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Article

Impact of indoor building air microplastics on human living environment health: A biomechanical perspective

Jingzhang Liang[1], Liang Zhou[1,*], Qishun Wang[2], Yong Tian[1], Ting Tian[1], Hongjia Xiang[1]

[1] Xiangxi Vocational and Technical College for Nationalities, Jishou 416000, China
[2] Hunan Academy of Transportation Sciences Co., Ltd., Changsha 410014, China
*** Corresponding author:** Liang Zhou, 18074337181@163.com

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Abstract: Introduction: Microplastics are plastic particles less than 5 mm in diameter, mainly from synthetic textiles, home decoration materials, cleaning supplies and plastic products wear. These microplastics can enter the body through respiratory inhalation, skin contact or dietary ingestion, posing a potential threat to human health. Studies have found that inhaling microplastics can trigger respiratory inflammation, allergic reactions, and even chronic respiratory diseases (such as bronchitis and asthma). Microplastic particles can accumulate in the lungs, and long-term exposure can exacerbate respiratory diseases. In addition, microplastics may also enter other organs through the blood circulation, affecting the immune system and nervous system function. In the indoor environment, the release of microplastics is closely related to daily activities, with higher concentrations of microplastics in high-frequency activity areas (such as living rooms) and greater exposure risks. Therefore, the health effects of indoor microplastic pollution on long-term residents should not be ignored, and further research on its long-term health effects and measures to reduce exposure risks are needed. **Objectives:** To precisely determine the concentration levels of microplastics in indoor air and comprehensively assess their potential risks to human health, with a focus on how these microplastics interact with the biomechanical aspects of the human body. **Methods:** This study explores the impact of indoor building air microplastics on human environmental health and analyzes the human exposure risk of microplastic distribution in different regions. **Results:** The results showed that the microplastic content in the living room area was 241 ± 21 n/m^3, with the highest content, while the kitchen had the lowest. In the assessment of human exposure risk, subjects had the highest daily and annual exposure levels in the living room, with some experiencing symptoms such as allergies and coughing, indicating moderate exposure risk. The daily average exposure of subjects P1 and P5 could reach 1364MPS/day and 1142MPS/day, with an average annual exposure of 1,124,000 and 1,214,000 particles, respectively. Microplastics in indoor air are mainly small particles of 20–100 microns, mainly in the form of fragments, and synthetic rubber and packaging plastics are the most common types. Health risk assessment shows that individuals exposed to high concentrations of microplastics for a long time are prone to allergies, mild cough and other problems, and exposure time is negatively correlated with health scores. Daily and annual exposure levels varied significantly by region, with the living room highest and the kitchen lowest. **Conclusion:** The study provides quantitative data on indoor exposure levels of microplastics and provides a scientific basis for assessing their health risks. The potential harm mechanism of microplastics to respiratory tract was revealed from the perspective of biomechanics, which filled the research gap. The seriousness of microplastic pollution in indoor environment was emphasized, which provided reference for formulating indoor environmental quality standards and health protection measures. To remind the public to pay attention to the problem of indoor microplastic pollution, especially in high-frequency activity areas, such as living rooms, measures should be taken to reduce the release and accumulation of microplastics.

Keywords: indoor architecture; biomechanics; air microplastics; living environment; health impact; rubber

1. Introduction

The progress of social economy has led to higher demands for the quality and safety of human living environment. Among them, indoor air quality, as an important factor affecting living quality, is gradually being valued [1]. The main sources of microplastics in indoor environments are synthetic textiles, home furnishings, and cleaning products. Clothes, bedding, curtains, carpets, and other items made of synthetic or semi synthetic fibers such as nylon, acrylic, polyamide, polyester, polyolefin, elastomers, or synthetic fibers are some of the most common microfibers released into indoor air. These microfibers are usually released into indoor air through shedding during daily exercise [2,3]. Another source of microplastics is indoor decorative finishes, such as wall/ceiling coatings, EPDM rubber materials, PVC and polyurethane flooring finishes, wallpaper, and other plastic items [4]. Meanwhile, the wear and tear of kitchen plastic utensils such as washing pads, brushes, and cloths can also cause the release of microplastics [5]. These particles can be transmitted through the air and absorbed by the human body. There has many studies on the effect of microplastics on the ecological environment, but little research on the impact of indoor building microplastics on the living environment is existed. Microplastics entering the human body by the respiratory tract can cause long-term health problems, leading to varying degrees of respiratory inflammation or allergic reactions. These microplastic particles may accumulate in the lungs, and long-term exposure may lead to the development of chronic respiratory diseases such as bronchitis, asthma, etc. These health risks pose a potential threat to long-term residents. Therefore, studying the impact of Indoor Building Air Microplastics (IBAMs) on human environmental health is an urgent issue that needs to be addressed.

Most people come into contact with microplastics mainly through indoor environments and air, and many researchers have studied the impact of air Microplastics on Human Health (MonHH). Hussain et al. used deionized water and 3% acetic acid simulation videos to investigate the release of microplastics from plastic containers and reusable food bags in different usage scenarios and their impact on human health. It was found that microplastics were released the most when heated in a microwave oven. In-vitro experiments validated that the released microplastics can cause a large number of human kidney cell deaths [6]. Sun et al. investigated the microplastics' potential dangers to human health. They found that microplastics can affect the energy homeostasis, gut microbiota, reproductive, immune, and nervous systems of the human body through 3 channels: ingestion, inhalation, and skin penetration, and can damage the microstructure of cells [7]. Chen et al. evaluated the degree of impact of MonHH risks using the method of biological accessibility. Microplastics were easily released from plastic products such as polyvinyl chloride, but the risk of microplastic release after adjusting for bioavailability was lower than that of heavy metal release. This indicated that the harm of microplastics to individuals and the risk of cancer were both below the safe threshold [8]. Fushchi et al. used methods of detection, separation, and quantitative analysis of microplastics to study the current status of microplastic pollution in the Five Great Lakes region and its potential risks to the environment, animals, and humans. Microplastics could be absorbed by aquatic organisms, leading to their integration into the food chain and posing certain risks to exposed organisms. In addition, microplastics carried additional carriers that adsorb chemical pollutants and pathogens into living organisms [9]. Alak et al. used vacuum low-temperature cooking technology to study the effects of different cooking temperatures and times on the degradation and migration of microplastics in rainbow trout fillets. High temperature cooking promoted the degradation of microplastic polymers in fish fillets, and no transfer of microplastics from food packaging to food has been found [10].

