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Indoor airborne particle sources and semi-volatile partitioning effect of outdoor fine PM in offices

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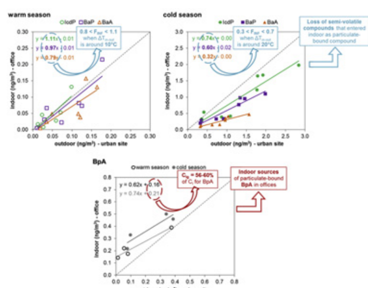
HIGHLIGHTS

- ► Indoor-to-outdoor relationship for PM1 and PM2.5 (I/O, F_{INF} and C_{ig}).
- ► Chemical characterization of inorganic ions, PAHs and BpA in fine PM.
- ► More than 50% of urban (Milan) fine PM enters the indoor office environments.
- ► Office indoor sources generate about 60% of indoor particulate-bound BpA.
- ► Semi-volatile loss from outdoor PM when entering a warmer indoor environment.

GRAPHICAL ABSTRACT



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ABSTRACT

To date, few studies have focused on PM air quality in offices, despite the fact that a lot of people spend many working hours a day in such offices. The aim of the present study is to investigate PM1 and PM2.5 in offices in Milan (Northern Italy) and in the air outside those offices. The PM samples were analyzed to determine the entity of certain compounds with possible direct or indirect adverse effects on human health: PAHs, BpA, and water soluble inorganic ions.

A good correlation between outdoor and indoor PM mass concentrations emerged (R^2 ~0.87). The maximum I/O concentration ratio was 0.92, suggesting that the indoor PM level was always lower than the outdoor level. The average infiltration factor, F_{INF}, was 0.55, showing that about a half of the outdoor PM had come indoors. The indoor-generated particles, C_{ig}, had values ranging from 0 to 4.4 μg m^{-3} (<25% of the indoor PM), showing that PM indoor sources had only made a limited contribution to total indoor PM.

The results of the indoor-to-outdoor comparisons for the aforementioned chemical compounds demonstrate that the offices were characterized by the absence of effective indoor sources of particulate-bound PAHs and inorganic ions, whereas C_{ig} was around 58% of the indoor concentration for BpA. Our analysis of the F_{INF} data pointed to the presence of a volatilization effect from PM for semi-volatile compounds like ammonium nitrate and 4- or 5-ring PAHs, which affected the measurement of their F_{INF}. We propose the introduction of a new and simple parameter, called volatilization correction, to take account of this effect.

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1. Introduction

Over the last twenty years or so, considerable efforts have been made to clarify the relationship between airborne particulate matter (PM) and human health, and a number of excellent accounts of this relationship are now available (e.g.: Englert, 2004; Lippmann et al., 2003; Valavanidis et al., 2008). Both the short-terms effects (premature mortality, hospital admissions, etc.) and the long-term effects (morbidity, lung cancer, cardiovascular and cardiopulmonary diseases, etc.) of PM have been described.

The toxicity associated with PM is related to both the size and the chemical composition of the particles in question. The smaller (fine and ultra-fine) PM particles have a greater ability to penetrate deeper into the lungs, and as a consequence the majority of studies conclude that they are basically more harmful. Moreover, the presence of specific compounds within the particles seems to increase their potential dangerousness.

Such compounds include several organic species, like Polycyclic Aromatic Hydrocarbons (PAHs) and Bisphenol A (BpA), as well as other inorganic species, such as elements. More specifically, certain PAHs have been classified as proven, probable or potential human carcinogens (International Agency for Research on Cancer). The action mechanisms of PAHs are still being studied, although results so far would seem to suggest that they can directly or indirectly damage DNA (Baird et al., 2005; Farmer et al., 2003). BpA is a suspected endocrine disruptor (Dodds, 1938). Despite the considerable number of studies of the distribution of BpA in different environmental compartments, very few focus on the atmosphere (Fu and Kawamura, 2010; Matsumoto et al., 2005; Wilson et al., 2001).

In addition to the aforementioned compounds, the acidity of the particles has also been associated with negative effects on human health, mainly in terms of lung functions. Many compounds concur to determine particle acidity, although it mainly results from the balance between sulfate and nitrate as acidic compounds, and ammonium as a neutralization species (Seinfeld and Pandis, 2006). Depending on ammonia availability, acidic sulfate and nitrate may be partially or totally neutralized in PM, thus determining particle acidity.

With regard to human health, air quality in indoor environments have been widely studied in recent years, with the focus primarily on schools and residential housing (e.g., Blondeau et al., 2005; Fromme, 2008; Martuzevicius, 2008; Polidori et al., 2009). On the contrary, considerably fewer studies have focused on PM levels in offices (Gemenetzis, 2006; Saraga et al., 2010), despite the fact that they are one of the most common workplaces in a great many countries, where lots of people spend a considerable part of their working day. As a consequence, indoor air quality in offices is of key importance, and is essential, from a health assessment point of view, when drawing up a detailed characterization of the most dangerous compounds present in the PM of offices.

A typical office is generally characterized by a very limited number of PM sources, which only occasionally contribute to indoor PM mass levels, whereas outdoor air quality can strongly affect the indoor environment. Office PM sources are represented by electronic equipment, such as: printers, photocopiers, multifunction office machines and computers (He et al., 2007; Koivisto et al., 2010; Ren et al., 2006; Wensing et al., 2008). Air conditioners (Fisk et al., 2000), together with human activity (Luoma and Batterman, 2001), can also generate PM.

The aim of the present study is to investigate PM pollution and its chemical characterization in offices in Milan and in the air outside those offices. Milan is the most densely populated, heavily polluted city in Northern Italy (Fig. 1). The service sector is the city's most important from the employment point of view, and many people spend a large part of their working day in such offices. Thus, the air quality in Milan's offices is very important for the health of a large number of workers. Moreover, the outdoor is a very strong particle source for indoor environments. The target of the study is fine PM (PM2.5 and PM1), which has been identified as the most dangerous fraction from a human health point of view. Moreover, the degree of infiltration of particles into buildings depends on particle size, and is lowest for the coarse fraction, PM2.5–10 (Hussein et al., 2005; McAuley et al., 2010). The PM samples were analyzed to determine some of the compounds with possible adverse effects on humans, i.e., PAHs, BpA, and water soluble inorganic ions.

Fig. 1. Location of the four sampling sites distributed across the city of Milan, North Italy.