A first overview of textile fibers, including microplastics, in indoor and outdoor environments

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1. Introduction

There is a large amount of materials in our daily life that are made of fibers, either synthetic or natural (furniture, textile, etc.). A study detected the presence of these man-made fibers in the atmospheric fallout in the Parisian agglomeration (Dris et al., 2016). It suggests that the atmospheric phase contains fibers that lead to human exposure. This exposure raises concern. Pauly et al. (1998) observed human lungs with a microscope. It was showed that 87% of the studied lungs (n = 114) contained fibers. Cellulosic and plastic fibers were both observed. Moreover, the same study revealed that 97% of malignant lung specimens contained the fibers. The length of the fibers was mainly around 50 µm but could reach a length longer than 250 µm. It was recently pointed at the risk of inhalation of microplastic particles and fibers (House of Commons Environmental Audit Committee Oral evidence: Environmental impact of Microplastics, HC 925 Monday 9 May 2016).

The observed fibers in these studies are often textile fibers (Dris et al., 2016; Pauly et al., 1998). Those made of natural material are classified as either natural fibers (cotton, wool) or as artificial fibers (viscose, rayon, cellulose acetate). Fibers made of petrochemicals are considered as synthetic fibers and are included in the definition of microplastics (ISO/TR 11,827:2012 Textiles — Composition testing — Identification of fibers). Microplastics are particles smaller than 5 mm (Arthur et al., 2008). Many studies have highlighted the presence of these particles in the marine environment (Cole et al., 2013) and their impact on aquatic organisms (Wright et al., 2013). It is assumed that the main part of these plastics come from the continental environment (Jambeck et al., 2015). So far, only few freshwater bodies have been studied and only little information is provided regarding the inputs/sources and pathways of microplastics (Dris et al., 2015b; Wagner et al., 2014). Some studies showed relatively high concentrations of microplastics in rivers and gave first insight on the role of urban areas in this pollution (Dris et al., 2015a; Mani et al., 2015; McCormick et al., 2014). To date, few studies focused on the sources of microplastics in surface water and wastewater treatment plant discharges were mainly incriminated (Browne et al., 2011; McCormick et al., 2014).

This study was designed first, to extend the knowledge on fibers found in the air and to explore their occurrence in order to assess the potential exposure for people, and second, to estimate the proportion of microplastics among these fibers and estimate the role that could play indoor environments in the global dynamics of this new contaminant. In this context, this work studies fibers in indoor and outdoor environments. The indoor deposition rate of the fibers and their concentration in settled dust collected from vacuum cleaner bags were also investigated.

2. Materials and methods

Three different indoor sites were selected: two private apartments (apartments A and B, with an approximate ceiling height of 2.4 m) and one office (with an approximate height of 2.7 m). The apartments and the office (work place) were considered in order to have a complete overview of the contamination on the places where a regular person spends most of its day. In parallel, outdoor air was sampled on the roof of the office building. For each site, samplings were carried out on February, May, July and October of 2015. This choice was made in order to cover the four seasons and include any seasonal variation (due to a different air exchange between indoor and outdoor or a difference in the clothing).

All sampling sites were located at about 10 km from Paris city center (Fig. 1). Two adults and one child lived in each apartment (48°48′15.3″N 2°27′53.7″E apartment A, 48°48′20.2″N 2°24′48.9″E apartment B). The sampling was performed in the living room. The office and the outdoor sampling site were located at the University of Paris-Est-Creteil (48°47′17.8″N, 2°26′36.2″E). Three persons were working in the office during the sampling.

