Unravelling The Deposition of Indoor Microplastics at Various Heights Across Rooms

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Abstract. Microplastics (MP) are widely present in both outdoor and indoor environments. Extensive research has thoroughly documented the potential negative impacts of MPs on human health. This study utilized a deposited sample method for 3 weeks, with eight-hour daily exposures, using funnels and bottles to investigate the properties of MPs in the office and laboratory settings of the Faculty of Civil Engineering & Technology (FCET), Universiti Malaysia Perlis. The characteristics examined included the deposition rate, size, form, and colour of the microplastics. Samples were collected at three different heights. The samples underwent pre-treatment procedures, such as physical counting and categorization (size, colour and shape). Micro-Raman analysis was performed to determine the primary polymer types. The deposition rate in the office was found to be 4,960 counts/(m^2.h), while the rate in the laboratory was 6,940 counts/(m^2.h). Human activities and the appearance of synthetic materials, especially from textiles, play a big role in the deposition rate of MPs in the environment. During the day, the rates were higher than at night. The results of the study showed that indoor MPs come in many different colours, with transparent and black being the most common. About 42% of the size range of fibrous MPs was between 200 µm and 2000 µm, and more than 15% of the particles were between 20 µm and 200 µm. Most of the time, fragments were smaller than strands. The most abundance polymers detected in both rooms were polycarbonate (PC), pigments and polymethyl methacrylate (PMMA).

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1 Introduction

Microplastics are plastic particles ranging in size from 1 μm to 5 mm [1, 2]. Plastics are synthetic or partially synthetic materials made up mainly of polymers. Numerous synthetic plastics were created following the introduction of the initial plastic material, "celluloid," by John Wesley Hyatt in the 1860s. The following materials were developed: Bakelite in 1907, polystyrene (PS) in 1929, polyester (PES) in 1930, polyvinylchloride (PVC), polythene or polyethylene (PE) in 1933, and nylon (NY) in 1935 [3]. Plastics are commonly used because of their exceptional qualities, including adaptability, lightweightness, strength, durability, corrosion resistance, and thermal and electrical insulation [4]. [5] found a substantial rise in yearly plastic production from 1.7 to 360 million tonnes in the last 70 years. This indicates a tripling annually. Plastic's long history in manufacturing has led to its widespread recognition as an environmental concern. [6] observed higher indoor microplastics concentrations (1 – 60 fibers/m³) compared to outdoor concentrations (0.3 – 1.5 fibers/m³). However, there is limited awareness about the harmful effects of microplastics (MPs) on organisms and the environment. Indoor microplastic concentrations were found to be higher than outdoor concentrations in multiple studies [6].

Microplastics are insoluble particles that can be classified as primary or secondary. Primary microplastics are intentionally manufactured particles used for commercial purposes. Secondary microplastics are plastic waste fragments that have been reduced in size in the environment through physical, chemical, and biological processes [3]. Primary microplastics are produced for commercial purposes such as cosmetics, fibre production, and air blasting technology. Most indoor microplastic particles come from synthetic textiles commonly used or worn indoors. Fibres from clothing, carpets, curtains, and beds are the most common shape of microplastics [1, 6]. Indoors, PE pieces and fibres were the primary microplastics, while PVC fragments were more common in the outdoor air [7]. Secondary microplastics are formed by breaking down larger plastic materials. Fragmentation, including mechanical and biological degradation, can decrease the structural integrity of plastic debris to a size that is not visible without magnification. Plastic fragments can come from diverse sources including car tyres, furniture, clothing, and toys. Secondary microplastics primarily originate from the degradation of polymers due to solar ultraviolet (UV) radiation, which catalyses the oxidation process [8]. Several studies have examined microplastics in marine environments, but there is limited research on their presence in outdoor and indoor air [1, 7].

Humans can be exposed to microplastics through contaminated food, water, and air. Microscopic particles can enter the bodies of humans and animals through ingestion or inhalation, accumulating in the digestive or respiratory tracts, and potentially entering the circulatory system. This may obstruct the pathways [10, 11]. Additionally, these particles can potentially induce mucous membrane abrasion, irritation, and inflammation. In addition, they can impede digestion, decrease food intake stimulation, delay development, become embedded in tissues, and interfere with reproduction [3, 11]. [12] found that microplastics can adsorb organic pollutants and heavy metals, increasing their impact on human health. Microplastics aid in the transport and growth of pathogenic bacteria by their capacity to travel in the atmosphere [13]. Microplastics are present in the atmosphere, as well as in the food and drinking water consumed by individuals. [1] found that microplastic ingestion through table salts ranged from 0 to 7.3×10^4, through drinking water ranged from 0 to 4.7×10^3, and through inhalation ranged from 0 to 3.0×10^7. Inhalation is a more significant route of human exposure to MPs than ingestion through food and water. Indoor MPs concentration exceeds outdoor concentration [6]. Urban areas have higher levels of

MPs than semi-urban and rural areas [5]. Therefore, the indoor inhalation risk of MPs is very high.

