as air flow and humidity, the study seeks to provide a clearer understanding of the extent of indoor microplastic pollution and its potential health impacts. This knowledge can support efforts to mitigate exposure and improve indoor air quality management strategies. Thus, this study examines the environmental influences on atmospheric and particulate matter resuspension in the air to gain a better understanding of the extent of microplastic pollution indoors.

2. METHODOLOGY

The research aims to investigate the resuspension of microplastics (MPs) and Particulate Matter (PM) in indoor environments influenced by AC systems within the initial 0-6 hours after activation. The sampling was done at Air Resource Research Laboratory, situated on the Universiti Teknologi Malaysia Kuala Lumpur Campus. from November 2023 to March 2024. The sampling method used was passive sampling, conducted under two different conditions: with air conditioning (labeled as AC) and without air conditioning (labeled as XAC). A total of 42 samples are gathered under settings when the air conditioning system is both operational and non-operational. Each condition was subjected to a total of six-hour cycles by using six basins each cycle, in addition to one control sample for contamination control. The sampling circumstances will ensure a consistent temperature of 16 degrees Celsius, utilizing fan settings at a moderate pace. Particle counters (Model: Lighthouse Handheld 2016) were used to measure the average total particulate matter concentration. Visual identification using a Stereomicroscope (Model: Leica EZ4W) to evaluate physical attributes such as size, shape (e.g., fiber, film, foam, fragment), and color variations (e.g., transparent, black, red, blue, green, orange, yellow).

An anemometer (Model: Lutron; AM4214SD) was used to measure environmental parameters such as temperature, humidity, and air flowrate to evaluate their influence on particle resuspension. The association between atmospheric MPs and PM levels were established using comparison between abundance of MPs and particulate concentration. Meanwhile the Estimated Daily Intake (EDI) was evaluated across different age groups by using Equation 1.

$$EDI\ \left(\frac{particles}{kg.day}\right) = \frac{Cp \times f \times IR}{BW} \qquad (1)$$

Where, Cp is the concentration of target MPs(particles/g) found in this study, f is the exposure time fraction of MPs based on age group, IR is the indoor dust ingestion rate (g/day), and BW is the average body weight of various age groups (kg). The exposure time fraction was taken based on 8 hours of working time meanwhile the IR value was taken as 0.03g/day [10] and the BW was taken as 53kg and 63kg for teenagers and adults respectively [11].

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics of Indoor MPs

Figure 1 shows various shapes of MPs (A), sizes of MPs in different conditions (B), and colors of MPs (C) which consist of beads, film, fragments and fiber for both conditions. In the AC environment, beads make up the largest portion, accounting for 52% of the MPs, followed by fragments at 18%, fibers/filaments at 17%, and films at 13%. This shows that bead-shaped MPs are the most common in air-conditioned spaces, with a relatively balanced distribution among the other types of MPs. In contrast, the XAC environment shows a significantly higher proportion of beads, comprising 72% of the MPs. Fragments and fibers/filaments are both present at 18% and 6%, respectively, while films make up only 4%. This suggests that bead-shaped MPs are even more dominant in non-air-conditioned environments, while the other types of MPs, particularly films, are less prevalent. Overall, the charts indicate that air-conditioned spaces have a more varied distribution of MP types, whereas non-air-conditioned spaces tend to be dominated by beads. This difference may be due to how air circulation, temperature, and humidity in AC settings affect the fragmentation or distribution of different types of MPs. This finding is contradicted with the finding from previous study where fiber is the most common shape found in indoor environment [5]. This may be attributed to the mechanical breakdown of plastics within the air conditioning system, where air circulation through filters and ducts causes abrasion and turbulence, resulting in a higher proportion of bead-shaped MPs.