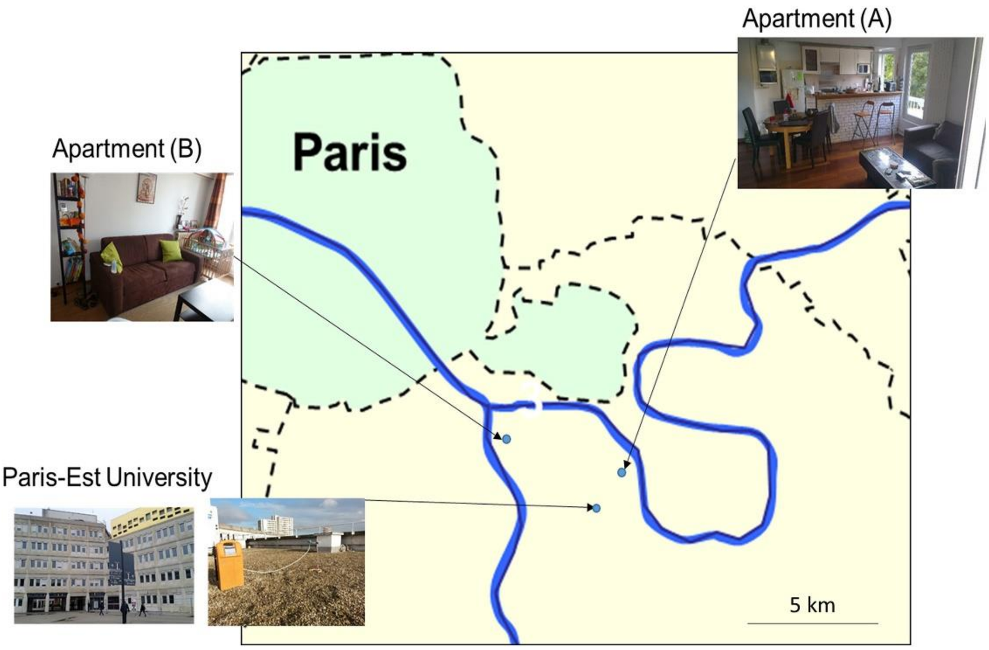

Fig. 1. Location of the monitored sites.

A pump (Stand-alone sampling pump GH300,Deltanova, France) allowed to sample 8 L/min of indoor air on quartz fiber GF/A Whatman filters (1.6 µm, 47 mm). Sampled volumes range between 2 and 5 m^3 depending on occupants presence. The samplings were carried out at a 1.2 m height because it is standardly used to correspond to the breathing height of an adult (Noguchi et al., 2016). Sampling periods ranged between 4 and 7 h. It was carried out discontinuously for both apartments, a part of the sampling in the morning before the inhabitants left home and the other half in the afternoon when they were back home, in order to sample the air only when the they were present. The sampling for the office site was carried out continuously during office hours. The same method was used for outdoor air but higher volumes (5–20 m^3) were sampled for a period between 10 and 40 h. A triplicate was carried out per season for each of the indoor and outdoor sites and the number of fibers per cubic meter was estimated.

A passive sampling of dust fall was carried out in order to estimate the deposition rate of fibers. Quartz fiber GF/A Whatman filters (1.6 µm, 47 mm) were exposed once per season at each of the apartments A and B and the office. Sampling was carried out in the living room at 1.2 cm height. The duration of the collection varied between 4 and 15 days. The deposition rate was normalized and expressed as a number of fibers per square meter per day.

Three samples of vacuum cleaner bags were taken, twice in apartment A (winter and autumn) and once in apartment B (winter). The samples were taken directly from the vacuum cleaners that the participants use in their daily life. In order to facilitate the following sample treatment steps, it was necessary to pass the vacuum cleaner's bag contents through a 2.5 mm mesh size sieve. The retained fraction (>2.5 mm) was visually inspected to verify if it contained plastics. As this was never the case, this fraction was systematically discarded. A mass of 5.5 mg was introduced in a separation funnel with 50 ml of Zinc chloride ($ZnCl_2$ - 1.6 g/cm^3) for density separation. Preliminary tests showed a very high number of fibers. In order to make the counting feasible, a sub-sample of a small volume had to be considered. The floating fraction was homogenized and a subsample of 1 ml taken and filtered on quartz fiber GF/A Whatman filters (1.6 µm, 47 mm).

All samples were observed with a stereomicroscope (Leica MZ12– Buffalo – United states). Previously used criteria were employed in order to identify man-made fibers (Dris et al., 2015a; Hidalgo-Ruz et al., 2012; Norén, 2007). The fibers have to be equally thick through their entire length and should not be entirely straight. Moreover, neither cellular nor organic structures should be visible to consider a fiber as man-made. The fibers were counted and their length was measured with the software Histolab® (Microvision instruments – Evry – France) coupled with the stereomicroscope. The lower observation limit was 50 µm.