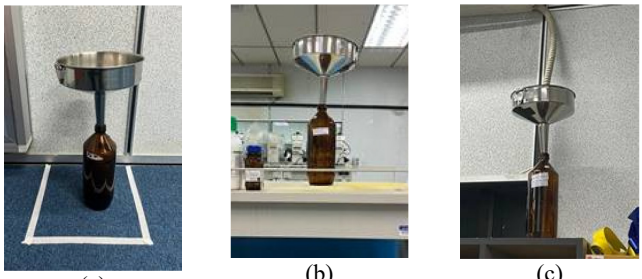
While previous studies have focused on the transport and deposition of microplastics in natural environments, limited research has been conducted on their behaviour in indoor settings. This study aimed to bridge this knowledge gap by investigating the settling velocities of microplastics of varying sizes and exploring the potential influence of indoor comfort parameters on their deposition.

2 Methodology

Two indoor environments within the Faculty of Civil Engineering & Technology (FCET) at UniMAP were chosen for this study: the laboratory and the main office. The laboratory facility was used by undergraduate and postgraduate students for conducting experiments. The laboratory observed an average of 5 individuals per hour. However, the chosen office space was mainly used by staff members, including a small number of academic staff. The average office occupancy per hour was 3 individuals. Daily tasks were commonly performed during regular office hours, with individuals typically situated in front of their desktop computers. Sampling occurred on weekdays from late December 2022 to January 2023, specifically on Wednesday in the office and Thursday in the laboratory.

2.1 Samples Collection

Biweekly collections of indoor microplastic fallouts were conducted for a duration of two weeks. In each room, 24 samples were collected during the daytime. These samples were taken at three different heights (Figure 1), with one sample collected every hour within an 8-hour period. In addition, a single sample was collected at a height of 1.2 m in each room. Samples were collected during both daytime and night-time of the second week at a height of 1.2 m. A total of 54 samples were collected over a two-weeks period. Activities occurred in both rooms were recorded throughout the sampling period. A simple fallout sampler consists of stainless-steel funnels with an open area of 0.0314 m^2, and an amber Duran bottle was employed at both sampling locations. Glassware, sampling funnels, tweezers, glass Petri dishes and vacuum filtration device components were rinsed with pre-filtered ultrapure water, 35% ethanol and acetone. Units were stored with non-plastic lids or wrapped in aluminium foil to minimize laboratory air contamination. Sample preparation should be completed prior to sample transportation to the designated sites. The funnel was exposed at heights ranging from 0.4 m to 2.2 m in each room, depending on the available furniture or supporting objects. After one hour of dry deposition, the funnels are covered with aluminized paper and transported to the laboratory. The funnels were washed with ultrapure water to collect atmospheric fallouts in the Duran bottle. The experiment recorded room temperature hourly to determine sample viscosity and settling velocity. Precautions were taken to prevent contamination, such as wearing cotton clothing, avoiding plastic gloves, and using a glass box for MP visual identification (Figure 2).



(a) (b) (c)

Fig. 1. Fallout sampler at various height: (a) 0.4 m, (b) 1.2 m and (c) 2.2.

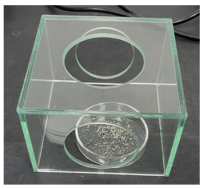


Fig. 2. Glass box used to minimize contamination from surrounding air.

2.2 Samples Preparation

The current state of research on microplastics extraction from environmental sample matrices reveals the existence of numerous knowledge gaps. These gaps primarily stem from the lack of standardized methodologies for the extraction process. The present study, however, employed the fundamental analytical methods commonly utilized for the analysis of water samples as described by [14]. Prior to polymer identification via micro-Raman analysis, the following procedure and processes were employed as illustrated in Figure 3. After an 8-hour period of sample collection, the sample is extracted by rinsing the funnel and bottle with ultrapure water to remove any particles that may have become attached to the surface. The sample is filtered using a vacuum filtration system employing mixed cellulose ester (MCE, ϕ47mm, 0.45 µ pore size) filter paper.