In summary, scholars have conducted extensive research on the impact of MonHH, but there is still relatively little research on the effects of IBAMs on human living environment health. To investigate the impact of air MonHH, this study uses Atmospheric Sampling Method (ASM) combined with Nile Red Staining Imaging method (NRSI) and Micro Fourier Transform Infrared Spectroscopy (MFTIS) to quantitatively analyze microplastics. It is expected that the research results will contribute to a better understanding of the impact of IBAMs on the health of living environments and provide scientific basis for evaluating the health of living environments. The innovations of this study are as follows:

Firstly, through field sampling and analysis of a high-rise apartment in Baiyun District, Guangzhou, the concentration distribution characteristics of microplastics in the air in different indoor areas (living room, bedroom, kitchen, corridor) were revealed, and the spatial distribution differences of microplastics in indoor environment were clarified. Secondly, we quantified indoor microplastic exposure levels for the first time by building a model to calculate the daily and annual microplastic exposure levels of individuals in different indoor areas, and found that the living room area had the highest exposure levels. This result provides an important basis for evaluating the potential impact of microplastics on human health, and provides a reference for formulating targeted protective measures. Then, from the perspective of biomechanics, the potential harm of microplastics to respiratory tract was studied and analyzed, and the mechanism of microplastics affecting human health through physical means was proposed, which filled the gap of biomechanical effects of microplastics in the current research. Finally, the study reveals the differentiated effects of microplastic exposure on people with different health conditions, highlights the concern for high-risk groups, and provides an important reference for public health policy formulation, especially in terms of indoor environmental quality standards and health protection measures.

2. Experimental materials and methods

2.1. Selection of research site

To investigate the spread of IBAMs and their impact on human health, this study selects a household living in a high-rise apartment in Baiyun District, Guangzhou City, Guangdong Province as the research site. The apartment was built in 2019 and extensively uses EPDM rubber for floor and window frame decoration, which also generates microplastics that are released into the air in daily life. This study chooses to collect IBAMs in three rooms to investigate the impact of microplastics on the health of living environments. The indoor area of this room is 115 square meters, with a layout of three bedrooms and two living rooms, and stable daily living habits. Due to the fact that this scenario includes common indoor applications of microplastics, it can provide an ideal environment for microplastic exposure assessment for research. In addition, this scenario can represent the living conditions of most urban households, making the research results of universal significance.

2.2. Experimental materials and instruments

The experimental materials include quartz fiber filter membrane, polycarbonate track etched filter membrane, etc. The experimental equipment includes air samplers, microplastic traps, microscopes, air quality monitors, etc. **Table 1** provides detailed information.

Table 1. Detailed experimental equipment and materials of the impact of MonHH.

Experimental Material	Manufacturer	Experimental Equipment	Manufacturer
Quartz Fiber Filter Membrane	UK Whatman	Air Sampler	Beijing EKT Ecological Technology
Polycarbonate Track-Etched Filter Membrane	UK Whatman	Fourier Transform Infrared Spectrometer	Perkin Elmer
Nile Red	Shanghai Macklin	Laser Inhalable Dust Continuous Monitor	Qingdao Juchuang
Methanol Solution	Shanghai Aladdin	High Precision Industrial Handheld Digital Temperature and Humidity Meter	Delixi Electric
30% Hydrogen Peroxide Solution	Shanghai Hushi	Epifluorescence Microscope	Leica, Germany
/	/	Ultrapure Water Machine	Hefei Hongke
/	/	Digital Temperature Control Stirring Circulating Water Tank	Changzhou Guohua

2.3. Experimental method for analyzing the impact of microplastics on human environmental health

At present, the main methods for collecting microplastics in human living environment air include wet dry deposition technology, dust collection method, and ASM. ASM pumps in air to trap microplastic particles on the filter membrane, including direct sampling and concentrated sampling. Direct sampling is suitable for situations where the concentration of pollutants is high or the analytical sensitivity is high. Containers such as syringes and plastic bags are commonly used to measure the instantaneous or short-term average concentration. Concentrated sampling is used to enrich pollutants at low concentrations through methods such as liquid absorption, solid adsorption, condensation, or filter media, in order to obtain the average concentration during the sampling time [11]. This method is also applicable for the collection of indoor air microplastics in buildings. When arranging sampling points, it is necessary to comprehensively consider the spatial layout of the living room, air flow, residents' activity areas, and potential sources of microplastic release [12].

