ISO ePM1 60 % GRADE TYPE FILTER (F7) BEHAVIOUR IN A BUILDING WITH AIR RECIRCULATION

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ABSTRACT

Mechanically ventilated buildings use filtration to remove particles from supply air. In cases without recirculation, the concentration of particles in the supply air is simply the outdoor concentration multiplied by the filter penetration. However, some building ventilation systems partially recirculate exhaust air to reduce energy consumption and, to some extent, lessen particle loading on the filters. Under these circumstances the indoor air concentration is more difficult to estimate. Here, we present a case study from measurements in an office building, where the average recirculation ratio (the portion of recirculated exhaust air of the total supply air) was measured as 0.65. The single-pass efficiency of the filter is compared to the apparent particle penetration when air is recirculated, showing a benefit of air recirculation.

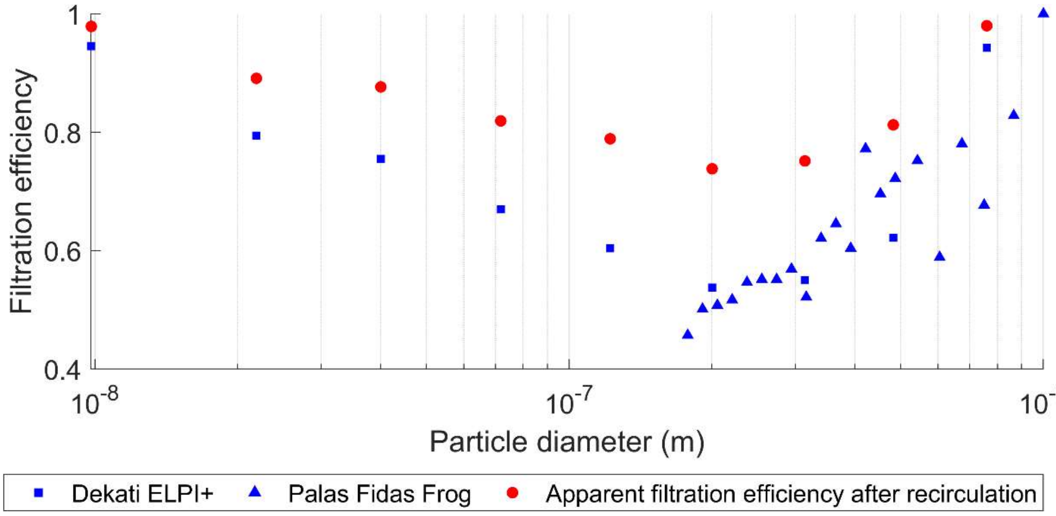

Figure 1: Efficiency of supply air filtration. Blue markers show the filtration efficiency while red markers show the effective filtration efficiency based on supply air and outdoor air concentrations. In a building without recirculation, these two would be equal. ELPI+ and Fidas Frog are the measurement instruments employed in this study.

Comparing the filter efficiency to the apparent filtration efficiency in Figure 1 shows that particle concentration in indoor air is reduced significantly due to recirculation and filtration. However, this ventilation system also has significant drawbacks: carbon dioxide is not removed by particle filters and will dispense more slowly, and particles formed indoors will have the chance to recirculate, including airborne pathogens exhaled by infected individuals.

KEYWORDS

Aerosol particles, Building filtration, Mechanical ventilation, Recirculation

Introduction

Buildings require ventilation to remove carbon dioxide along with any indoor-originating pollutants from the indoor air. Ventilation systems can be broadly divided into natural and mechanical, with natural ventilation being relatively typical for residential buildings while mechanical ventilation is more common in high occupancy settings. In public and commercial buildings, such as offices, indoor CO_2 concentrations are often regulated by law and mechanical ventilation is generally necessary to meet these regulations. Some mechanical ventilation systems recirculate a portion of the exhaust air by mixing it into the fresh outdoor air to lessen the need for either heating or cooling of indoor air. The benefit of this is increased energy efficiency. In Finland, 26 % of all energy use is for heating buildings (Official Statistics of Finland, 2016), thus it is both economically and ecologically beneficial to reduce the need for heating. Up to 70 % of air can be recirculated without causing changes in air freshness that are noticeable by occupants (Jaakkola et al., 1994).