A Fourier Transform infrared (FT-IR) microspectroscopy (Microscope LUMOS FT-IR – Brucker, Champs-sur-Marne, France) coupled with an ATR (Attenuated Total Reflectance) accessory was used for chemical characterization. A subsample of n = 28 fibers randomly selected between indoor fibers was analyzed in order to estimate the proportion of synthetic and natural fibers. The analysis can be carried out on fibers down to the diameter of 5 µm. The fibers were categorized according to the classification proposed by the international organization for standardization (ISO/TR 11,827:2012 Textiles - Composition testing - Identification of fibers).

3. Results and discussion

All filters for all types of samples contained fibers, probably due to the proximity of the sources and the fact that fibers might tear easily of clothes and some house furniture (polyamide, polyethylene-terephthalate or polypropylene carpets, curtains, textiles, etc.).

Fig. 2 shows the size distribution of all the collected fibers in indoor and outdoor air, as well as in dust fall. A similar pattern is observed in all compartments with a majority of fibers being sub-millimetric. A decrease of the number of the fibers towards the large sizes was noticed. A similar distribution was highlighted for total atmospheric fallout fibers (Dris et al., 2016). The difference between the compartments lies in the size of the longest observed fibers: while fibers in the range of 4650–4850 µm can be found in dust fall, no fiber longer than 3250 µm is observed in indoor air and the size of the fibers in outdoor air is always smaller than 1650 µm. The fact that large size fibers are observed in dust fall is probably related their size: larger fibers settle more rapidly and gather on soil surface. While fibers under 50 µm were not counted due to the observation lower limit, the size distribution pattern suggests that much smaller fibers, that are likely inhalable, might be present, and even more concentrated.