To ensure complete particle capture, the bottle was rinsed with pre-filtered ultrapure water. Hydrogen peroxide (H_2O_2) was employed in the wet peroxide oxidation process (WPO) of organic matter removal. Subsequently, the beaker was enveloped in aluminium foil and allowed to rest for a minimum duration of 24 hours, up to a maximum of 8 days. For density separation process, decantation was utilized to separate lower density of microplastics than the H_2O_2. One-third of the solution is discarded to remove the denser material, which was believed not part of microplastics. To prevent contamination, the filtered paper is placed in a petri dish and covered with aluminium foil, placed inside a desiccator for a minimum of one day to remove excessive moisture before further analysis. The blank sample also undergoes the aforementioned steps for contamination control.

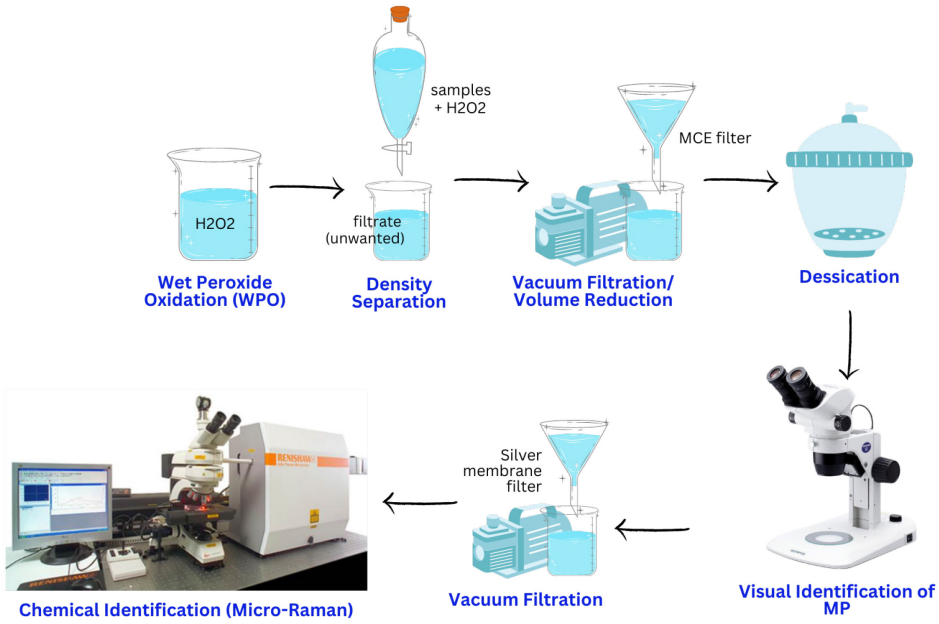


Fig. 3. Samples extraction procedure prior to polymer identification employed in the study.

2.3 Microplastic Counting and Visual Identification

The approach involved quantifying the quantity, morphology, chromaticity, and dimensions of microplastic particles found in every room. The MCE filter membranes were examined using a stereomicroscope (SZ51, Olympus) set at a magnification range of 8–35x. All probable microplastics were spotted and identified. Hot needle test was occasionally used for uncertain particles. The measurement of microplastic size was conducted by utilizing the ToupView and LasEz softwares for image processing, namely along the longest side. The particle properties, encompassing their form, colour, and size, were simultaneously documented during the observation of the particles under investigation. During the counting procedure, we additionally conducted measurements of the diameter of fibrous microplastics along their transect length using the same software for image processing. The measurements of fragmented and filmy microplastics' thicknesses were also conducted using the same procedure. The abundance rate of MPs can be obtained using equation 1.

$$\text{Microplastic abundance (count/m}^2\cdot\text{d)} = \frac{MP\ count}{A \times t} \quad (1)$$

Where, A is cross-sectional area of the funnel in m^2 and t is exposure time of sampling in days.

2.4 Polymer Identification

The materials were analysed for polymer identification using micro-Raman spectroscopy (XploRA™ PLUS, Horiba) in this study. For this purpose, microplastics picked up during the physical identification via stereomicroscope was deposited on the silver membrane filter paper (Sterlitech, ϕ25mm, 0.8 µm pore size). The curve smoothing procedure was executed utilising the OriginPro software with the aim of improving the smoothness of the

curves produced from the raw data acquired through micro-Raman spectroscopy. Typically, custom-built libraries are constructed using spectra obtained from pure polymer pellets, which can exhibit notable variations when compared to spectra derived from microplastics collected from ambient sources. Hence, the chemical identification was performed utilizing micro-Raman analysis, aided by the "RamanMP" R package, a software tool developed by [15]. The present software functions as a complete compilation that methodically combines Raman spectral peaks of frequently encountered plastic polymers and their additives, utilizing existing datasets that have been suitably revised for this specific objective.