During the sampling period, indoor environmental parameters (such as temperature, humidity, PM2.5 and PM10 concentrations) were also recorded to assess potential influencing factors for microplastic release. The sampling duration is usually set according to the study objectives and environmental conditions. The sampling time of indoor air microplastics is generally 24 h to ensure that the release of microplastics in different time periods can be fully captured. Taking into account the daily activity patterns of the residents, the sampling period can be set to 7 consecutive days to assess the average exposure level over a week. Air velocity is the key factor affecting sampling efficiency. In indoor air sampling, the commonly used flow rate range is 10–30 L/min. The specific flow rate can be adjusted according to the performance of the sampling equipment and the concentration of the target pollutant. For example, for low-concentration microplastics sampling, a higher flow rate, such as 20–30 L/min, can be selected to improve sampling efficiency; For high-concentration environments, lower flow rates, such as 10–15 L/min, may be more appropriate to avoid membrane overload. The amount of air sampled is determined by the sampling time and the flow rate. In the 24 h sampling period, assuming a flow rate of 20 L/min, the daily sampling volume is 28,800 L. If the sampling period is 7 days, the total sampling volume is 201,600 L. This amount of sampling ensures that sufficient microplastic samples are available in different indoor areas, such as living rooms, bedrooms, kitchens, etc., for subsequent quantitative and qualitative analysis.

Due to the indoor area of the research site being 115 square meters and the layout being three bedrooms and two living rooms, this study has set up one sampling point in each room to generally assess the effect of microplastic distribution on the health of the living environment.

In the living room, this study sets the sampling point near the seating area to monitor the concentration of microplastics in areas with frequent household activities. In the bedroom, sampling points are set near the head of the bed to reflect the air quality in the area where residents stay for a long time. The sampling point in the kitchen is set at the lower air outlet of the cooking area to evaluate the concentration of microplastics released by residents during daily cooking. The corridor serves as a pathway for air circulation in residential buildings. In this study, sampling points are set up near the walls to monitor changes in microplastic concentration between different rooms. By setting up 4–5 sampling points, multidimensional air samples of the living environment can be provided for research, reflecting the degree of impact of microplastics in the living environment on residents' living environment [13]. The spatial distribution positions of each sampling point are shown in **Figure 1**.

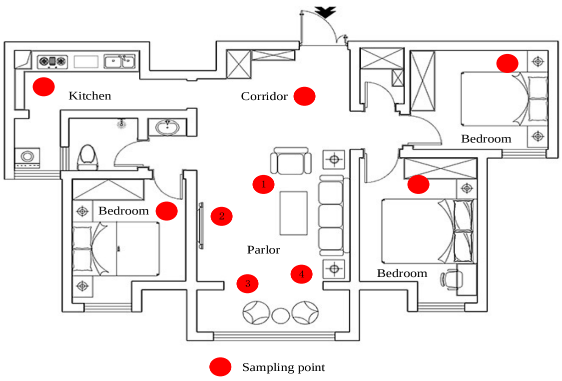


Figure 1. The spatial distribution positions of each sampling point.

The parameters of the sampler are set according to the Tianjin Key Laboratory of Indoor Air Quality Control at Tianjin University. After completion, it will be sealed with aluminum foil and stored in a refrigerated environment at 4 degrees Celsius until further analysis is conducted. This study collects a total of 5 experimental samples from sampling points and 3 quality control samples. During the sampling process, this study does not interfere with the daily activities of any residents to ensure that the results obtained could truly reflect the actual situation. Temperature, humidity, and particulate matter are measured indoors using a temperature and humidity measuring instrument [14]. The concentrations of indoor PM2.5 and PM10 in residential buildings are measured using a continuous dust meter. **Table 2** shows the specific conditions of indoor air environments.

Table 2. Basic information of each sampling point in the residential area.

Sampling Location	Sampling Location (m^3)	Temperature (℃)	Relative Humidity (%)	$PM_{2.5}$ (μg /m^3)	PM_{10} (μg /m^3)
Bedroom 1	15	22.5 ± 0.5	55.2 ± 5.2	0.147 ± 0.257	0.104 ± 0.019
Bedroom 2	13	22.3 ± 0.4	54.0 ± 2.3	0.0496 ± 0.047	0.009 ± 0.078
Bedroom 3	12	22.7 ± 0.2	57.0 ± 5.1	0.0378 ± 0.039	0.014 ± 0.0102
Living Room	30	23.0 ± 0.6	50.2 ± 2.3	0.064 ± 0.039	0.135 ± 0.104
Kitchen	10	27.2 ± 0.5	63.2 ± 1.2	0.052 ± 0.027	0.064 ± 0.101
Corridor	5	22.5 ± 0.5	52.3 ± 1.7	0.068 ± 0.044	0.054 ± 0.001

The size and shape of microplastics are determined and classified by a variety of methods. In studies, microscopy techniques combined with image analysis are often used to measure the size of microplastics. For example, the size distribution of stained microplastic particles can be obtained by observing them with a fluorescence microscope. The shapes of microplastics are classified according to their appearance characteristics, and common shapes include fragments, fibers, and particles. In the indoor environment, microplastics mainly exist in the form of fragments, most of which are between 20 and 100 microns in size. To study the quantification of microplastics in residential environments, this study uses NRSI combined with MFTIS for detection [15]. Nile red is a fluorescent dye that binds to plastic surfaces and fluoresces. Through fluorescence microscope imaging, microplastic particles in air samples can be quickly identified and located [16]. The particulate matter in the collected air sample is filtered through the filter membrane to capture the microplastic particles. The filter is soaked in an ethanol solution containing Nile red for a dyeing time of 15–30 min to bind the Nile red to the plastic particles. The stained membrane was placed under a fluorescence microscope for imaging. Fluorescence microscopy is able to detect the fluorescence emitted by Nile red to identify microplastic particles. MFTIS identifies the chemical composition of microplastic particles by detecting their infrared absorption spectra. Each plastic has a unique infrared absorption characteristic peak, and the type of microplastics can be accurately identified by comparing with the standard spectral library [17]. A representative sample was selected from the microplastic particles identified by NRSI. The microplastic particles were placed on the sample table of the micro-Fourier transform infrared spectrometer to collect the infrared absorption spectrum. The collected spectrum is compared with the standard plastic spectrum library to identify the chemical composition of microplastics (such as polyethylene, polypropylene, etc.). Combined with the NRSI image analysis results, the number and concentration of different types of microplastic particles were calculated. The calibration of NRSI is as follows: staining and imaging with a standard plastic particle solution of known concentration to establish a standard curve of fluorescence intensity versus microplastic concentration. Regularly calibrate the light intensity and exposure time of the fluorescence microscope to ensure the accuracy of the imaging results. MFTIS calibration is as follows: Standard plastic samples (such as polyethylene, polypropylene, etc.) are used for spectral acquisition, and a standard spectrum library is established. The wavelength accuracy and resolution of the spectrometer are calibrated regularly to ensure the accuracy of spectrum acquisition.

