CLEAN AIR BRIEF 2019

REDUCING EXPOSURE TO PARTICULATE MATTER IN INDOOR ENVIRONMENT

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SUMMARY

The objective of this policy brief is to give practical information to policymakers and health authorities on reducing exposure to particulate matter (PM) in indoor environment that are naturally or mechanically ventilated and strongly influenced by outdoor air pollution sources. Prolonged exposure to harmful PM indoors can have adverse health effects, such as increased respiratory symptoms and reduced lung function. PM concentrations and size distributions in indoor air are influenced significantly by outdoor air quality, as airborne particles migrate into indoor environment through open windows and doors, leaks in the building envelope and ventilation systems.

The concentration of indoor PM depends on indoor human activities, physical activity of occupants, effectiveness of natural or mechanical ventilation, air exchange rates, building characteristics and migration of outdoor air pollution from such sources as urban traffic and burning of biomass. Transport of PM from outdoor to indoor environment depends on several factors, including, among them, type of ventilation, air exchange rate and filtration, and leaks in the building structure. Buildings can be divided into two main categories on the basis of the type of ventilation mechanism employed: mechanical ventilation with supply of filtered air; and exhaust (natural or fandriven) ventilation with envelope infiltration. The ratio of indoor to outdoor PM concentration differs between those two categories. In mechanically ventilated buildings with air filtration systems, indoor particle concentrations are often lower compared to outdoor levels, but they can be almost equal or much higher in naturally ventilated buildings.

Air cleaning based on general ventilation systems is the primary technique for combating outdoor airborne particles. Reduction of PM exposure in buildings is normally carried out on a centralized basis, with use of air filters in a general ventilation system. This approach has many good features, including ease of maintenance, but it also has some drawbacks, for example, different levels of air treatment cannot be provided easily in different parts of a building.

There are no regulatory standards to comply with for indoor air pollutants, but **general guidance is provided on improving indoor air quality of air-conditioned office premises to avoid adverse impacts on productivity at the workplace.** Effective control of PM emissions is the best approach to protect public health. If that approach is not feasible because of practical constraints, air filtration can then play a major role in providing good indoor air quality. Ventilation systems need to be designed, installed and maintained appropriately to create a healthy, safe and comfortable indoor environment in mechanically ventilated buildings.

01 SCOPE

High levels of indoor airborne particulate matter (PM) or particles pose a serious health threat to building occupants. On inhalation, air containing those tiny particulate matter travels into the respiratory system. Along the way, the particles stick to the sides of the airway and sometimes penetrate deeper into the lungs, potentially inducing a variety of health complications.

A common way to limit exposure to PM is to use air cleaning devices, such as portable air cleaners and media filters fitted with air handling units in central air conditioning systems. This policy brief gives practical information on reducing exposure to PM in naturally and mechanically ventilated indoor environment exposed to outdoor air pollution sources, especially during major air pollution episodes, such as uncontrolled biomass burning and dust storms. It is intended to help health authorities and policymakers promote good public health practices by providing practical guidelines on use of appropriate air cleaning systems when local communities remain indoors during major outdoor air pollution events.

02 OVERVIEW OF PARTICLES IN INDOOR ENVIRONMENTS

Many epidemiological studies indicate that ambient exposure to PM adversely affects human health [1]. Observed effects include increased respiratory symptoms, reduced lung function, elevated respiratory morbidity and elevated cardiopulmonary mortality [2, 3, 4, 5]. In contrast to outdoor PM, research on indoor PM and its impact on health has been at a much smaller scale even though people tend to spend more than 80 per cent of their time indoors. Exposure to PM indoors may be even more harmful than exposure to ambient PM. This can be attributed in part to the following: intense human activities carried out indoors, such as cooking with biomass, smoking, incense burning and vacuum cleaning; poor ventilation; proximity to strong outdoor air pollution sources [6, 7, 8, 9]. The exposure concentration of PM can be influenced by transport processes such as mixing, interzonal transport, and resuspension, and transformation processes such as coagulation and phase change within indoor environment [10].

The concentration of PM indoors usually ranges from 20 to 200 $\mu g/m^3$. Extreme values of PM can be as high as 1000 $\mu g/m^3$ in highly polluted indoor environment [11]. In general, concentrations of indoor PM depend on indoor human activities, the physical activity of occupants, natural or mechanical ventilation,air exchange rates, building characteristics and migration of outdoor particles from such sources as urban traffic and biomass burning [2, 12]. Indoor levels of PM exhibit temporal and spatial variations, reflecting the influence of contributing outdoor PM concentrations in the absence of indoor human activities [8, 13]. Combustion processes, including smoking tobacco, burning wood, burning incense, cooking and other indoor sources, such as emissions from office equipment and building materials and resuspension of resettled dust modify those variations in air-tight buildings [14, 15].

