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Indoor/outdoor particulate matter number and mass concentration in modern offices

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ABSTRACT

Indoor/Outdoor (I/O) particulate mass concentration (PM_{10}) and number concentrations were measured online in modern office environments with mechanical ventilation. The measurement took place during June 2014 in a building, which, belongs to the Norwegian Institute for Air Research, in Norway. Particle number size distribution was measured with an SMPS (0.014–0.7 μm) and an APS (0.5–18 μm) instruments, whereas, mass concentration was measured with a Dust-Trak II photometer. Two offices were selected to examine the outdoor contribution of particles and the influence of indoor sources. One office was fully occupied during working hours and the second one unoccupied at all times. The results suggested that human presence during the working hours affected considerably indoor particles in the occupied office both in terms of number and mass concentration compared to the non-working hours conditions. In the absence of any significant indoor source generating new particles (hardcopy devices), the indoor environment was influenced mainly from the presence of people with resuspension activities being the most important source for particle sizes larger than 1 μm. Moreover, indoor particle number and mass concentration was influenced substantially from outdoor sources. Generally, both indoor number and mass concentrations showed temporal fluctuations similar to those observed outdoors, suggesting that particle penetration was significant in both offices. However, low I/O ratio (90^{th} percentile < 0.3 for both offices) indicated the efficient removal of particles from the air filtration system.

1. Introduction

During the past two decades, indoor air quality has attracted the scientific interest since it influences human exposure to ambient particulate matter (PM) as well as gaseous indoor pollutants (CO_2, NO_2, volatile organic compounds). Common indoor environments, where people spend most of their time, include houses and workplaces. Although, PM characteristics and sources inside houses have been extensively studied, indoor particle behavior in commercial buildings is still a challenging area. Furthermore, human comfort and work performance are associated with indoor air quality in office environments [1,2].

It is well-known that airborne particles indoors may originate from outdoors or be generated indoors [3–5]. However, different indoor or outdoor sources are associated with different indoor environments. In regard to houses, indoor human activities contribute considerably to both indoor particle number and mass concentrations. These activities include e.g. cooking, vacuuming, burning candles, smoking, solid fuel combustion, walking [6–14] or even the use of electric appliances [15–17]. Work environments, on the other hand, are mostly affected by the use of office equipment [17–21]. However, in the absence of any significant indoor source, activities that resuspend particles from indoor surfaces are very common particle sources [22].

Hardcopy devices and especially printers generate particles at ultrafine size range [21,23] with almost no impact on mass concentration of particles [18,21]. He et al. [18] investigated different types of printers and found that the type of the printer is closely related with characteristics of particle emissions. Kagi et al. [19] studied chemical emissions from printers and found a considerable amount of volatile organic compounds released during the

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printing process. Printing speed, type of toner, number of printing pages, coverage of the paper [17,24,25] are factors strongly associated with emissions from printers. These characteristics make hardcopy devices a major pollutant for the indoor environment influencing further human exposure.

Nevertheless, the resuspension of dust settled on indoor surfaces is a matter of growing interest in the recent years. Indoor surfaces serve as a source of allergen-containing particles which can be resuspended by human activities [26–28]. Adverse effects on human health are associated with inhalation of these particles. Several studies focused on characteristics of particle resuspension in indoor environments or in chambers [7,29]. It was found that particle size plays an important role on resuspension with bigger particles resuspended easier [3,30–32]. Investigation of factors such as floor type, dust type, walking speed, floor loading, number of persons, type of shoes and environmental conditions (relative humidity, temperature) provided knowledge on the impact of different human behavior and indoor environment characteristics to particle resuspension [7,29,32–35].

A key role on indoor air quality of office environments is the location of the building along with the filtration system. Matson [36] found a decrease in ultrafine particle indoors (and outdoors) when moving from urban to rural areas. Quang et al. [37] measured higher indoor particle concentration in an office building close to a busway road compared to other offices. These studies highlight that the location of the building is a considerable factor when dealing with indoor air quality, since, penetration of outdoor particles through cracks and leaks is a major contribution to indoor particulate matter [4,38–41]. Ventilation of the building (natural or mechanical) is important and has strong impact on particle penetration from outdoors. In the case of natural ventilation, the building envelope serves as particle filter [42], where, infiltration from outdoors is controlled by particle size and building characteristics [43]. On the other hand, modern filtration systems prevent a considerable fraction of sub-micron particles to enter the building [37,44,45]. Hence, development of a suitable ventilation system can reduce human exposure to outdoor particles and improve indoor air quality in residential buildings [46].