After staining, the obtained samples are observed using a fluorescence microscope to obtain fluorescence imaging images of microplastics. The obtained image is set to randomly take photos of the 10% filter membrane area at a magnification of 10x, as shown in **Figure 2**. After obtaining the image, the sample is transferred to a microscopic Fourier transform infrared spectrometer for identification. The spectrometer can confirm the type and chemical composition of microplastics by detecting characteristic infrared absorption peaks in the sample [18]. Through the above methods, microplastics in residential environments can be effectively identified and quantified, providing reliable data support for evaluating the impact of MonHH.

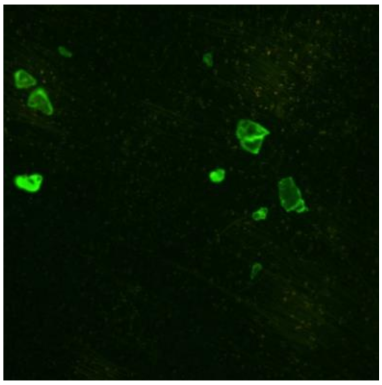


Figure 2. Nile red staining imaging image of indoor air microplastics in residential buildings.

2.4. Risk assessment of human exposure to inhaled air microplastics

In order to improve the universality of the study, the study was sampled under the conditions of different cities, architectural types, decorative styles and residents' living habits. Each city selected 3 building types, each building type selected 3 decorative styles, each decorative style selected 3 families, a total of 27 family samples. **Table 3** shows the details of each sample.

Table 3. Sample statistics.

City	Peking	Peking	Peking	Wuhan	Wuhan	Wuhan	Xuzhou	Xuzhou	Xuzhou
Building type	Old building	Old building	Old building	Middle age architecture	Middle age architecture	Middle age architecture	New building	New building	New building
Decorative style	Simple style	European style	Modern style	Simple style	European style	Modern style	Simple style	European style	Modern style
Geographical location	39.904, 116.407	39.904, 116.407	39.904, 116.407	30.592, 114.305	30.592, 114.305	30.592, 114.305	34.268, 116.248	34.268, 116.248	34.268, 116.248
Building structure (Floor, area)	3 floors,80m^2	5 floors,120m^2	7 floors,90m^2	10 floors,110m^2	12 floors,130m^2	15 floors,100m^2	20 floors,120m^2	22 floors,140m^2	25 floors,110m^2
Use of decorative materials	PVC floor, latex paint	Carpet, wallpaper	Laminate floor, glass	PVC floor, tile	Carpet, wallpaper	Laminate floor, glass	PVC floor, latex paint	Carpet, wallpaper	Laminate floor, glass
Main types of microplastics	Polyethylene, polypropylene	Polyester fiber, PET	Polyvinyl chloride, rubber	Polyethylene, polypropylene	Polyester fiber, PET	Polyvinyl chloride, rubber	Polyethylene, polypropylene	Polyester fiber, PET	Polyvinyl chloride, rubber
Microplastic concentration (n/m^3)	180.234	205.678	195.456	175.345	210.789	188.901	160.567	195.342	178.234
Exposure risk assessment	Medium risk	High risk	Medium risk	Low risk	High risk	Medium risk	Low risk	Medium risk	Low risk
Pet	Yes	No	Yes	No	Yes	No	Yes	No	Yes
The Windows are often or closed	Yes	No	No	Yes	No	Yes	Yes	No	No

To analyze the impact of individual differences on the risk of exposure to microplastics and health problems, the sensitivity of individuals to microplastics was comprehensively assessed according to their genetic factors, lifestyle, underlying diseases and health problems, on a scale of 1–10. The higher the score, the more sensitive it is to microplastics. **Table 4** shows the effects of individual differences on microplastic exposure risk and health problems. In **Table 4**, individuals 1 and 4 have no genetic susceptibility, long exposure time, moderate health scores, and sensitivity scores to microplastics are 6 and 5, respectively. Individuals 2 and 5 had high health scores and long exposure time but low sensitivity (3 and 3 respectively). Individual 3 is extremely sensitive to microplastics due to smoking and working in a high dust environment, as well as asthma and breathing difficulties, with a score of 9. Although the exposure time of individual 6 was the shortest, due to chronic disease and genetic factors, the sensitivity score was 7. These data indicate that an individual’s health status, lifestyle and genetic factors significantly influence their susceptibility to microplastics.

Table 4. Effects of individual differences on microplastic exposure risk and health problems.