2.5 Data Analysis

Parameters of comfort in an indoor environment such as relative humidity and temperature were recorded. All samples were statistically 6nalysed with IBM SPSS Statistics 26 and SigmaPlot 14.0 softwares. Finally, the Pearson correlation analysis was applied to the microplastics abundance with the comfort parameters.

3 Microplastics Abundance Across Rooms

3.1 Day- and night-time abundance of microplastics

Based on Figure 4, night-time deposition rates were seen lower than daytime rates. Rooms were vacant at night. Daytime deposition rates in two rooms ranged from 1,110 count/m^2·h to 1,130 count/m^2·h, while night-time rates ranged from 450 count/m^2·h to 875 count/m^2·h. Night-time deposition rates were lower than daytime rates due to reduced presence of microplastic sources from human clothing. The lack of human activity at night also contributed to lower deposition rates. Higher daytime deposition rates are due to increased human activities, resulting in more microplastic sources from clothing and resuspension [1]. The deposition rates of both rooms during daytime in week 1 were higher compared to the other samples.

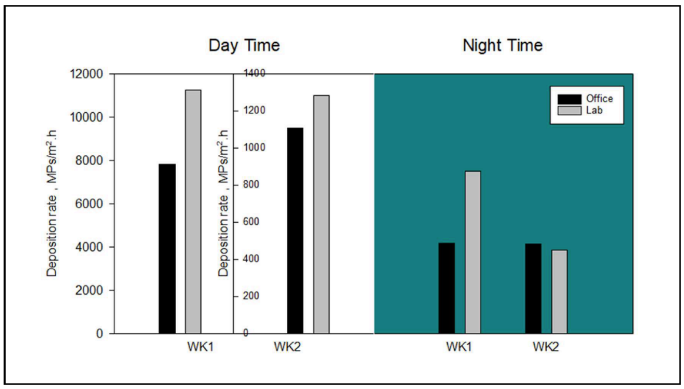


Fig. 4. Average deposition rates of microplastics during daytime and night-time between the office and laboratory.

During daytime, the average deposition rate in the office was 7,840 ± 6,100 count/m^2·h, while in the laboratory was 11,300 ± 8,670 count/m^2·h. In week 2, the deposition rates were lower compared to week 1, measuring 1,110 count/m^2·h in the office and 1,290 count/m^2·h in the laboratory. The high deposition rate in week 1 is due to the different sampling scheme used. Samples were collected every hour at different heights for eight hours,

resulting in 24 samples per room. The other samples were collected continuously for eight hours during daytime in the second week. During the sampling period, airflow turbulence occurred due to factors like air conditioners and human activities such as walking and closing doors [1]. These factors influenced the deposition rate by resuspending settled particles on the funnel. During night-time, the average deposition rate inside the office and laboratory were recorded at 662 ± 301 count/m^2·h and 485 ± 3 count/m^2·h, respectively. The levels of microplastic abundance observed in various rooms within FCET were found to be relatively consistent with the findings of Zhang's study (ranging from 600 to 29,000 count/m^2·h) [1], but notably greater when compared to the results of other investigations [6, 16].

3.2 Microplastic deposition at various height

The mean deposition rates of microplastic particles (MP) were computed at three distinct elevations above the floor, as observed in each room. According to the data presented in Figure 5, it was observed that the deposition rate was comparatively greater at the lower height within the office environment. The deposition rates at heights of 0.4 m, 1.2 m, and 2.2 m were recorded as 9,920 count/m^2·h, 7,140 count/m^2·h, and 6,450 count/m^2·h, respectively. As the elevation climbed, the rates of deposition exhibited a gradual decline. The study found that there was a drop in particle concentration as the height of the room increased, from the floor to the ceiling, similarly observed in other study [17].