The aim of the present study was to investigate particle number and mass physical characteristics in a modern working environment in the region of Scandinavia, where ventilation of the building is mechanically controlled. Indoor and outdoor concentrations were measured online in two offices with different occupation scenarios and technical characteristics in order to examine the contribution from outdoors as well as the influence of indoor sources in the indoor environment. Moreover, human occupation and infiltration of outdoor particles were investigated in respect to indoor concentration levels and particle size.

2. Materials and methods

2.1. Measurement location/office description

The location of the building is in a rural/suburban area 17 km northeast of the city of Oslo, Norway. It belongs to Norwegian Institute for Air Research and it is part of a science park surrounded by a residential area consisting of urban area and forest with several streets of medium traffic. A map of the location of the building is shown in Fig. 1. Several busses of public transport run through the area. Besides the vehicular traffic and domestic activities there are no other major sources in the vicinity of the area where the building is located.

The building has one main entrance at the front and a second one at the right hand side used for storage purposes. It is a three floor building, mainly consisting of offices and is separated into two sections connected through an inside bridge. The frame of the building is constructed by bricks with a few areas covered by glass (mainly windows and doors). All offices are connected to outdoors with windows. The building is mechanically ventilated, although the windows in the offices can be opened at any time by the occupants. Smoking and burning candles is prohibited inside the building in all areas.

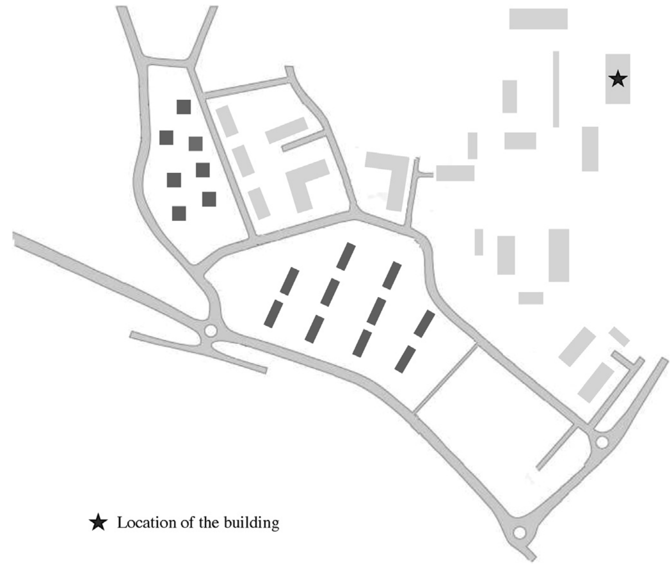

Fig. 1. Map of the location of the building under study and the surrounding area.

A few open areas cover the indoor space mainly belonging to the entrance hall and the laboratories. The laboratories are a mix of open space and small offices connected through corridors. Two offices were selected to perform the measurement, one at the first floor and one at the second floor. The office on the first floor is located inside a laboratory at the right section of the building, whereas, the office at the second floor is connected through a corridor with other offices located at the left section of the building. Figs. 2 and 3 provide the floor plan and the location for each office. Office A corresponds to the office at the second floor and office B corresponds to the office at the first floor. Office A faces the front of the building and is very close to the main entrance, whereas, office B faces the backside of the building. Several windows connect the two offices both with other indoor places and with outdoors. Fig. 4 presents a detailed scheme of the two offices.

Office A was furnished with shelves covered by books and papers, a desk with a computer and chairs. Blinds covered the windows at all times both the ones facing indoors and outdoors. The area of office A was 21 m^2 and its volume was 56 m^3. Office B on the other hand, was furnished with a long desk, one chair and shelves mostly covered with laboratory equipment. No blinds covered the windows. The area of office B was 16 m^2 and its volume was 40 m^3. Office A was connected to the main corridor of the section through a small office of the same width but smaller length, whereas, office B was directly connected to the laboratory through the door. The floor in both offices was covered with linoleum.

2.2. Experimental set up

Particle size distribution was measured with a TSI 3936 Scanning Mobility Particle Sizer (SMPS) and a TSI 3321 Aerodynamic Particle Sizer (APS). SMPS consisted of a TSI 3775 Condensation Particle Counter (CPC), a TSI 3080 Electrostatic Classifier (EC), a TSI 3081 Differential Mobility Analyzer (DMA) using a Neutralizer