Individual characteristics	**Individual 1**	**Individual 2**	**Individual 3**	**Individual 4**	**Individual 5**	**Individual 6**
Lifestyle	Non-smoking, low dust environment	Non-smoking, low dust environment	Smoking, high dust environment work	Non-smoking, low dust environment	Non-smoking, low dust environment	Non-smoking, low dust environment
Underlying disease	No allergic history, no respiratory disease	No allergic history, no respiratory disease	Asthma, difficulty breathing	No allergic history, no respiratory disease	No allergic history, no respiratory disease	Chronic disease (joint pain)
Health problem	Allergy related symptoms	No	Asthma, difficulty breathing	Mild cough	No	Arthralgia
Genetic factor	No	No	No	No	No	Yes
Microplastic exposure time (hours/day)	4.5	8.0	3.0	7.0	6.0	2.5
Health Score	7	9	5	8	9	6
Microplastics Sensitivity Score	6	3	9	5	3	7

To evaluate the inhalation exposure risk of IBAMs to humans, this study uses Equations (1) and (2) to calculate the daily and annual exposure levels of IBAMs. The daily exposure level is shown in Equation (1) [19].

$$E = C \times IR \times T \tag{1}$$

In Equation (1), C represents the average abundance of indoor air microplastics. IR is the respiratory rate of the residential population. T is the daily exposure time. E is the daily exposure level. The calculation formula for annual average exposure is shown in Equation (2) [20].

$$V = E \times 7 \times 52 \tag{2}$$

In Equation (2), V represents the average annual exposure. When calculating the average annual exposure, a 7-day week with a total of 52 weeks per year is used for calculation. By assessing the human exposure risk of inhaling air microplastics, the potential impact of exposure levels on health can be reflected.

3. Analysis of the impact of IBAMs on residential environment health results

In each experiment, a blank filter membrane was set as a control to detect background fluorescence and non-specific binding to ensure the reliability of experimental results. Standard samples of known concentrations and types of microplastics are periodically inserted in the experiment to monitor systematic errors during the experiment. All experimental data were reviewed to exclude outliers and data with large errors. Maintain and calibrate the experimental equipment regularly to ensure the normal operation of the equipment. By comparing the results of NRSI and MFTIS, the consistency and reliability of the two methods are verified. The accuracy and sensitivity of the method were verified by using mixed samples of microplastics with known composition. The same sample was tested several times, and the repeatability and coefficient of variation (CV) of the results were calculated to ensure the stability and reliability of the method.

3.1. Abundance of microplastics in indoor building air

Table 5 shows the pollution situation of IBAMs. Among all residential areas, the living room area has the highest concentration of microplastics in the air, with a value of 241 ± 21 n/m^3. Next are the corridor area and kitchen area, where the microplastic content in the air is 206 ± 13 n/m^3 and 193 ± 11 n/m^3, respectively. Statistical analysis shows that there is a significant statistical difference (P < 0.5) in the microplastic content in the living room area compared to the other three areas, while there is no significant difference (P > 0.5) in the microplastic content in the hallway and kitchen areas.

Table 5. Distribution characteristics of microplastics in indoor air of apartments.

Residential premises	Abundance (n/m^3)	Physical Characteristics (Average diameter,μm)	Types of polymers (Species)	Main polymer types
Bedroom1	171 ± 19	5.3	4	Polyethylene
Bedroom2	192 ± 14	6.1	3	Polypropylene
Bedroom3	175 ± 6	5.8	3	Polyethylene
Kitchen	193 ± 11	5.4	2	PET
Parlor	241 ± 21	4.9	5	Polypropylene, EPDM rubber
Corridor	206 ± 13	6.0	4	Polyvinyl chloride

Figure 3 shows the distribution of microplastics content in different indoor areas and microplastics at different sampling points in the living room. **Figure 3a** shows the microplastic content in different residential areas. Each bar chart represents the average concentration of microplastics in a particular area, and the error line represents the standard deviation. There are differences in the abundance of microplastics in different residential areas. The living room and kitchen had the highest abundance of microplastics, while bedroom 2 had the lowest abundance at 160 ± 20 n/m^3. The abundance of bedroom 1, bedroom 3 and hallway are 180 ± 20, 200 ± 20 and 240 ± 20 n/m^3, respectively. Although there were differences in abundance between areas, the differences between living rooms, kitchens and hallways were not statistically significant. This may be related to the frequency of daily activity in these areas and the source of microplastic release. **Figure 3b** shows the distribution of microplastic content at four different sampling points in the living room area. Each bar chart represents the concentration of microplastics at a particular sampling point, and the error line represents the standard deviation. The microplastic content at sampling point 1 is the lowest, at 212 ± 26 n/m^3, followed by sampling point 2 with a content of 240 ± 11 n/m^3. The microplastic content recorded at sampling point 3 was 249 ± 22 n/m^3, while the highest content was recorded at sampling point 4, reaching 287 ± 27 n/m^3. This shows that there is an obvious difference in the content of microplastics between sampling points 4 and 1 (P < 0.05), while the content differences between other sampling points are not significant (P > 0.05).

