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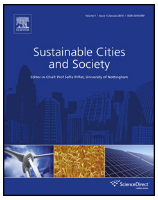

Pilot-study on airborne $PM_{2.5}$ filtration with particle accelerated collision technology in office environments

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ABSTRACT

Particulate matter in an indoor air is the cause of various health concerns. Implementing appropriate air filtration strategies to mitigate its effects would improve occupants' wellbeing who spend many hours a day inside buildings. This study examined $PM_{2.5}$ with a new filtration technology that incorporates particle-accelerated collision, utilizing semiconductor airborne contamination reduction. In-situ monitoring for 240 h was conducted for an office space. Outdoor $PM_{2.5}$ concentrations were measured during high variability periods, and indoor-outdoor ratios (I/O) were classified by occupancy conditions. The results indicated that under the new technology, 95% of the hourly indoor $PM_{2.5}$ concentration readings were below the acceptable threshold of 12 $\mu g/m^3$, yielding a median of 5 $\mu g/m^3$ and interquartile range of 3 $\mu g/m^3$. The factor by which I/O increased from unoccupied to occupied hours ranged between 1.10–2.88, with indoor $PM_{2.5}$ exceeding outdoor concentrations for 11.67% of the time. The respective range for a comparative filtration system with a standard efficiency rating was 4.35–10.43, with excess rate of 25.45%. Scatterplots of co-located indoor and outdoor $PM_{2.5}$ generated regression line with a slope of 0.004 and deviation of 15.3% for the new technology, deeming indoor levels almost independent of outdoor conditions

1. Introduction

Air pollution could adversely affect human health and the environment. One of the predominant concerns originates from fine particulate matter of 2.5 μm ($PM_{2.5}$) or less in diameter that is a by-product of chemical reactions in the atmosphere and fuel combustion (Platt et al., 2014; Solomon, 2012; Zhang et al., 2013). It is carcinogenic to humans (IARC, 2013). Particles enter the blood stream causing various health effects with increased cardiovascular and respiratory disease, aggravated asthma attacks, chronic obstructive pulmonary disease, bronchitis, rhinitis, coughing symptoms and difficulty in breathing, birth effects to degenerative disease, and neuropsychological effects, leading to higher mortality rates in both children and adults (Garcia, Yap, Hye-Youn, & Weller, 2016; Guxens & Sunyer, 2012; Jantunen, deOliveira Fernandes, Carrer, & Kephalopoulos, 2011; Krewski et al., 2011; Liu, Ying, Harkema, Sun, & Rajagopalan, 2013; Mohammadyan, 2012; Proietti, Rsli, Frey, & Latzin, 2013; Rückerl, Schneider, Breitner, Cyrys, & Peters, 2011; Twum, Zhu, & Wei, 2016;). The Environmental Protection Agency (EPA) estimated that about 74 million people in 2012 were exposed to levels of $PM_{2.5}$ higher than the U.S. standard limit of 12 $\mu g/m^3$ (Caiazzo, Ashok, Waitz, Yim, & Barrett, 2013; U.S. EPA, 2015b). These levels also exceeded the World Health Organization's (WHO) thresholds for $PM_{2.5}$: 10 $\mu g/m^3$ annual average and 25 $\mu g/m^3$ 24-h period (Pandey et al., 2012; WHO, 2006).

Research on the health effects of $PM_{2.5}$ has caused revisions to the National Ambient Air Quality Standards (NAAQS) in the U.S. (U.S. EPA, 2013). ASHRAE 62.1-2013 (ANSI/ASHRAE Standard 62.1-2013, 2013) and the new WELL Building Standard (WELL, 2014) outline the best practices in building design and operation for ensuring healthy air in buildings. These standards set new filtration criteria to improve indoor air quality and related exposure limits to particulate matter. Even with $PM_{2.5}$ exposures below the U.S. standards, public policies to reduce fine particulate matter air pollution are constantly expected to benefit public health (Lepeule, Laden, Dockery, & Schwartz, 2012).

Generally, indoor air particle concentration depends on the rate of intake and duration of exposure. The distribution patterns of

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$PM_{2.5}$ in addition to filtration effectiveness and contemporary systems are briefly discussed below.

1.1. Indoor and outdoor patterns of $PM_{2.5}$

Emissions and particle formation in the urban environment are the main sources of outdoor particles (Cheung, Morawska, & Ristovski, 2011). Buildings of varied sizes, shapes, and heights located in different built fabrics influence wind patterns and vehicular traffic movement, impacting exposure to $PM_{2.5}$ (Yuan & Ng, 2011). Particle formation in urban areas is additionally affected by wind direction and air masses from different regions (Cheung et al., 2011; Hussein et al., 2008; Qian, Sakurai, & McMurry, 2007; Salma et al., 2011). Researchers have concluded that buildings with higher ratios of external surface area to internal volume are more susceptible to high indoor levels of $PM_{2.5}$ (Taylor et al., 2014). It has been confirmed that middle floors of high-rise office buildings are surrounded by the highest concentrations of $PM_{2.5}$ as compared to upper or lower floors (Quang, He, Morawska, & Knibbs, 2013). Indoor particulate concentrations involve outdoor particles entering buildings through ventilation and infiltration. Using regression analysis, the penetration of fine outdoor particles in indoors was determined to be 30%–66%, with high case-dependency (Meier et al., 2015). Indoor particulate matter is further reported to be dependent on variability with different infiltration factors of outdoor particles and the large influence of potential indoor emissions, most importantly due to supplementary use of appliances in office spaces (Sangiorgi et al., 2013).