Figure 1(B) shows the percentage of MPs across four size ranges: less than 50 µm, 50–100 µm, 100–500 µm, and greater than 500 µm. The smallest MPs, those under 50 µm, dominate both environments, accounting for 54.2% in XAC and 53.9% in AC, showing a nearly identical distribution. The second largest group is MPs sized between 50 and 100 µm, making up around 26.5% and 25.4% in XAC and AC, respectively. MPs in the 100–500 µm range represent a smaller proportion, with 15.1% in XAC and 14.2% in AC. The largest MPs, those greater than 500 µm, are the least common, contributing only 6.0% in XAC and 5.3% in AC. Overall, the size distribution of MPs is similar between the two environments, with smaller MPs being the most prevalent in both. This indicates that the presence of air conditioning does not significantly alter the size range of MPs found indoors, although it may still influence their movement or suspension. The dominance of MPs smaller than 50 µm is particularly concerning, as these are more likely to be inhaled and pose potential health risks. This finding also contradict with previous study found by Sin Yee et al., (2023) and Zhang et al., (2020) [6] where the majority size falls in more than 50µm. This discrepancy may be attributed to differences in sampling methodologies, environmental conditions, or the specific office environments studied.

Furthermore, Figure 1(C) shows seven (7) different colours are present in the room, which are transparent, black, red, blue, green, orange and yellow. Transparent and black microplastics dominate both conditions, with transparent MPs accounting for approximately 42.5% and 40.1%, respectively, making them the most prevalent. Black MPs as the second most common, making up around 22.4% and 21.1% in the two sets. In both conditions, orange microplastics appear next in significance, comprising around 12.5% and 13.6%. Meanwhile, red, blue, green, and yellow microplastics are less frequent but still notable. Red MPs contribute between 6.1% and 8.0%, while blue and green MPs each range from 5.0% to 7.1%. Interestingly, yellow microplastics show a marked increase from 3.5% in the first dataset to 6.9% in the second. This prevalence is indicative of typical plastic materials commonly found in office environments, such as packaging and office supplies. The frequent occurrence of transparent MPs in this and other studies suggests the potential for these particles to be affected during organic matter removal processes, such as acid digestion, potentially leading to their leaching or degradation [7, 5].

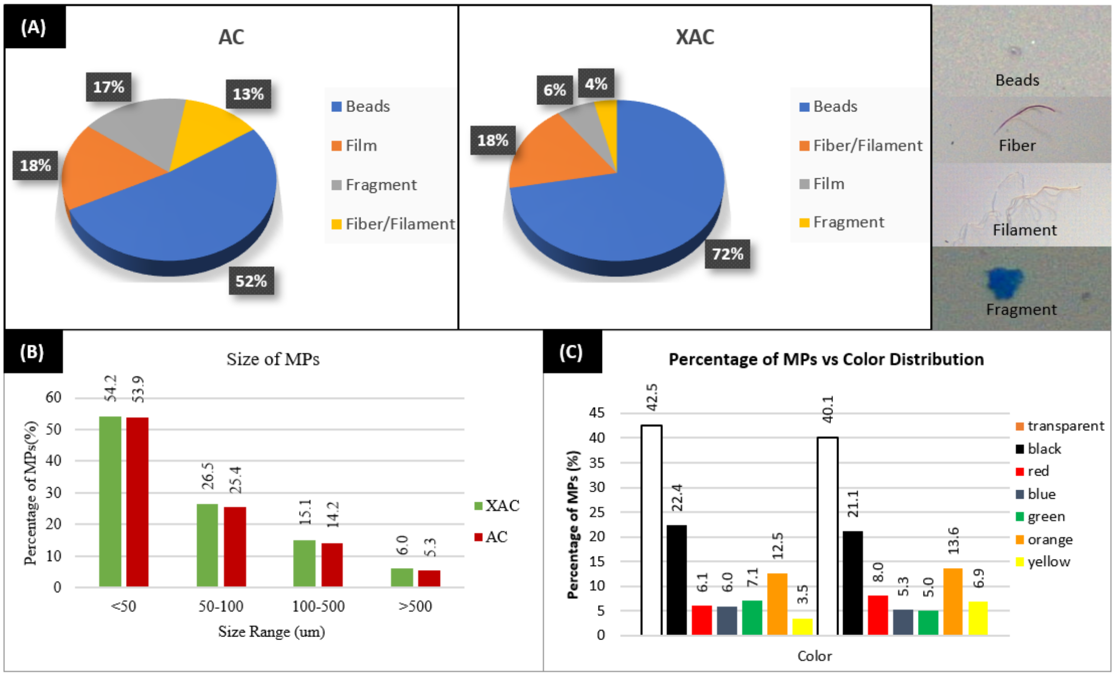

Fig. 1. Physical characteristics of indoor MPs (A) Shapes, (B) Sizes and (C) Colour