The role of particle size, mass and number is still unclear. Fine particles ($PM_{2.5}$: PM with aerodynamic diameters at or less than 2.5 micrometers) are widely recognized as a matter of significant concern in indoor air quality (IAQ). It is suspected that ultrafine particles ($PM_{0.1}$, PM with aerodynamic diameters at or less than 100 nanometers) may be more harmful than larger particles.

As particle size decreases, surface area and the particle number per unit mass increases. Combustion processes primarily produce ultrafine particles with a large surface area per unit mass that can penetrate deep in the respiratory track and access the pulmonary interstitium [16, 17]. Indoor particle emission from combustion sources often occurs in a short duration, but it can increase particulate levels substantially for an extended period.

Indoor chemical reactions generate secondary organic aerosols, typically monitored as ultrafine particles [18]. The presence of those particles may raise indoor airborne particle concentrations above outdoor air concentrations. Indoor combustion activities tend to generate high particle concentrations, sometimes several orders of magnitude higher than background particle levels. In addition to chemical components in PM, bio-aerosols (biological particles) are prevalent in indoor environment [19].

In mechanically ventilated buildings equipped with air filtration systems, indoor particle concentrations are often lower compared to outdoor levels, but they can be much higher in naturally ventilated buildings, where particle composition can also be very different [12, 19]. No regulatory standards to comply with for indoor air pollutants have been set, but general guidance is provided on improving the indoor air quality of air-conditioned office premises with the objective to avoid adverse impacts on productivity.

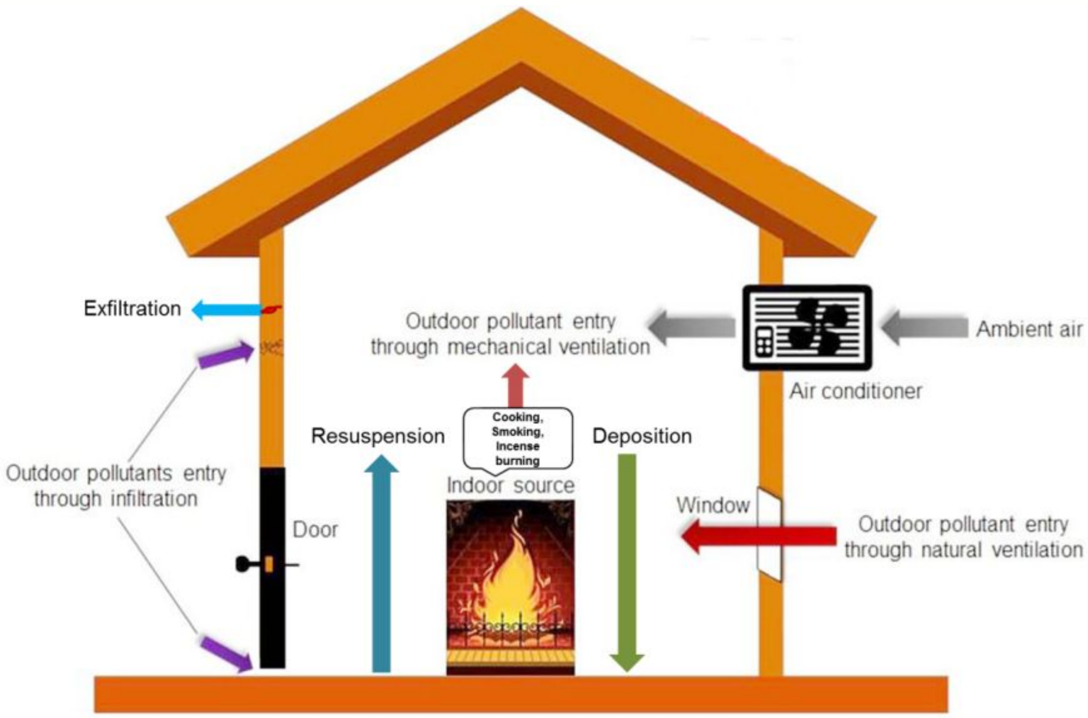
03 INDOOR - OUTDOOR PM CONNECTION

Indoor aerosol concentrations and size distributions depend on (a) transport of airborne particles from outdoors to indoors, (b) indoor emission sources, and (c) aerosol dynamics indoors [12, 20]. Transport of PM from outdoor environment to indoors depends on several factors, including, among them, type of ventilation and air exchange rate and filtration, and leaks in the building structure [21]. The main aerosol dynamical processes are deposition (particle attachment to surfaces), condensation (particle growth from vapours) and nucleation (particle formation from vapours), evaporation, and occasionally agglomeration (particle collision and attachment) [22]. Those processes affect particle size distributions indoors. Accordingly, detailed studies on indoor aerosols require information on size distributions. Sources, pathways and fate of indoor air pollutants are illustrated in Figure 1.