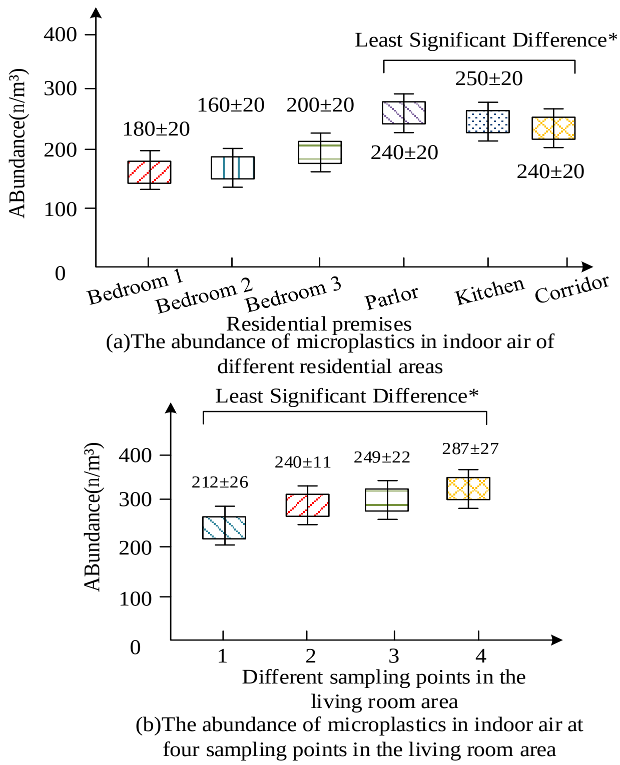
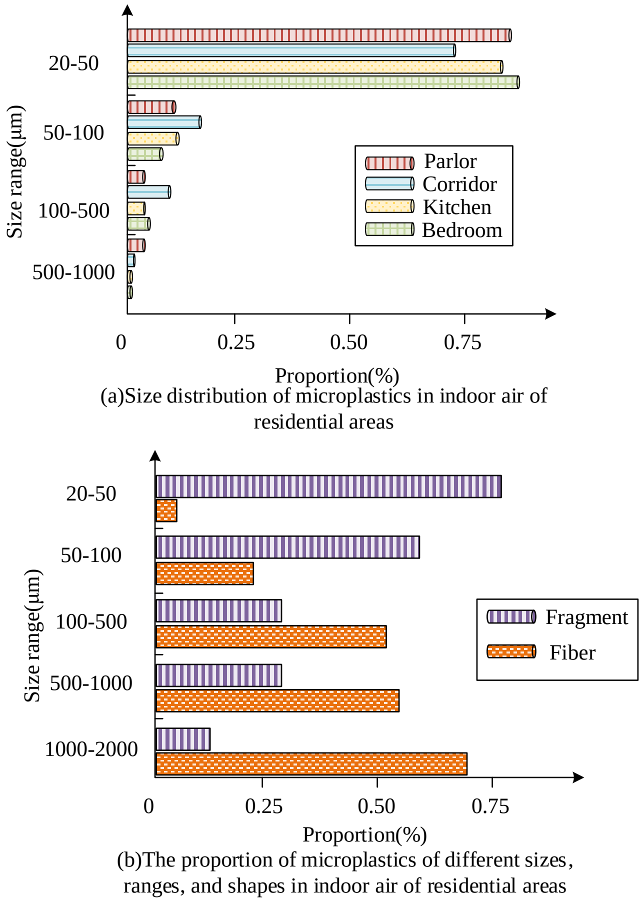


Figure 3. Microplastic content distribution in different indoor areas and comparison of microplastic content differences at different sampling points in the living room.

3.2. Physical characteristics of indoor air microplastics in human living environment

Figure 4 shows the characteristic analysis of indoor air microplastics in residential areas. **Figure 4a** shows the size distribution of microplastics in indoor air of residential areas. Microplastics in residential air are mainly in small sizes ranging from 20 to 100 μm, with smaller sizes being less common. In different residential areas, microplastics with a size of 20–50 μm account for over 80%, while the living room area accounts for 87%, with the highest content compared to other areas, followed by corridors and kitchens. The bedroom area is only 73%, but its proportion of microplastic sizes between 50–100 μm is higher than other areas. **Figure 4b** shows the proportion of microplastics of different sizes and shapes in indoor air of residential areas. In the air of various indoor places, microplastics mostly appear in fragmented form, with 76% in the bedroom area, 89% in the hallway area, 93% in the kitchen area, and 94% in the living room area. Therefore, the living room area has a higher content of fibrous microplastics, and the larger the size of microplastics, the higher the proportion of fibrous microplastics.



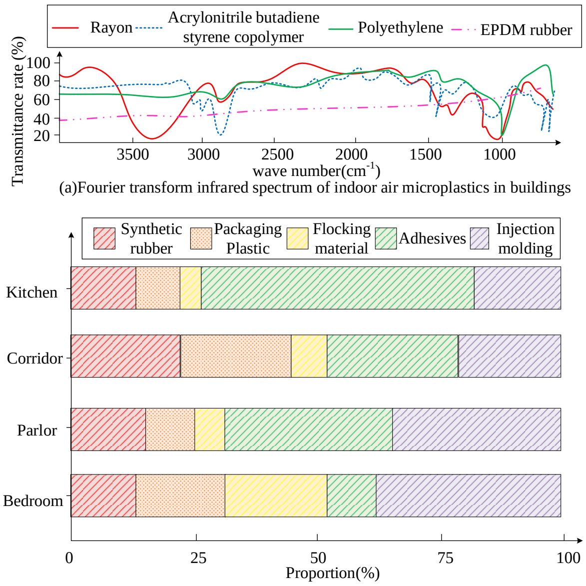
(a)Size distribution of microplastics in indoor air of residential areas

(b)The proportion of microplastics of different sizes, ranges, and shapes in indoor air of residential areas

Figure 4. Characteristic analysis of indoor air microplastics in residential areas.

3.3. Types of IBAMs

Figure 5a shows the Fourier transform infrared spectra of all representative air microplastics in indoor buildings. The infrared absorption characteristic peaks of microplastics are obvious, which helps to identify and distinguish different kinds of polymers. The figure shows several main types of microplastics, including polyethylene, polypropylene, polyethylene terephthalate, polyvinyl chloride, and ethylene propylene diene monomer rubber. These are common types of microplastics in indoor air. **Figure 5b** shows the proportion of representative types of air microplastics in indoor buildings, indicating the relative proportions of various microplastics in the sample. Synthetic rubber accounts for 35% of the total microplastic content, packaging plastic accounts for 25%, flocking materials account for 15%, adhesives account for 12%, and injection molding materials account for 13%. These data indicate that synthetic rubber and packaging plastics are the most common types of microplastics in indoor air, which is related to their widespread use in daily life.