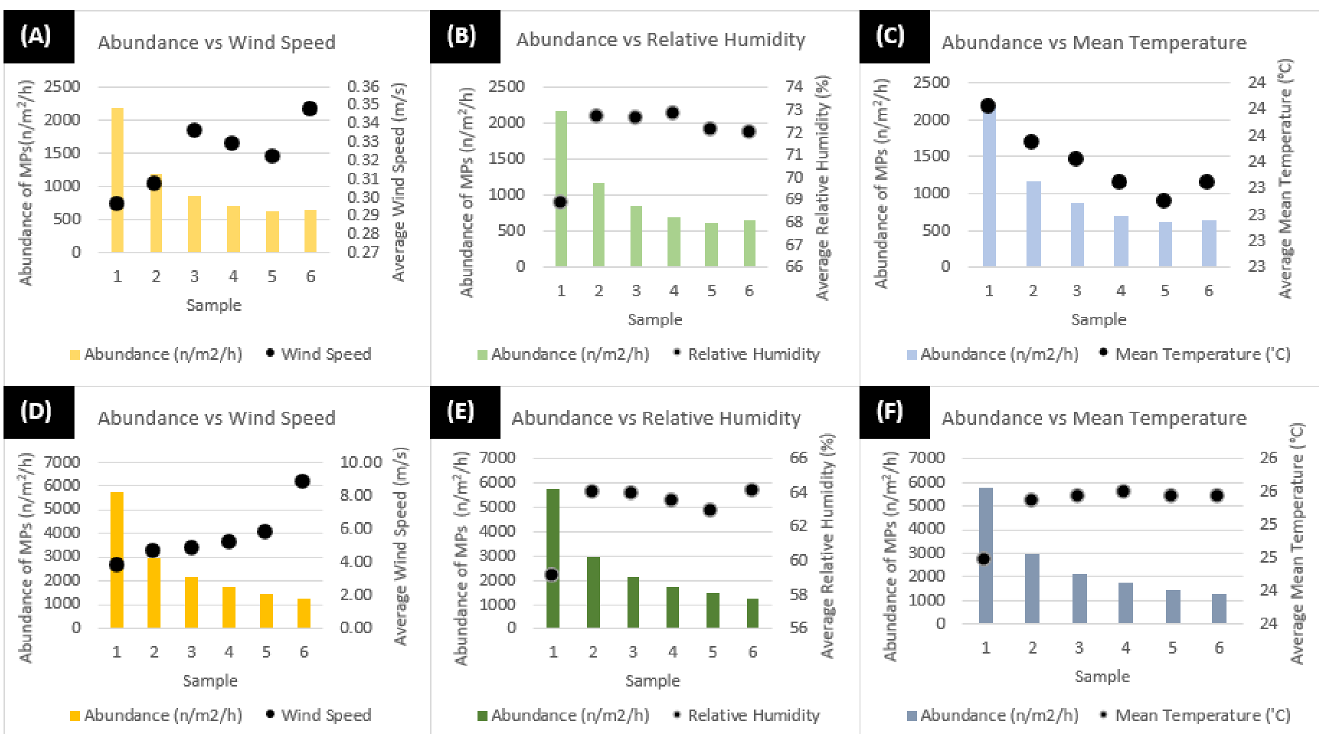

Fig. 2. Environmental Factor of MPs (A) Wind Speed with AC, (B) Relative Humidity with AC, (C) Mean Temperature with AC, (D) Wind speed without AC, (E) Relative Humidity without AC, and (F) Mean Temperature without AC**.**

3.2 Influence of Environmental Parameters on MPs Abundance in Air-Conditioned and Non-Air-Conditioned Environments

Figure 2 illustrates the relation of different environmental parameters on MPs abundance which shows environments. The environmental parameters include average wind speed, relative humidity, and mean temperature. The result shows that higher wind speeds correlate with decreased MP abundance, especially in air-conditioned environments. This outcome may be explained by the air circulation patterns in air-conditioned spaces, where HVAC systems could create a more controlled and consistent airflow that disperses MPs more effectively, reducing their localized concentration.