1.2. Rate of filtration effectiveness

ASHRAE 62.1-2013 recommends buildings, located in an area where $PM_{2.5}$ concentration exceeds the NAAQS guideline, should install particle filters or air cleaning devices to clean the outdoor air that is being infiltrated to indoor occupied spaces (ANSI/ASHRAE Standard 62.1-2013, 2013). In North America, some commercial buildings use both a medium-efficiency pre-filter and a high-efficiency extended surface filter with high minimum efficiency reporting value (MERV) rating, which is assigned to each filter based on a standard testing method by ASHRAE 52.2-2007 (ANSI/ASHRAE Standard 52.2-2007, 2008). A summary of MERV ratings is presented in (Sublett et al., 2010). The major advantage of using a pre-filter is to extend the life of the high-efficiency filter. In the absence of pre-filters, high-efficiency filters may load quickly with large particles, which would increase the airflow resistance (Bèmer, Morele, & Regnier, 2015). In extreme cases, it can cause filter bypass due to leakage at joints in the heating, ventilating and air conditioning (HVAC) system.

According to Bennett et al. (2012), the commonly used filters are relatively ineffective in removing the small particles most important to health. It was concluded that approximately 62% of buildings have low-efficiency filters with an MERV4 or lower. In contrast, more than 90% of the filters in large office buildings were cited with a higher MERV rating (Apte, 2009; Buchanan, Mendell, Mirer, & Apte, 2008). In the Building Assessment Survey and Evaluation (BASE) study that was conducted on 100 large U.S. office buildings, about 60% of these buildings had filters rated lower than MERV8, with 15% employing the top rating of 14 (Buchanan et al., 2008). Lower MERV rating causes ineffective air filtration that leads to higher particulate matter exposures among the occupants. Despite providing maximum airflow, filters with MERV4 or lower have 20% removal efficiency for particles in the 3–10-μm size range and have no efficiency rating for smaller particles (ANSI/ASHRAE Standard 62.1-2013, 2013). On the other hand, a high-efficiency particulate arrestance (HEPA) filter is often impractical in central HVAC systems due to the large pressure drop the dense filter material causes. Experimentation indicated that medium-efficiency filters are optimal when coupled with the capability of removing particulate matter (U.S. EPA, 2009; U.S. EPA, 2013).

1.3. Contemporary filtration systems

Air filtration in practice may be broadly classified into two categories: fiberglass filters and electrostatically charged (or electret) filters. Fiberglass panel filters (shallow (2.5 cm) with a MERV rating of 9 or less are typically bilayer filters with a fiberglass front collection layer and a backing layer for strengthening (Stephens & Siegel, 2013). Electret filters (deep-bed (12.7 cm) with a rating of MERV10 or above) exploit the electrostatic mechanisms (coulombic force among charged particles and polarization between neutral and charged particles) to filter particles (Chazelet, Bemer, & Grippari, 2011; Stephens & Siegel, 2013). Such filters could reduce the bypass effect in HVAC (Edelman, 2008). Azimi, Zhao, and Stephens (2014) presented the performance of each of these filtration technologies in terms of their $PM_{2.5}$ removal efficiency. In both categories, the filtration efficiency varies widely with particle size.

With the particle-accelerated collision technology (PACT), filtration works by first accelerating the small sized particles to a higher speed, and then providing an electric field through conductors in their path to cause inelastic collisions. This is done in two steps; each step involves providing an alternating current to the conductors (with different frequencies) to increase electrostatic attraction between particles. The advantage of this technology is two fold: Firstly, particles with greater diameter are easy to get trapped in the filters, hence improving their removal efficiency. Secondly, by increasing the particle size, the static charge on the particles is removed by neutralization. Therefore, the primary mode of particle transport is changed from electromagnetic forces to airflow, thus relieving the filter from the widespread problem of static pressure (Hess, 2014).

While the preliminary and limited literature indicates that the PACT system significantly decreases peak indoor- and outdoor-generated contamination and reduces small particulate count levels by 66% (Trumbull, 2015), the purpose here was to specifically examine airborne $PM_{2.5}$ concentrations. The performance of the technology was assessed in conjunction with the mostly used filter of an average MERV8 rating, as noted in Bennett et al. (2012).

2. Materials and methods

2.1. Sampling site

The field measurements were undertaken at the Skidmore, Owings & Merrill offices in the humid continental city of Chicago, USA. The space is located on the 5th floor of the Railway Exchange Building at 224 South Michigan Avenue. The analysis was set for the central ventilation system where the fresh outdoor air and recirculation air from the building were mixed, cleaned and conditioned by filters and air handling units (AHUs) with variable air volume, prior to being introduced into the office space. Outdoor air was admitted from air intakes, and the flow rate could be easily changed if required. A summary of study room description and system input parameters is given in Table 1. The used parameters (Mixing Factor, Ventilation Rate, and Penetration Factor) have typical values from previous studies in literature for testing HVAC filtration systems (Fadeyi, 2012). During all testing, the door to the office space was primarily closed, opening only for occupants to enter and exit. The four occupants spend the vast majority of the time on their computers. No operable windows to the outdoors were present. Maintenance of the room was consistent across two tests (vacuuming and surface wiping was done on a daily basis).