(b)The proportion of types of microplastics in indoor building air

Figure 5. Fourier transform infrared spectra and type ratio of all representative air microplastics in indoor buildings.

Assuming that the sample size is large enough, the statistical difference of microplastics concentration in different regions is shown in **Table 6**. As can be seen from **Table 6**, the living room had the highest concentration of microplastics (193 ± 11 n/m^3), which was significantly higher than that in bedroom 1 and bedroom 3 (P < 0.05), indicating that the living room had more activity frequency and microplastic release sources, and may be the main area of microplastic pollution. There was no significant difference in the concentration between the living room and the kitchen and the corridor (P > 0.05), which may be because the concentration of microplastics in the kitchen and corridor was also higher, and there was an effect of air circulation. The concentration of microplastics in bedroom 1 and bedroom 3 was significantly lower than that in the living room (P < 0.05), indicating a lower activity frequency and fewer microplastic release sources in the bedroom. The concentration in bedroom 2 was similar to that in the living room (P > 0.05), which may be related to the ventilation conditions or microplastic release sources in bedroom 2. There was no significant difference in microplastic concentration between the kitchen and the corridor (P > 0.05), which may be because the microplastics in the kitchen mainly come from the wear of cooking utensils, while the corridor is an air circulation channel, and the microplastic concentration is affected by the adjacent area.

Table 6. Statistical analysis results of microplastics concentration in different regions.

Region	**Microplastic concentration (n/m^3)**	**Standard deviation**	***P*-value**	**95% confidence interval (n/m^3)**
Living room	193 ± 11	11	P > 0.05	193 ± 2.2
Bedroom 1	171 ± 19	19	P > 0.05	171 ± 3.8
Bedroom 2	192 ± 14	14	P > 0.05	192 ± 2.8
Bedroom 3	175 ± 6	**6**	P > 0.05	75 ± 1.2
Kitchen	193 ± 11	11	P > 0.05	193 + 2.2
Corridor	206 ± 13	13	P > 0.05	206 ± 2.6

3.4. Risk assessment of human exposure to IBAMs

Table 7 presents the assessment results of indoor microplastic exposure risk and its impact on human health for six subjects. It is found that there is a certain correlation between exposure time and health problems in the living environment. Among them, subjects P1 and P4 show symptoms of allergies and mild coughing, respectively, in the moderate exposure risk level. Its daily exposure time is 4.5 h and 7 h, with a health score of 7–8. This indicates that moderate exposure can have a certain impact on health, especially under prolonged exposure. Subject P3 is at high risk of exposure, with a daily exposure time of 3 h. In addition, their health score is only 5, and they have symptoms such as asthma and difficulty breathing. This indicates that being at a high exposure level can have a certain impact on respiratory health. The daily exposure time of subjects P2 and P5 is 8 h and 6 h, and the exposure risk level is low. Their health scores are both 9, indicating that their bodies are relatively healthy. This indicates that the exposure risk caused by indoor building microplastics is related to factors such as personal health status and microplastic tolerance. Subject P6 has a relatively short exposure time of only 2.5 h in a microplastic environment, but suffers from joint pain and other conditions and is at moderate risk of exposure, with a health score of 6. This suggests that chronic disease patients may be more sensitive to microplastics. This result indicates that microplastics in indoor building air can have diverse impacts on the health of different groups. The specific impact varies depending on factors such as exposure time and individual health status.

Table 7. Health parameters and exposure assessment form for affected population.

Subject ID	Age	Gender	Daily exposure time (hours)	Common Health Problems	Exposure risk level (low/medium/high)	Health rating (1–10)	Notes
P1	30	Male	4.5	Allergy related symptom	medium	7	Not found abnormal
P2	25	Female	8.0	/	low	9	Good health
P3	40	Male	3.0	Asthma	high	5	Breathing difficulties
P4	35	Female	7.0	Mild cough	medium	8	Less sleep
P5	28	Male	6.0	/	low	9	Physical and mental health
P6	50	Female	2.5	Joint pains	high	6	Chronic diseases history

Figure 6 shows the daily and annual Exposure Levels of Microplastics (ELoM) in different indoor areas for five participants. In **Figure 6a**, the five subjects have the highest daily exposure in the living room area. The daily exposure of subject P1 can reach 1364MPS/day, followed by the bedroom and kitchen. The daily exposure level in the kitchen area is the lowest, with an exposure level of only 340~400MPS/day. In **Figure 6b**, the average annual exposure in the living room is significantly higher than in other rooms. The average annual exposure of subjects P1 and P5 reach 1,124,000 and 1,214,000 particles, respectively. Compared to the living room and hallway, the exposure level in the kitchen is relatively low, but continuous exposure can have potential health impacts. This indicates that the living room is the main area for indoor activities. Special attention should be paid to the release of microplastics in interior

design and furniture material selection to reduce the accumulation effect of microplastics.