Meanwhile, Figure 2(B and E) indicates that higher relative humidity levels are linked to greater MP presence, likely because elevated humidity can influence particle behavior, such as by enhancing their suspension or reducing adhesion to surfaces. Previous study has shown that environmental parameters such as wind speed and humidity play significant roles in the distribution and transport of MPs in the atmosphere [8]. This study discussed how higher wind speeds could lead to the dispersion of MPs, while elevated humidity levels might enhance their suspension or reduce adhesion to surfaces, which aligns with the findings of the current study.

3.3 Comparison of MPs Abundances and Particulate Matter Concentration in Air-Conditioned and Non-Air-Conditioned Environments

Figure 3(A) shows six charts comparing the abundance of MPs under different environmental conditions, both with and without AC. Each chart depicts how MP abundance (n/m²/h) correlates with a specific environmental factor such as wind speed, relative humidity, or mean temperature. The black dots in each chart represent the average values of the environmental factor, while the bars represent the MP abundance. Without AC, MPs initially deposited at a rate of 5736.7 n/m²/h in the first hour, decreasing to 1261.7 n/m²/h by the sixth hour. This decline suggests factors like reduced air turbulence and decreased shedding from office materials and occupants. In contrast, with AC, deposition rates were lower, starting at 2174.2 n/m²/h and decreasing to 648.3 n/m²/h by the sixth hour, indicating improved air circulation and reduced particle settling. Thus, the findings highlight that AC systems play a critical role in managing indoor MPs pollution by maintaining lower and more consistent deposition rates compared to non-AC environments.

According to Figure 3(B and C), with the air conditioner running, PM concentrations ranged from 18 to 25 µg/m³, correlating with MPs abundance ranging from 620.8 to 2174.2 n/m²/h. Without the air conditioner, PM levels varied between 26 and 32 µg/m³, alongside MPs abundance ranging from 1261.7 to 5736.7 n/m²/h. These results suggest a positive correlation between higher PM concentrations and increased MPs abundance, particularly noticeable in non-airconditioned settings which is agreeable with previous study [9].

In the presence of AC, the relationship between environmental factors and MP abundance appears more moderate. For example, wind speed (Chart A) shows a slight variation, and MP abundance generally decreases across the samples. Similarly, relative humidity (Chart B) reveals no clear trend, indicating that higher humidity levels under AC conditions do not significantly impact MP abundance. Meanwhile, mean temperature (Chart C) demonstrates a slight decline in both temperature and MP abundance, suggesting a more stable environment when AC is used.

In contrast, without AC, the environmental factors have a more pronounced effect on MP abundance. Wind speed (Chart D) shows a strong positive correlation, where higher wind speeds are associated with a significant increase in MP abundance. For relative humidity (Chart E), there is an inverse relationship, where higher humidity levels lead to a marked decrease in MP abundance. Finally, the mean temperature (Chart F) without AC shows a more substantial decrease in both temperature and MP abundance, with MP levels being notably higher compared to the AC scenario.

Overall, the figure highlights that air conditioning plays a moderating role in mitigating the impact of environmental factors such as wind speed and temperature on microplastic abundance, while conditions without AC lead to greater fluctuations in MP levels.

Previous study suggested that PM2.5 and MPs could potentially serve as carriers for airborne MPs and polycyclic aromatic hydrocarbons (PAHs). The study implies shared emission sources or accumulation mechanisms affecting both PM and MPs in ambient air. Additionally, the findings suggest that air conditioner usage may influence this relationship, potentially reducing the buildup of both pollutants.