(i) Particle size distributions

Urban outdoor particle number size distribution is typically trimodal. Size distribution consists of a strong nucleation mode with a geometric mean diameter (GMD) of <30 nm, an Aitken mode with a GMD of between 20 and 100 nm, and a weak accumulation mode with a GMD of >90 nm [23]. Number size distribution in nucleation and Aitken mode GMDs, as well

Figure 3: Sources, pathways and the fate of indoor air pollutants



Source: Adapted from Leung D.Y.C. (2015). Outdoor-indoor air pollution in urban environment: challenges and opportunity. Frontiers in Environmental Science, 15 January. Accessed 16 June 2018. https://www.frontiersin.org/articles/10.3389/fenvs.2014.00069/full.

as in accumulation-mode particle concentrations, has been shown to be dependent on the distance between the measurement location and the main source, traffic.

Indoor particulate population is modified by typical aerosol processes, such as deposition, condensation, nucleation, evaporation and coagulation. Particle deposition is the dominant process affecting population size distribution. Deposition lowers indoor particle levels and is a strongly size-dependent aerosol process. Small particles (diameter below 100 nm) are deposited because of Brownian or turbulent diffusion while large particles (diameter above 1000 nm) are the result of gravitational forces [22]. Deposition is the only process that lowers particulate concentration indoors in buildings without a mechanical air supply. It also affects particle concentration in buildings with a mechanical supply and exhaust, but exhaust airflows also reduce particle concentrations. Deposition rates increase with higher air exchange rates[24].

Although the scientific world is intently studying indoor particulate dynamics and indoor-outdoor connection, those phenomena remain poorly understood. Researchers are finding it difficult to draw generalizations about them because of the simultaneous aerosol processes, such as deposition and filtration, unidentified indoor sources and the diversity of indoor spaces and measurement methods, together with the strong size dependency.

Assuming that there are no indoor sources, one could suggest that particulate concentrations would be lower in mechanically ventilated indoor spaces than in the outdoors [25]. Indoor to outdoor ratio is typically lower in indoor spaces with a mechanical supply of filtered air ventilation [6, 25].

(ii) Air cleaning

Buildings can be divided into two main categories based on the type of ventilation mechanism employed: mechanical supply; and exhaust ventilation with supply air filters and exhaust (natural or fandriven) ventilation with envelope infiltration. The ratio of indoor particle concentration to outdoor particle concentration differs between those two categories.

Mechanical ventilation and air filtering play a major role in contributing to good indoor air quality. Particle concentrations can be reduced by mechanical ventilation systems and filtering supply air, namely the intake of fresh outdoor air. Efficient filtration of supply air is one of the major tools for improving indoor air quality. The efficient filtration of supply air significantly reduces the transport of airborne particles from outside [20, 26]. The performance of an air filter is linked to two parameters: efficiency; and pressure drop (resistance to airflow). Efficiency is normally illustrated by removal efficiency, which provides information about the fraction of particles collected by the filter. However, in most cases, the collected particles are not of great importance compared to the particles that penetrate the filter. As a result, filter penetration is preferred over efficiency. The features of a good filter are low penetration (high removal efficiency) and low pressure drop. In buildings without a mechanical air supply, the indoor to outdoor ratios vary strongly in line with outdoor pollution levels and increase as outdoor concentrations increase [27]. No clear outdoor particulate concentration dependency is seen for buildings with a filtered supply air.

Several studies have attempted to prove the benefits of room air cleaners in terms of health [20, 28, 29, 30, 31, 32, 33, 34]. The comprehensive quantitative experiments were carried out to assess the capabilities of several air-cleaning devices to create a particle-free microenvironment as a therapy for people with sleeping problems caused by allergic rhinitis and asthma [34-35]. In general, portable room air cleaners can be used to reduce exposure to fine particles of outdoor origin in existing residential buildings and houses fitted with mechanical exhaust air systems [20]. To be effective, the airflow rate must be sufficiently high, however, and noise levels must be low, especially in bedrooms.

In naturally ventilated indoor spaces, air recirculation and filtration of room air can be effective in reducing the concentration of particles in indoor air [20, 26].