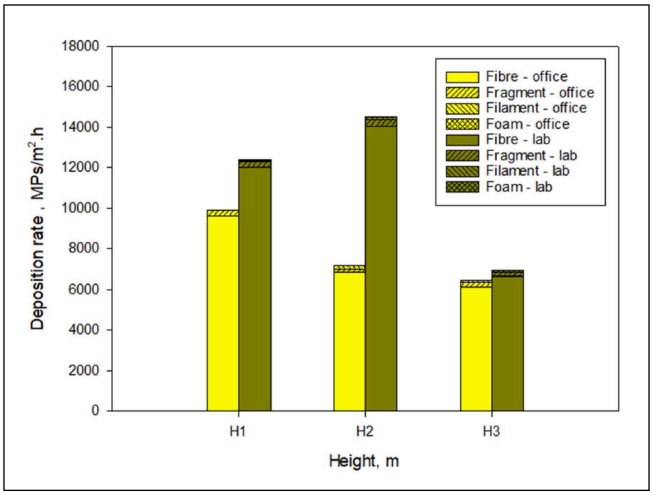


Fig. 5. Average deposition rates of microplastics shape at various heights in both rooms (H1: 0.4 m, H2: 1.2 m, H3: 1.8 or 2.2 m).

Within the laboratory setting, the rates of deposition were measured to be 12,400 count/m^2·h, 14,500 count/m^2·h, and 6,950 count/m^2·h, at heights of 0.4 m, 1.2 m, and 1.8 m, correspondingly. The deposition rate exhibited its maximum value at a vertical distance of 1.2 m in comparison to the other measured heights. The rates at which particles are deposited can be influenced by the process of resuspension, which is contingent upon various factors including particle size, the number of particles present on the floor, the kind of flooring material, the pattern of activity, and the level of occupancy [18]. The laboratory was populated by a significant number of students who were engaged in various activities. Consequently, the movement of air causes the resuspension of particulate matter at a lower altitude, subsequently transporting it to a higher altitude. In addition, it is worth noting that

the flooring in a laboratory consists of a hard surface that is notably smoother compared to the carpeted flooring typically found in an office setting. Hard flooring is not conducive to the accumulation of dust particulates [19], while carpet surfaces and vinyl flooring exhibit the highest adhesion forces [20]. Vinyl composite tile hard flooring had resuspension rates that were 3.6 times greater than those of flow through flooring, and 12.8 times greater than those of variable cushion tufted textile flooring [19].

Upon conducting a comparison of the average deposition rates at a height of 2.2 m in an office setting and 1.8 m in a laboratory setting, it was observed that there was no statistically significant difference in the average deposition rates between the two rooms. The average deposition rate in an office setting, at a height of 2.2 m, was measured to be 6,450 count/m^2·h. Similarly, at a height of 1.8 m, the average deposition rate was found to be 6,950 count/m^2·h. Nevertheless, there was a large disparity in the average deposition rates observed at various heights within different rooms. As an illustration, the mean deposition rates at a height of 1.2 m in both office and laboratory settings were recorded as 7,150 count/m^2·h and 14,500 count/m^2·h, respectively. Several studies have also demonstrated variations in deposition rates at various elevations [17] attributed to the influence of gravity and the increased dimensions of microplastic particles. Fibres were identified as the prevailing type of microplastics detected at all elevations within both rooms. The existence of numerous sources in the rooms, such as carpet, fibrous chairs in the office, and laboratory coats and heat resistant gloves in the laboratory, can be identified as the contributing factors to the quantity of fibres.

4 Characteristics of Microplastics Fallout Across Rooms

Fifty-four samples were observed under a stereomicroscope to analyse the shape of microplastics on the filter membrane (Figure 6). The office had an average of 3,200 fibers/m^2·h (96%), while the laboratory had 4,566 fibers/m^2·h (96%). Fibre was the main source of microplastic, followed by fragments, filaments, and foam. Indoor microplastics were primarily in the form of fibres, normally found in fabric and textile products followed by fragments [1]. Indoor air showed more colours than outdoor air, in various shapes [21]. The study identified transparent, black, blue, red, orange, yellow, and brown colours. Transparent was the most dominant colour (72%) in the office, followed by black (18%), and other colours such as blue, brown, red, yellow, and orange. In the lab, transparent was the most dominant colour (72%), followed by black (20%), and other colours such as brown, blue, red, yellow, and orange (Figure 7). Transparent colours in the samples may be due to the bleaching effect of hydrogen peroxide used to remove organic matter during pre-treatment [21]. Microplastic colour reporting is inconsistent. In other studies [5, 18, 21, 22], black was the most common colour observed among irregular particles, while films were predominantly grey or yellowish grey in indoor air in Northern New Jersey [18]. The presence of microplastics may be attributed to various sources, including tyre wear and brake pads [23].