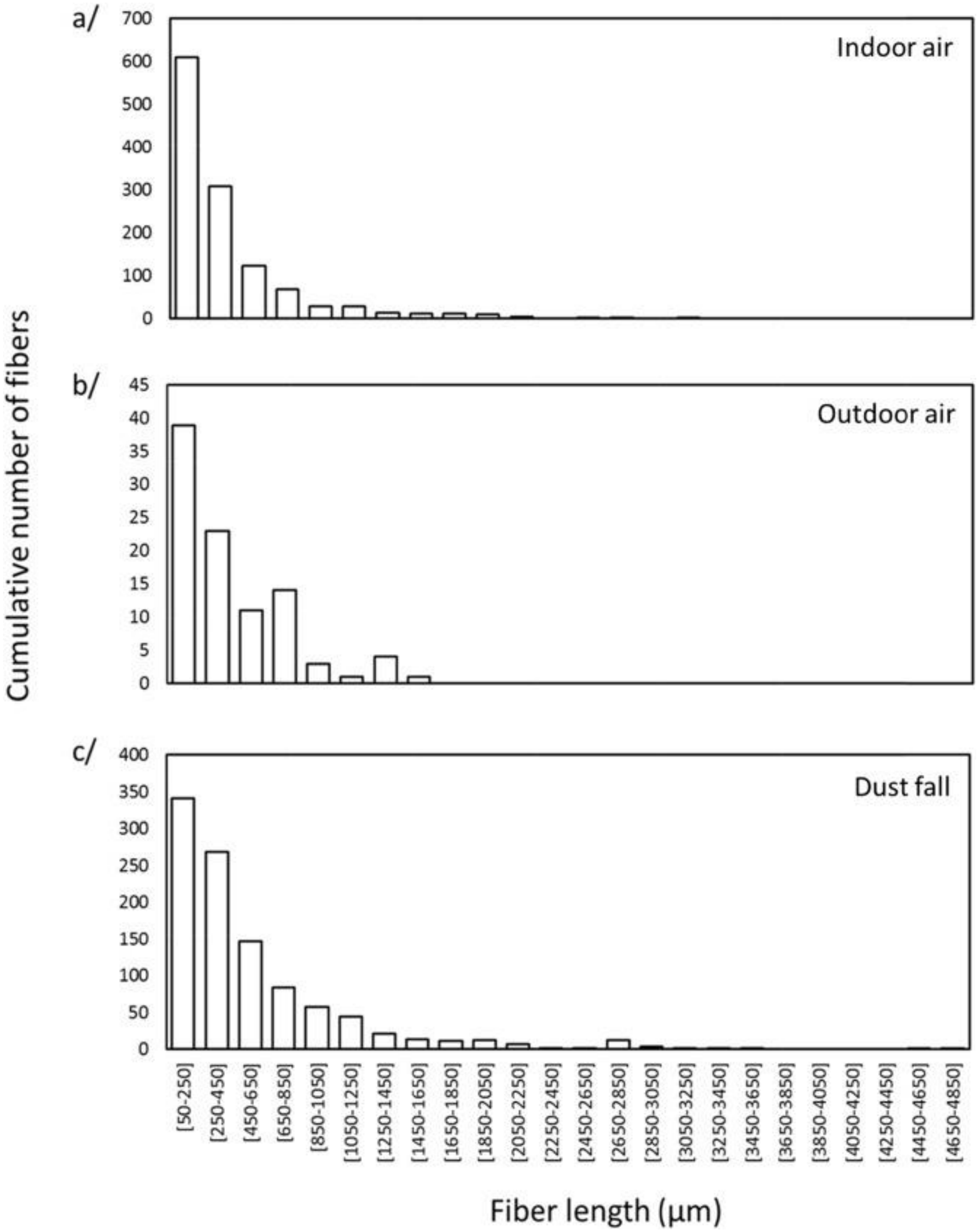

Fig. 2. Cumultaive number of fibers observed in each size range between 50 and 4850 µm in various samples, a/indoor air, b/outdoor air, c/dust fall.

Overall, indoor concentrations range between 0.4 and 59.4 fibers/m^3 with a median value of 5.4 fibers/m^3 (Fig. 3). Higher concentrations are observed in apartment A (2.5–18.2 fibers/m^3) and the office (4.0–59.4 fibers/m^3) in comparison to apartment B (1.1–16.3 fibers/m^3). Linear model showed that there is no influence of the season on the concentration levels (p-value = 0.247, default statistical significance based on a $P < 0.05$ level for all tests) while these levels are site dependent (p-value = 0.002). Mann-Whitney pairwise comparisons showed no significant differences between apartment A and the office (p-value = 0.053). Apartment B presented statistically lower concentrations compared to the apartment A (p-value = 0.003) and the office (p-value < 0.001). Different building materials, furniture, cleaning habits, and activities between the two apartments could explain this difference. However, there is only little knowledge about how these parameters could affect the concentrations. One of the information we obtained by questioning the volunteers about their lifestyle, is that in the apartment A, the laundry is line-dried in the living room while this is avoided in the apartment B thanks to a tumble dryer. This could explain that more fibers are released from textiles in the apartment A. In addition, the floor in the apartment A is majorly carpeted contrarily to the apartment B. We could suppose that the carpets could retain the fibers while they would re-suspend more easily from naked floor. Is not determined for now if carpets would act more as sources or retainers of fibers. Both apartments present similar volumes. We lack of knowledge on the exchange rate between the indoor and outdoor for each apartment as well as on the differences in the use of the mechanically controlled ventilation. It is likely that those parameters impact the observed levels. The elevated contamination of indoor air with fibers could indicate that indoors represent one of the sources of the fibers found in atmospheric fallout (Dris et al., 2016).

