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The influence of air cleaners on indoor particulate matter components and oxidative potential in residential households in Beijing

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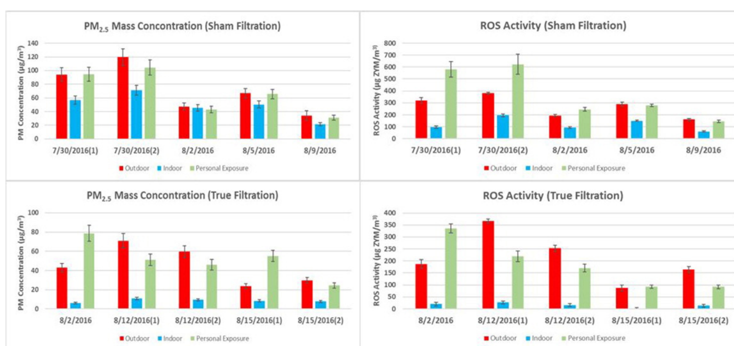
HIGHLIGHTS

- Air cleaner can reduce $PM_{2.5}$ and its components concentration in the indoor environment.
- No significant reduction on personal exposure to $PM_{2.5}$ and its components which is likely from high $PM_{2.5}$ microenvironments.
- The indoor ROS activity of the particles reduces, but the personal exposure ROS activity does not show significant reductions.

GRAPHICAL ABSTRACT



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ABSTRACT

In many developing regions with poor air quality, the use of air filtration devices to clean indoor air is growing rapidly. In this study, we collected indoor, outdoor and personal exposure filter-based samples of fine particulate matter ($PM_{2.5}$) with both properly operating, and sham air cleaners in six Beijing residences from July 24th to August 17th, 2016. Mass concentrations of $PM_{2.5}$ and several health relevant components of $PM_{2.5}$ including organic carbon, elemental carbon, sulfate, nitrate, ammonium, and 21 selected metals, were analyzed to evaluate the effectiveness of air cleaners. The effect of air purification on $PM_{2.5}$ reactive oxygen species (ROS) activity, a metric of the oxidative potential of the aerosol, was also evaluated. The average indoor $PM_{2.5}$ concentration during true filtration was 8.47 μg/m^3, compared to 49.0 μg/m^3 during sham filtration; thus, air cleaners can significantly reduce the indoor $PM_{2.5}$ concentration to well below WHO guideline levels and significantly lower all major components of $PM_{2.5}$. However, the utility of air cleaners in reducing overall personal exposure to $PM_{2.5}$ and its components was marginal in this study: the average personal exposure $PM_{2.5}$ concentration was 67.8 and 51.1 μg/m^3 during true and sham filtration respectively, and it is likely due to the activity patterns of the subjects. Short-term exposure contributions from environments with high $PM_{2.5}$ concentrations, including exposure to traffic related emissions as well as uncharacterized indoor microenvironments, likely add substantially to the total $PM_{2.5}$ exposure burden. The toxicity assay indicates that the air cleaners can also significantly reduce ROS activity in the indoor environment; however, this decrease did not translate to a reduction in personal exposure. Elemental carbon,

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lead, and arsenic were well-correlated with the ROS activity, thus adding to the knowledge base of drivers for ROS activity.

1. Introduction

Air pollution is a serious problem in developing countries worldwide as it can cause harm to humans and the natural environment (Kinney, 2008; Kim et al., 2013). It is believed to kill more people worldwide annually than AIDS, malaria, breast cancer, and tuberculosis combined (WHO, 2014). Airborne particulate matter (PM) is especially harmful to human health, and several studies have shown that long-term exposure to PM is associated with mortality from cardiovascular diseases (Hoek et al., 2013). In China, a country suffering from high concentrations of PM, a study of the hourly air pollution data from over 1500 sites found that the population-weighted average exposure to fine particulate matter ($PM_{2.5}$) was 52 μg/m^3, and 38% of the population experienced average concentrations that were above the US EPA 24-hour standard of 35 μg/m^3 (Rohde and Muller, 2015). The indoor environment may protect people from harmful exposure to outdoor pollutants to some extent; however, many studies have shown that outdoor PM can enter an indoor environment with little attenuation unless filters or other PM-removing devices are used in the building ventilation systems or within a room. This is especially concerning for the elderly, the very young, and those of ill health who spend a greater amount of time indoors and who are also more susceptible to the adverse health effects of exposure to air pollution (Byrne, 1998). Given these concerns, there is a fast-growing market for air cleaners to improve indoor air quality in countries such as China that suffer long-term air pollution issues, although there are few studies documenting their effectiveness and, in particular, the extent to which they reduce overall human exposure to specific pollutants.