3.4 Comparison of MPs Estimated Daily Intake in Air-Conditioned and Non-Air-Conditioned Environments

The results shown in Table 1 are a comparison of the estimated daily intake (EDI) of MPs in particles per kilogram per day for teenagers and adults under two different conditions: with and without AC. For teenagers, the EDI of MPs is 0.42 particles/kg/day when AC is used, which increases to 0.88 particles/kg/day without AC. Similarly, for adults, the EDI is lower with AC at 0.25 particles/kg/day, but it rises to 0.53 particles/kg/day in the absence of AC.

Teenagers routinely exhibit elevated consumption rates compared to adults, irrespective of the presence of air conditioning, potentially because of disparities in activity levels or respiration rates. It also emphasizes that teenagers are more susceptible to greater amounts of MPs consumption compared to adults.

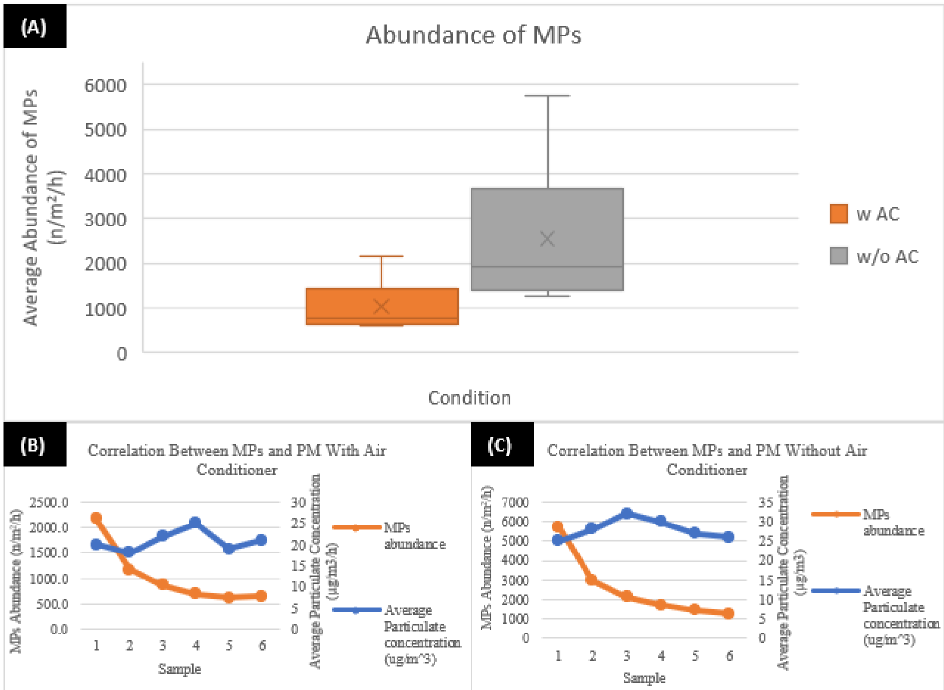

Fig. 3. Comparative Analysis (A) Abundance of MPs, Correlation Between MPs and PM (B) with Air Conditioner and (C) without Air Conditioner.

Table 1. EDI Comparison for Various Age Under Different Conditions

Conditions	Estimated daily intake of MPs (particle/kg.day)	
	Teenagers	Adults
With Air Conditioning	0.42	0.25
Without Air Conditioning	0.88	0.53

4. CONCLUSION

The study underscores the significant impacts of air conditioning on indoor MPs distribution and characteristics. AC environments show higher proportions of bead-shaped MPs, indicating potential fragmentation influenced by consistent temperatures and humidity levels. Both AC and non-AC settings feature MPs smaller than 50µm as predominant, raising concerns for respiratory health impacts upon inhalation. Transparent and black MPs dominate in both environments, with AC systems contributing to higher MP suspension rates due to increased wind speed and humidity. AC also reduces MPs accumulation on indoor surfaces, suggesting a complex interplay between AC use, indoor air quality, and potential health implications that warrant further investigation and management strategies. Future work should also investigate AC filtration systems to reduce indoor MPs concentrations.

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