Microplastic sizes were determined by measuring 10% of the most abundant fibre shapes [2]. Sizes of all non-fibrous microplastics were measured in each sample. Microplastic sizes were classified using a size classification scheme aligned with universal plankton [24]. Microplastic sizes were classified into four categories: <20 µm, 20 – 200 µm, 200 – 2000 µm, and >2000 µm. Figure 8 shows that fibres were the predominant microplastics in the 200-2000 µm size range in both office (46%) and laboratory (43%) rooms. Another study [1] also reported a similar finding, with the highest abundance of fibres ranging from 50 µm to 2000. Minimal foam was detected in the samples, with 6 counts in the office and 5 counts in the laboratory across all samples.

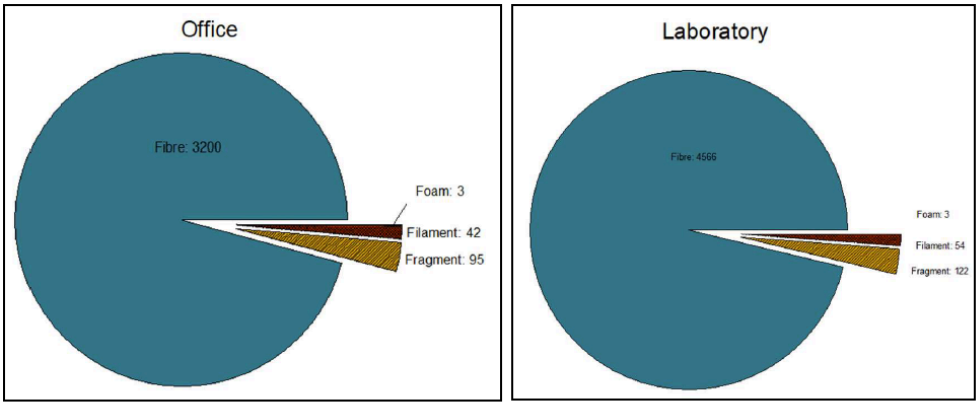


Fig. 6. Shapes of microplastics detected (a) in office, and (b) in laboratory.

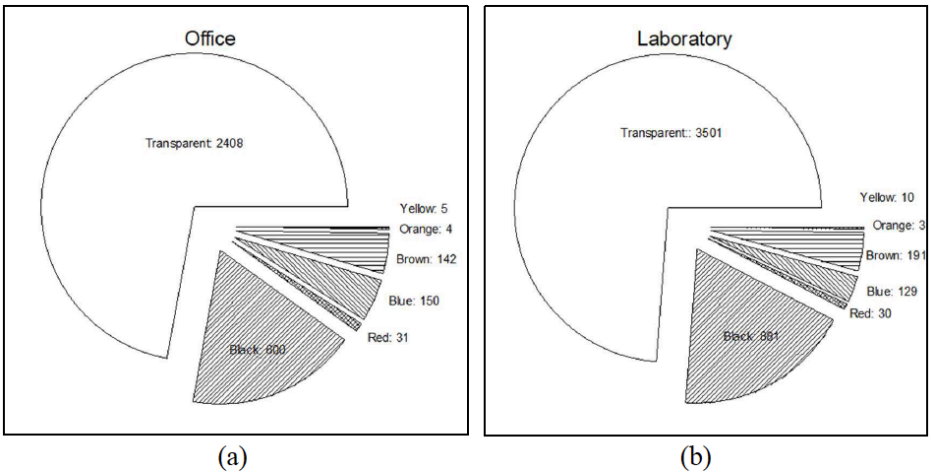


Fig. 7. Variation of colours in microplastics samples across rooms (a) office, and (b) laboratory.

Filaments showed a similar pattern to fibres, with the highest abundance observed in the size range of 200 – 2000 µm in both the office (7%) and the laboratory (5%). The abundance decreased in the 20-200 µm size range. Fragments were most abundant in the size range of 20-200 µm in both rooms, comprising 17% in the office and 15% in the laboratory. The fragments ranged from 200 µm – 2000 µm in size, with the second highest abundance. Smaller fragments were found compared to filaments. The maximum fragment length in the office was 268.75 µm, while for the filament it was 654.02 µm. Microplastics accounted for 56% and 51% of the total in the office and laboratory, respectively, falling within the size range of 200 µm to 2000 µm. In a study conducted in Surabaya, Indonesia, approximately 57% of microplastics were found within the range of 500 µm to 2000 µm, which aligns with our findings [25].