Many studies have concluded that there are correlations between the outdoor, indoor, and personal exposure concentrations of particulate matter and its components (Janssen et al., 2005; Jones et al., 2000; Williams et al., 2000; Janssen et al., 1999), and several studies have found that pollutant concentrations decrease from outdoor to indoor environments with indoor/outdoor (I/O) ratios of <1 (Cho et al., 2005; Chen and Zhao, 2011). Personal exposure is higher than outdoor concentrations in most studies (Williams et al., 2000; Meng et al., 2005; Wallace, 2000) and may be in part explained by the existence of excess mass near the person, a "personal cloud" related to personal activities (Ozkaynak et al., 1995).

Several studies have found that the use of high efficiency particulate air (HEPA) filters can reduce symptoms of asthma and lead to clinical benefits for asthma patients (Reisman et al., 1990; Sublett, 2011). There are also studies showing that HEPA filters decrease airborne allergens in indoor environments and reduce personal exposure to allergens (e.g., allergens from cats) (Gore et al., 2003), pollens, and fungal spores (Sublett, 2011) as well as relieve seasonal allergic rhinitis symptoms (Morris et al., 2006; Reisman et al., 1990). Additional studies found that HEPA filters reduced concentrations of particulate matter (Myatt et al., 2008), VOCs including toluene and formaldehyde (Xu et al., 2010), CO_2, and environmental tobacco smoke (ETS) levels (Myatt et al., 2008).

However, there are limited data available to determine how effective air cleaners are at reducing the concentrations of chemical components of $PM_{2.5}$. Components of $PM_{2.5}$ include elemental carbon (EC) and organic carbon (OC),which are indicators of carbonaceous species and account for up to 40% of $PM_{2.5}$ mass in urban atmospheres (Seinfeld et al., 1998); sulfate, nitrate, and ammonium, which account for a significant portion of the overall $PM_{2.5}$ mass concentration (Chan and Yao, 2008) and can be used to approximate the contribution of the power, industry, transportation, and residential sectors to overall emissions (Zhang et al., 2012; Hodan and Barnard, 2004); EPA regulated hazardous metal air pollutants (Sb, As, Cd, Cr, Pb, Mn, and Ni), and other toxic metals documented in the literature.

Many epidemiologic studies have shown associations between ambient fine particulate matter (PM) and adverse health outcomes including cardiovascular and respiratory diseases, increased mortality, increased emergency room visits, and time lost from school and work, after both short- and long-term exposure to ambient air pollution (Pope, 2000; Cho et al., 2005; Johnson, 2004; Sørensen et al., 2003). The mechanisms of PM-induced adverse health effects are many, and a fundamental biochemical understanding of these processes is still in its infancy. However, there is increasing evidence that many of the adverse health effects derived from oxidative stress are initiated by reactive oxygen species (ROS) within affected cells (Cho et al., 2005). A growing body of literature documents that PM is able to induce proinflammatory effects in the nose, the lung, and the cardiovascular system (Li et al., 2003; Donaldson et al., 2001; Baulig et al., 2003), an effects cascade initiated in-part by ROS generation. Ongoing research shows that ROS are formed in cells through the reduction of oxygen with the catalytic assistance of electron-transfer enzymes and redox-active chemical species such as redox-active organic chemicals and metals (Cho et al., 2005; Squadrito et al., 2001; Dellinger et al., 2001). Moreover, in one study ROS activity was closely related to outdoor $PM_{2.5}$ concentration and occupied period (Aris et al., 2017), but the effectiveness of HEPA filters at reducing the activity of reactive oxygen species (ROS), to our knowledge, has not been studied. Similarly, little research has been done to investigate personal exposure to pollutants after the installation of an air cleaner. Therefore, assessing the influence of air cleaners on the ROS activity of PM may be an important predictor of impacts on human health.

Therefore, in this study, the effectiveness of air cleaners at removing the chemical components and reducing the oxidative potential of particulate matter in the indoor environment was assessed. The relationship between air cleaner use and personal exposure to the above species was also addressed. It is the first study to investigate both the detailed chemical species and ROS activity of $PM_{2.5}$, and it serves as a pilot study for further research on the effectiveness of air cleaners at removing $PM_{2.5}$ and its specific chemical components as well as its ROS activity.

2. Sampling and analysis methods

2.1. Sampling summary

Sampling took place in Beijing, China, from July 24th to August 17th, 2016. The typical average daily $PM_{2.5}$ levels over recent years have ranged from 60 to 100 μg/m^3 in Beijing (Li et al., 2015; Liu et al., 2015). Samples were collected in the apartments of six participants in locations spread across Beijing; however, due to the technical issues and the impact of human factors, only five sampling dates for both the true and sham filtration condition from six different homes are shown here. Information about the apartments of participants, which was collected via questionnaire at the end of the sampling, is provided in Table 1 in the supplementary material section. All apartments are located in the city center, and all of them are older than 10 years (two of them are older than 20 years and one is $>$40 years old). The floors of the apartment range from ground to 19th floor, and there is a parking deck besides one building while other parking lots are underneath or not near the building. All participants use an air conditioner some or most of the time when people are at home. Four participants reported that they or other people in their apartment used the stove or oven to cook during the sampling week, and all of them used exhaust fans while cooking.