Mechanical ventilation systems are equipped with particle filters to keep ducts, fans, and motors free of dust and, to some extent, indoor air free of particles. Filters typically work best for large particles (diameter > 1 µm) and for very small particles (diameter < 0.1 µm Smaller particles are collected by diffusion, whereas larger particles are collected by impaction and interception (Hinds, 1999). Somewhere between these two sizes is the most penetrating particle size (MPPS). For example, the F7 filter has MPPS of roughly 200 nm (Karjalainen et al., 2017). The total efficiency of a filter depends on the ambient particle size distribution; efficiency is low if most particles are near the MPPS. In practice, filter efficiency is also affected by the flow rate through the filter (Raynor et al., 2011) and the age of the filter. When the filter is loaded with particles, its particle collection efficiency typically improves, but at the cost of a higher pressure drop across the filter (Wang et al., 2016). This will lead to increased energy usage to maintain the desired air flow rates in the building.

Lowering particle concentrations in indoor and outdoor air is very important for human health. The World Health Organization (WHO) estimates that 7 million deaths each year are attributable to air pollution (sub-2.5 µm particles ($PM_{2.5}$) and ozone). There is no established safe level for particle concentration, but WHO gives target levels. The target concentration for $PM_{2.5}$ is 15 $\mu g/m^3$ (24-hour average). Additionally, WHO guidelines suggest that for particle number concentration the upper limit for *low concentration* is 1000 $1/cm^3$ and the lower limit for *high concentration* is 10 000 $1/cm^3$. The same guidelines apply to both indoor and outdoor air. (World Health Organization, 2021)

In office buildings where recirculation of air is frequently used, an additional benefit of recirculation is the double filtration of outdoor air. Offices do not generally contain many indoor particle sources, so particle exposure is almost entirely due to infiltration of aerosol particles from outdoor sources (L. Morawska et al., 2017; Sangiorgi et al., 2013). Filters in mechanical ventilation systems remove a portion of these, but when air is recirculated the number of particles entering indoor air is reduced even further. In this study, we determined the effect of recirculation on the indoor particle concentration by conducting measurements in an office building. The results show that concentrations are lower than would be expected by the filtration efficiency curve, but we also discuss why recirculation is not always an ideal solution.

Methods

We conducted a two-week indoor air measurement campaign at an office building in Helsinki, Finland during March 2021. The building was equipped with ISO ePM1 60 % grade filters which were changed just before the measurements. Due to COVID-19 restrictions, the building was nearly empty, and the 4th floor where the measurements were conducted was completely unoccupied, except for when the location was visited for routine maintenance of the instruments, approximately 1 hour each weekday at 11-12. Thus, most particles in the room air were of outdoor origin. Air sampling alternated between supply air and room air from the center of the room. Simultaneously, outdoor air was sampled from the 7th floor of the building.

Figure 1 shows a schematic of the ventilation system and the measurement locations, as well as a map of the surrounding area. Outdoor air entered the ventilation system from the 7th floor of the building, from the courtyard on the west side. The studied office room was located on the opposite side of the building on the 4th floor, with windows facing east. The amount of recirculation air was controlled with dampers which used outdoor temperature as input, attempting to increase recirculation when outdoor temperature is far from the required indoor temperature. The building was also heated using the ventilation air. As can be seen from the map, Helsinki is a coastal city, and the target building was near the shore. Information on weather conditions was retrieved from a weather station operated by the Finnish Meteorological Institute (FMI), located 1 km north of the target building.

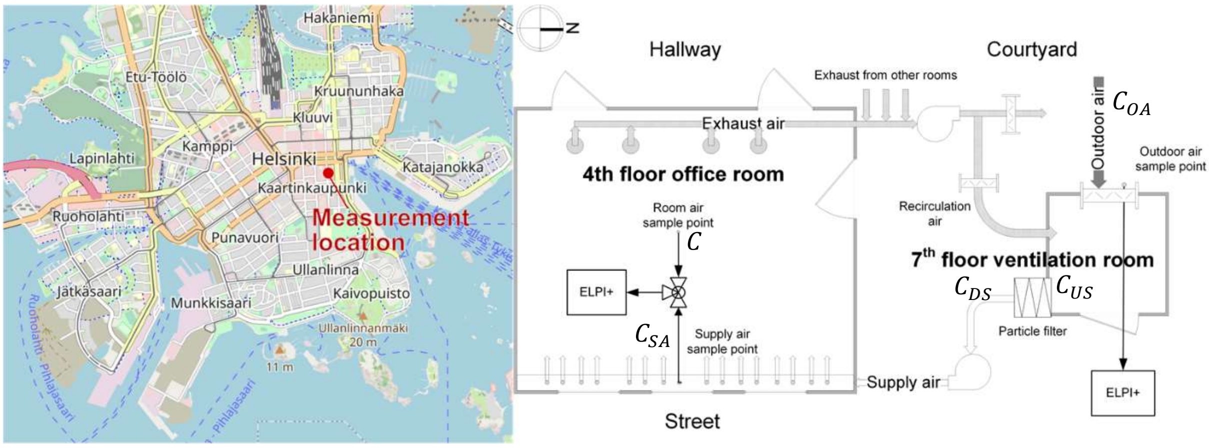

Figure 1: Location of the measurement building (left panel) and a schematic of the ventilation system and sampling points. Note that the schematic orientation is rotated. Map courtesy of: © OpenStreetMap contributors (https://www.openstreetmap.org/copyright).