Recirculation can be done using compact devices, known as portable room air cleaners. Units that contain filters and a recirculation fan are widely used in homes, offices and restaurants. One of the advantages of room air cleaners is that they can be used in buildings without mechanical supply air ventilation and centralized air filtration systems.
When evaluating the suitability and efficiency of a room air cleaner, the following aspects need to be carefully considered:

- volume of space where the air cleaner will be used;
- ventilation rate; and
- types and concentrations of particles to be removed.

The capacity of a room air cleaner must be assessed correctly to ensure a significant reduction in the concentration of particles. This requires that the effective flow rate or clean air delivery rate (efficiency x flow rate) is significantly higher than the airflow rate because of ventilation or infiltration. In addition, the effective flow rate must be high enough to cause a reduction in concentration that clearly exceeds the speed of natural removal of particulates.

04 REDUCTION OF EXPOSURE TO INDOOR PARTICULES

Air cleaning based on general ventilation systems is the primary technique for combating particles that migrated from the outdoors. The reduction of human exposure to indoor airborne particles in buildings is normally carried out on a centralized basis, with air filters in a general ventilation system. This approach has many good features, such as ease of maintenance. One of its drawbacks, however, is inflexibility, as different levels of air treatment cannot be provided easily in different parts of a building. Rising awareness about the harmful health effects of fine particles increases the need for higher efficiency filtration. With a large accumulation of particles on the filter surface, the pressure drops (resistance to the airflow) across the filter surface tends to increase, affecting the operating costs and the efficiency of the filtration.

Decentralized air filtration is beneficial in terms of efficiency and flexibility as compared to centralized systems. Some terminal devices provide an ideal location for air filters. Air cleaning can also be integrated with supply air duct systems to serve one room or a group of rooms.

Those applications require filters with high efficiency and capacity, and low pressure drop. Portable air cleaners remain a potential tool for improving air quality in limited areas of a building.

To achieve a significant improvement in air quality, the flow rates of air cleaners must be increased without generating excessive noise. Guidance on effective use of portable air cleaners should include information on types of units, appropriate sizing, limiting ventilation to reduce entry of outdoor air and potential risks from heat and indoorgenerated pollutants. The Clean Air Delivery Rate (CADR) is a voluntary industry rating system developed for portable HEPA filter devices that provides guidance on appropriate sizing.

In addition, the cost of air cleaners needs to be reduced if the technique is to gain wider acceptance. Environment with special indoor air quality requirement are an important application area for room air cleaners. Those environments include hospitals and areas intended for people with allergies or respiratory illnesses.

05 CONCLUSION

The impact of particles of outdoor origin on indoor air quality has been widely investigated in recent years. Prolonged exposure to high PM indoors can increase incidence of adverse health impacts. **Particle concentrations and size distributions in indoor air are influenced significantly by outdoor air quality** as particles migrate into indoor environment through open windows and doors and leaks in the building envelope and ventilation systems. Events that generate PM indoors are often of short duration but may increase considerably particle concentrations in the air. Exposure to fine and ultrafine particles may be more harmful than that to larger particles because ultrafine particles deposit deeper in the respiratory track. **There is a lack of detailed data, however, on PM numbers and mass concentrations in different size classes emitted from outdoor/indoor sources, which is essential to assess the health impact of particle exposure.**

If the aim is to reduce exposure in indoor environment, actions to reduce concentrations of PM and ultrafine particles should be focused on the breathing zone. **Effective control of PM emissions is the best approach to protect public health.** If that approach is not feasible because of practical constraints, air filtration can then play a major role in creating good indoor air quality. Ventilation systems need to be designed, installed and maintained appropriately to create a healthy, safe and comfortable indoor environment in mechanically ventilated buildings. Particular attention must be given to ventilation of rooms intended for special purposes, such as people with allergies. In naturally ventilated indoor spaces, use of portable air cleaners can be effective in improving indoor air quality. However, **use of commercial air cleaners for reducing outdoor air pollution levels is not a viable option because of their ineffectiveness, high capital, operating and maintenance costs and extensive energy consumption**. Similarly, it is not prudent to use commercial air cleaners to reduce PM levels directly emitted from strong indoor emission sources, such as burning of biomass for cooking. For such cases, pollution prevention or use of clean cook stoves is strongly recommended. In addition to PM, some other air pollutants of concern are carbon monoxide, formaldehyde and other volatile organic compounds, and microbial pathogens. Exposure reduction to such pollutants is also important and can be achieved by using multi-functional air filters. Such filters are in the development stage, or their performance has yet to be sufficiently evaluated under field conditions, especially in tropical environment, which have high indoor temperatures and levels of humidity.

Improvements in indoor air quality remains a challenging task. **More research and development using multidisciplinary inputs is required to make further advances in the assessment and mitigation of exposure to particulate matter in indoor environment**.

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