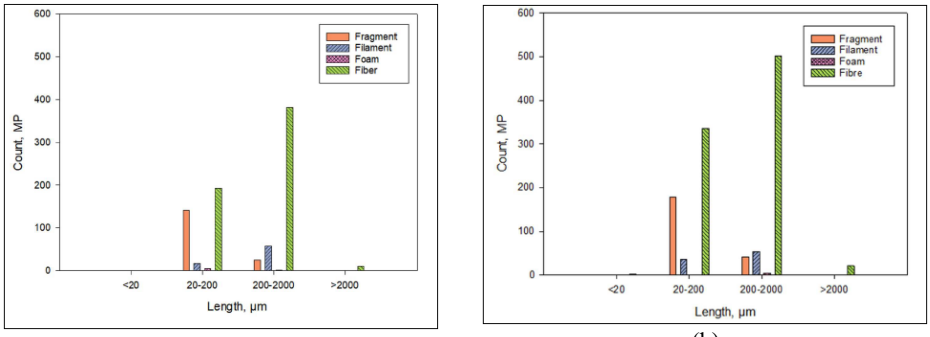


Fig. 8. Variation in sizes of microplastics across rooms (a) office, and (b) laboratory.

5 Polymers composition of microplastics

Polymers identification in all 54 samples was conducted based on assumption that microplastics featuring the same characteristics (shape and colour) were from the same source. Figure 9 shows the polymers variations in both office and laboratory rooms.

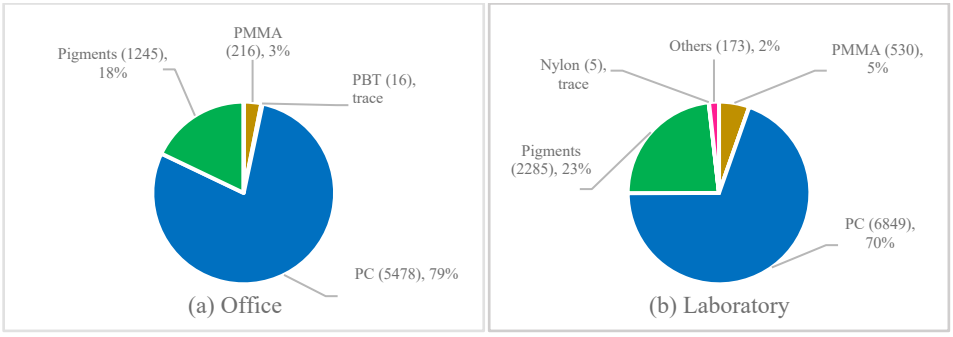
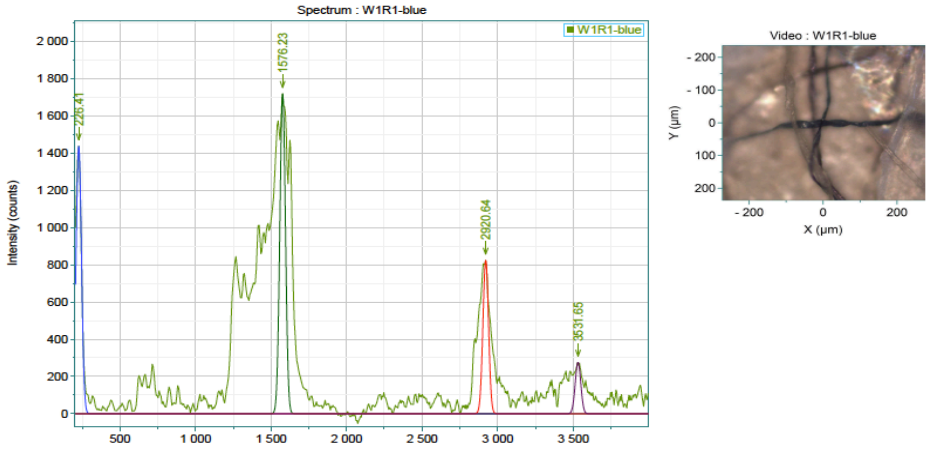
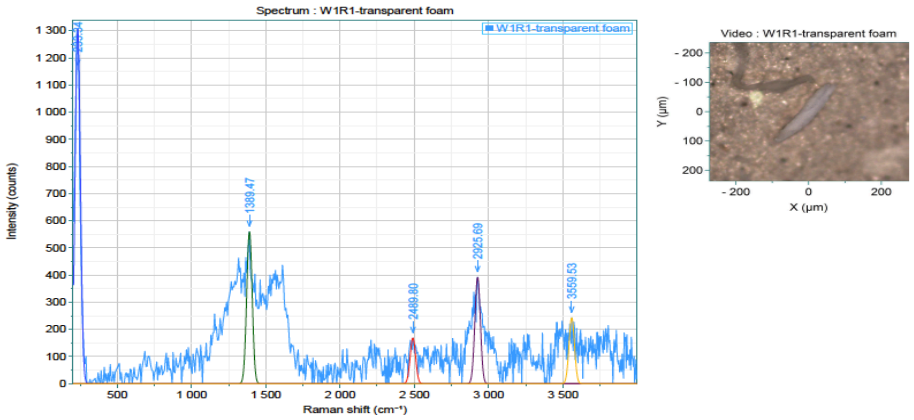