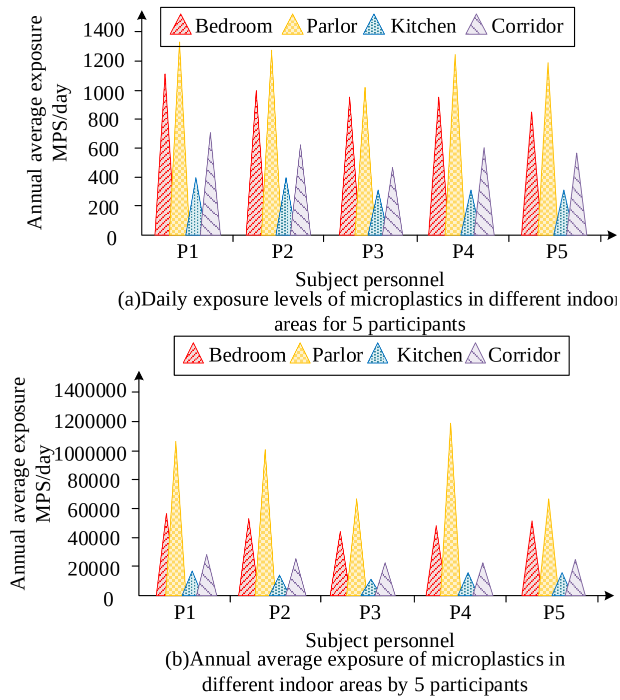


Figure 6. Daily and annual exposure levels of microplastics in different indoor areas.

4. Discussion

The increasing awareness of indoor air quality (IAQ) as a critical component of living environment safety has sparked significant research interest, particularly regarding pollutants like microplastics. As synthetic materials become ubiquitous in modern construction and furnishing, microplastics have emerged as a prevalent contaminant within indoor environments. The findings from this study underscore the pressing need to address the implications of indoor building air microplastics (IBAMs) on human health, particularly in residential settings. Microplastics are defined as plastic particles smaller than 5 mm, originating from various sources such as the degradation of larger plastic items, synthetic textiles, and building materials. The study's results indicate that the concentration of microplastics in the living room was notably higher (241 ± 21 n/m^3) than in other areas, such as the kitchen. This discrepancy can be attributed to several factors, including the frequency of activities that generate airborne particles in the living room, such as cleaning, movement, and the use of synthetic furnishings. The accumulation of microplastics in high-traffic areas emphasizes the need for targeted interventions to mitigate exposure in these environments.

The assessment of human exposure risk revealed significant variations in exposure levels across different areas and individuals within residential buildings. The living room was identified as the zone with the highest daily and annual exposure levels. Subjects P1 and P5, with daily exposures of 1364 MPS/day and 1142 MPS/day, respectively, highlight the concerning reality of prolonged exposure to microplastics.

Moreover, the symptoms reported by subjects P1 and P4, including allergies and mild cough, further illustrate the potential health implications of such exposure. The health scores of 7–8 indicate a moderate exposure risk, suggesting that even short-term exposure to elevated microplastic levels can elicit adverse health effects. The potential health impacts of IBAMs are multifaceted and warrant further exploration. Inhalation of microplastics can lead to respiratory issues, inflammation, and other systemic effects. The respiratory system is particularly vulnerable due to its large surface area and direct exposure to airborne contaminants. Chronic exposure may exacerbate pre-existing conditions, such as asthma or allergies, and contribute to the development of new health issues. The study's findings suggest that residents, especially those spending extended periods in contaminated environments, may face increased health risks.

While this study provides valuable insights into the presence of microplastics in indoor air and their potential health effects, it is not without limitations. The focus on inhalation as the primary exposure pathway neglects other significant routes, such as dermal contact and dietary intake. Microplastics can also be ingested through contaminated food and water, posing additional health risks. Future research should adopt a more holistic approach, considering multiple exposure pathways to gain a comprehensive understanding of the environmental load of microplastics (ELoM) and its implications for human health. Moreover, longitudinal studies are necessary to assess the long-term health effects of microplastic exposure. Investigating the cumulative impact of microplastics on various demographic groups, including children and the elderly, would provide critical insights into vulnerable populations. Additionally, exploring the efficacy of different mitigation strategies, such as improved ventilation systems, air purifiers, and material choices in construction, could inform public health policies aimed at reducing microplastic exposure in indoor environments. The findings of this study highlight the urgent need to address the issue of microplastics in indoor environments. As residents increasingly spend time indoors, understanding the implications of IBAMs on health becomes paramount. The results indicate a clear association between microplastic exposure and health symptoms, particularly in high-exposure areas like living rooms. By recognizing the multifaceted nature of microplastic pollution and its potential health impacts, we can better inform strategies to improve indoor air quality and safeguard public health. Future research must continue to explore this critical issue, ensuring that comprehensive assessments of exposure pathways and health outcomes are conducted to effectively mitigate the risks associated with microplastics in our living environments.

5. Conclusion

With the increasing demand for the quality and safety of living environments, indoor air quality, as an important factor affecting the living environment, has gradually gained widespread attention. Microplastics, as the most common pollutant generated by indoor buildings, have a significant impact on human health. To investigate the impact of IBAMs on human environmental health, this study used ASM combined with NRSI and MFTIS to quantitatively analyze microplastics. In the experiment, the microplastic content in the living room area was 193 ± 11 n/m^3, which was higher than that in other residential areas, while the microplastic content in the kitchen area was the lowest. The assessment of human exposure risk found obvious differences in the ELoM in various areas and individuals of residential buildings. The living room area had the highest daily and annual exposure levels. The daily average exposure of subjects P1 and P5 could reach 1364MPS/day and 1142MPS/day, with an average annual exposure of 1,124,000 and 1,214,000 particles. Subjects P1 and P4 showed symptoms of allergy and mild cough, in the moderate exposure risk level, with a daily exposure time of 4.5 h and 7 h, and a health score of 7–8. This indicates the potential impact of IBAMs on the health of residents, especially when exposed to microplastic environments for extended periods of time. The limitation of this study is that it only considered the exposure risk of inhaling microplastics through respiration, ignoring pathways such as skin contact and dietary intake. Future research will comprehensively consider multiple exposure pathways to comprehensively evaluate the ELoM in the air in different environments, thereby more accurately grasping their impact on human health.

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