The instruments used for particle detection were ELPI+ (electrical low-pressure impactor by Dekati Ltd.) and Fidas Frog (by Palas ®). ELPI+ combines a cascade impactor with a unipolar diffusion charger and can measure a wide size-range of particles (~10 nm to 10 µm) with a 1 s time resolution. Fidas Frog is an optical instrument, capable of measuring particles from 180 nm to 100 µm in 32 particle size channels. Its measurement principle is based on light scattering of single particles illuminated with a high intensity LED light source.

Results

The single-pass filtration efficiency E for the supply air filter in the size range 0.18 – 1.24 µm was determined using the optical particle counter Fidas Frog. Particle number concentrations were measured before and after the filter (C_{US} and C_{DS}, respectively) and the filtration efficiency was calculated as

$$E = 1 - \frac{C_{DS}}{C_{US}}. \tag{1}$$

The recirculation ratio R can be expressed as

$$R = \frac{C_{OA} - C_{SA}/(1 - E)}{C_{OA} - C}, \tag{2}$$

where C_{OA}, C_{SA} and C are the concentrations measured from the outdoor air, supply air and room air, respectively, and E is the filtration efficiency determined with Fidas Frog. Using equation (2) and the filtration efficiency E measured with Fidas Frog, the air recirculation ratio was determined from the ELPI+ number concentration data. Figure 2 displays the calculated recirculation ratio as a function of temperature (left panel) and both the recirculation ratio and outdoor temperature as a function of time. No clear correlation was observed between the temperature and the recirculation ratio (coefficient of determination $R^2 = 0.015$). The calculated recirculation ratio varied from roughly 0.4 to 0.9 with a mean at 0.65.

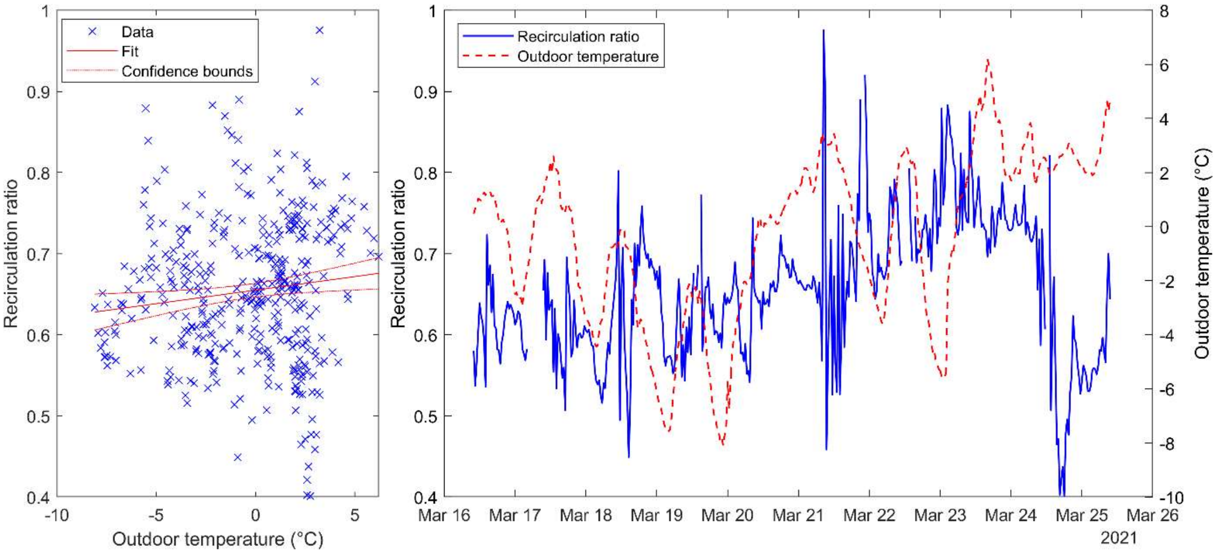

Figure 2: Measured recirculation ratio and outdoor temperature during the measurement campaign.