Fig. 9. Variations of polymers detected in microplastics samples at (a) office, and (b) laboratory. Values in ( ) is microplastics count.

Both rooms displayed comparable polymer variations, with the exception that a small quantity of Polybutylene Terephthalate (PBT) was detected in the office, while nylon (PA) was found in the laboratory. The presence of polycarbonate (PC) was observed in both the office room and laboratory, with counts of 5478 and 6849 respectively. This material, commonly found in fibres, originates from a variety of sources including food containers, non-metallic enclosures, lighting boards, cars, electronics, and telecommunication hardware [26]. In contemporary times, PC fibres have become extensively utilised in the field of upholstery and textiles, primarily owing to their exceptional durability and water resistance. In both rooms, pigments derived from paints were identified as the second most prevalent polymer. The pigments identified in the samples displayed intense and vivid hues and were identified as peaks of Aniline black (PBk1), Pigment Yellow (PY116), Pigment Red (PR47), and Pigment Violet (PV3 and PV23). Figure 10 depicts a collection of polymers and the corresponding µ-Raman peaks acquired from samples in two different environments.



(a)



(b)

Fig. 10. Micro-Raman peaks of polymers detected in microplastics samples (a) Blue, fiber microplastic (polycarbonate) in office room, and (b) Transparent, foam microplastic (Polybuthylene Terephthalate) in office room.

6 Conclusion

In conclusion, it was observed that:

(i) The deposition rates of microplastics indoors were higher in the laboratory (4,960 count/m^2·h) compared to the office (6,940 count/m^2·h). Measurements were taken during periods with an average of 3 occupants per hour in the main office and 5 occupants per hour in the laboratory. The deposition rate varied throughout the day, with higher rates during the daytime than at night.

(ii) Microplastic presence is influenced by synthetic material quantity and proportion in textiles, as shown by micro-Raman results. The main polymer types found in both rooms were polycarbonate (PC) fibres, pigments, and Polymethyl Methacrylate (PMMA). The PC fibres used in this study were durable and water-resistant, making them suitable for upholstery and textile applications.

(iii) Deposition rates in the office (7,840 count/m^2·h) and laboratory (11,300 count/m^2·h) showed a significant increase during daytime in week 1 compared to other samples. During the daytime in week 2, deposition rates were lower in the office (1,110 count/m^2·h) compared to the laboratory (1,290 count/m^2·h). The higher deposition rate in week 1 can be attributed to the hourly sampling scheme used, which lasted for eight hours and covered various heights. The experiment resulted in more samples collected compared to the continuous 8-hour sampling in week 2. The resuspension of settled particles and its impact on deposition rate were influenced by factors such as airflow turbulence from air conditioners and human activities. Higher altitude led to lower deposition rates.

(iv) The deposition rate increased with decreasing height in the office environment. Deposition rates were measured at heights of 0.4 m, 1.2 m, and 2.2 m, yielding counts of 9,920, 7,140, and 6,450 count/m^2·h, respectively. The laboratory had the highest deposition rate at 1.2 m. This study shows that microplastic deposition rates can be influenced by resuspension, which is determined by factors like flooring type, activity patterns, and occupant intensity. In the lab, student movement and smooth flooring contribute to microplastic resuspension.

(v) The predominant colour observed in the analysed samples was transparent (72%), followed by black (19%). Approximately 42% of fibrous microplastics were found in the size range of 200 μm to 2000 μm, while fragments of over 15% in the smaller range (20 μm to 200 μm). These findings reveal the presence and distribution of microplastics in indoor environments. Fragment size was smaller than filaments.

Acknowledgement

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