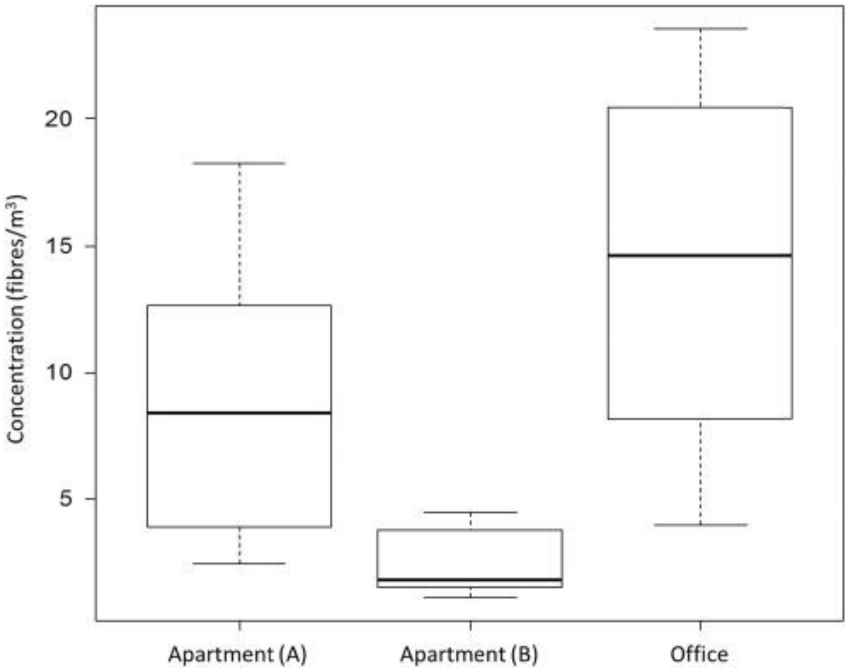

Fig. 3. Concentrations of fibers in indoor air for each of the three indoor sites (n = 12).

Outdoor concentrations range between 0.3 and to 1.5 fibers/m^3 with a median value of 0.9 fibers/m^3. During one sampling in winter carried out during a rain event, 5 times more fibers were collected on the filter attesting to the fact that rain produces a wash down of the fibers. A potential link between rainfall and fibers in atmospheric fallout has already been suggested (Dris et al., 2016). Outdoor concentrations are significantly lower than indoor concentrations

(Mann-Whitney, p-value < 0.001). The dilution in outdoors larger volumes explains probably this pattern.

Regarding inside deposition rate, from 2.7 to 19.7 fibers/day were counted on the surface of the filters (Fig. 4), corresponding to a deposition rate between 1600 and 11,000 fibers/day/m^2. Although this comparison is limited, these results are significantly higher than the atmospheric fallout previously assessed (2.1–355.4 fibers/day/m^2) (Mann-Whitney, p-value < 0.001) (Dris et al., 2016). This high deposition rate of fibers shows the importance in various studies on microplastics to carry out blank tests as contamination by indoor air is very likely.

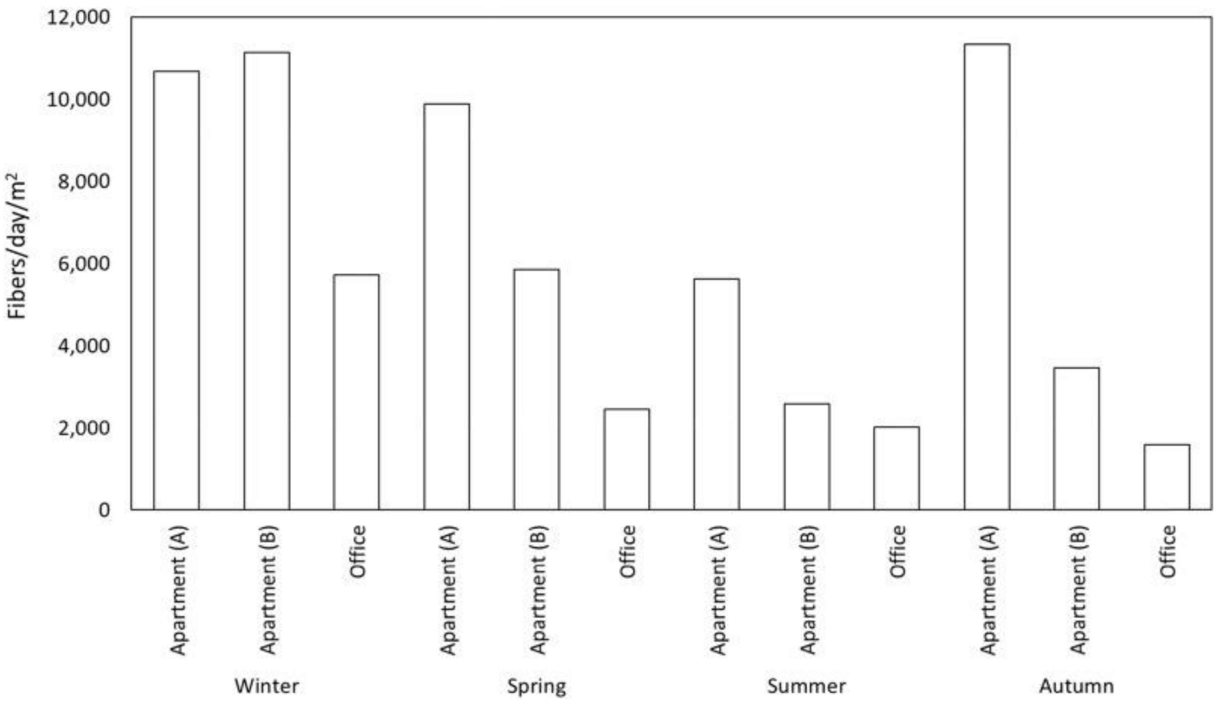

Fig. 4. Deposition rate of fibers in the three sites at each season.

Concentrations of fibers in the dust collected in the apartments from vacuum cleaner bags vary between 190.0 and 670.0 fibers/mg. A German study showed an average rate of deposition of dust of 10.9 mg of dust/day/m^2 (Seifert et al., 2000). Based on this value and considering that the amount of fibers in this dust is similar to what have been assessed in our study, the deposition rate of fibers is estimated to be between 2070 and 7300 fibers/day/m^2, which is fully consistent with our measured deposition rate.

Regarding the nature of the fibers in indoor environments, 67% are made of natural material, more particularly cotton (or other cellulose fibers), acetate cellulose and to a lesser extent wool. As it is hard to differentiate with the obtained spectra between various cellulose fibers, we cannot attest if the fibers are natural or artificial like rayon. The remaining 33% fibers contain petrochemicals (plastic polymers) with one fiber being a mixture of polyamide (nylon) and cotton and the others being totally synthetic. The more recurrent polymer is polypropylene which is consistent with the fact that houses and offices contain many potential sources of polypropylene (carpets, sofas, chairs, etc.). One of the volunteers for instance, confirmed to us the presence of a large polypropylene carpet on their living room where the samples were carried out. Polyamide fibers and copolymers of polypropylene and polyethylene were also detected. A similar proportion of petrochemicals have been found in atmospheric fallout (Dris et al., 2016) with however, a different polymer composition. For instance, polyethylene-terephthalate (polyester) which has been observed in atmospheric fallout has not been detected in the analyzed subsample of indoor environment fibers, even if it is used in textile industry.

4. Conclusions

While microplastic presence in various aquatic environments has been widely studied, this work shows also their ubiquity in all indoor compartments, either indoor air, dust falls or settled dust. To a much lesser extent, microplastics are also present in outdoor air.

The results show that human exposure to natural and synthetic fibers may occur in indoor environments. Because of their size, these fibers are not likely to be inhaled but as but as there is still no evidence, further work is needed to better understand this risk. Moreover, these fibers may contribute to human exposure through ingestion of settled dust, particularly by young children due to their frequent hand-to-mouth contacts. Moreover, smaller inhalable fibers (down to the nanofiber scale) may be present in indoor and outdoor air but could not be counted with the method used. There is currently no available data or information which provides evidence of the potential human health effects of ingested or inhaled microplastics. Further research is thus needed particularly regarding the impact of both plastic and natural fibers as well as the effects of the pollutants and additives they carry. We could expect, if some of the fibers could be inhaled, that they would release chemicals in lungs. Future studies could perform laboratory cell assays to assess any potential cellular interaction or toxicity of the fibers. A cross disciplinary research between environmental sciences and human health sciences could help fill the gaps and highlight the potential risks.

The higher concentration of fibers in indoor air compared to those measured outdoors could suggest that a fraction of the fibers are transferred to outdoors through the air exchange. This could contribute to atmospheric fallout and fibers could enter the aquatic systems through runoff. Moreover, fibers settled on indoor surfaces are most likely released in wastewater, e.g., when cleaning floors. Previous studies pointed out to washing machine effluents as a source of fibers in aquatic environments (Browne et al., 2011). This study is the first to propose this newly discovered and important receptor and pathway of fibers and microplastics. Further investigations are still needed to estimate its relative contribution as a pathway. Considering indoor and outdoor air is therefore important to understand the microplastic dynamics in an urban environment.

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