The particle number concentration in the mixing chamber C_{US} can be estimated as

$$C_{US} = (1 - R)C_{OA} + RC.$$

Because particle loss in the ventilation duct run due to deposition is negligible for submicron particles (Sippola et al., 2004; Zhao et al., 2006), equation (1) can be expressed as

$$E = 1 - \frac{C_{SA}}{(1-R)C_{OA} + RC}, \tag{3}$$

which gives the single-pass filtration efficiency of the supply air filter for the entire ELPI+ size range.

In Figure 3, the blue markers show the single-pass filtration efficiency of the filter in this study. The triangle markers show the filter efficiency measured with the optical particle counter and the square markers show the efficiency calculated with equation (3). The measured and calculated efficiencies are in good agreement and the curve is representative of a typical filtration efficiency curve. The most penetrating particle size (MPPS) is near 200 nm, which agrees with previous studies (Karjalainen et al., 2017; Stafford et al., 1972). The red markers show the relation of outdoor air particle concentration compared to the supply air, expressed as $1 - C_{SA}/C_{OA}$. The apparent filtration efficiency is improved from the single-pass efficiency of 54 % to 72 % after recirculation (for the MPPS). The effect is slightly larger during nighttime (18:30-07:00), when the ventilation air flow was lower.

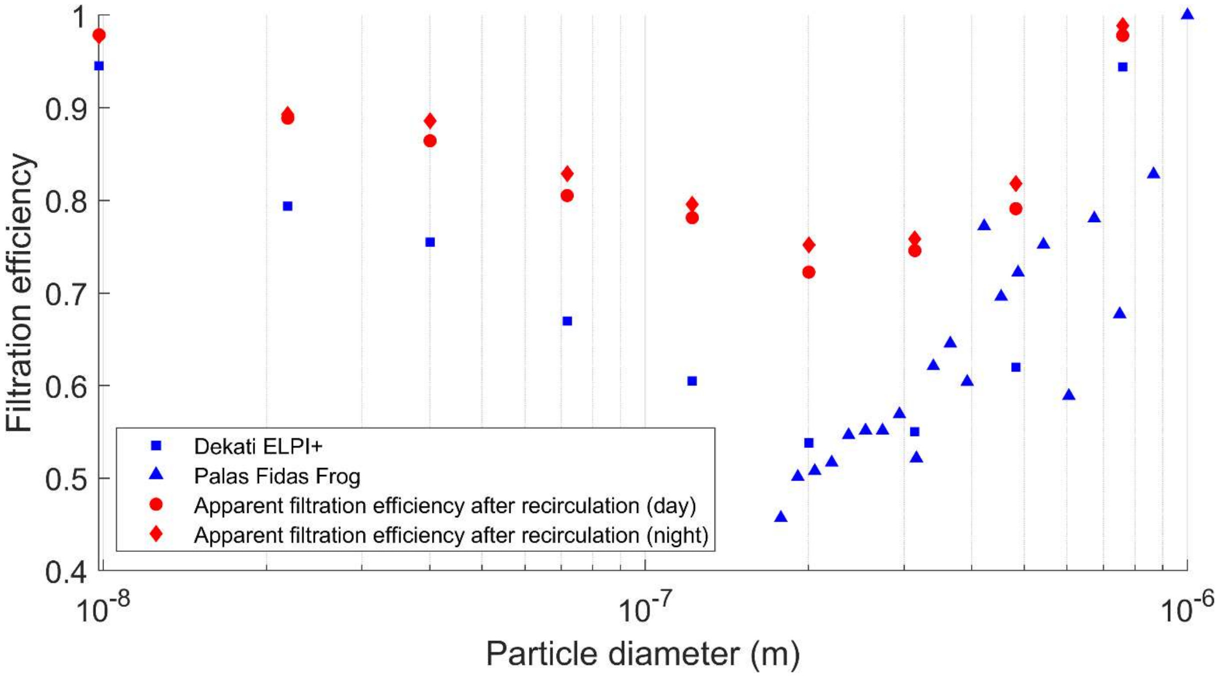

Figure 3: Efficiency of supply air filtration in an office building. Blue markers show the filtration efficiency while red markers show the effective filtration efficiency based on supply air and outdoor air concentrations. In a building without recirculation, these two would be equal.

Discussion and Conclusions

Air recirculation is used to improve energy efficiency of buildings by resupplying warm exhaust air. In the studied office building, the effect of outdoor particulate matter concentration on indoor concentration was reduced by indoor air recirculation compared to the actual filtration efficiency of the ISO ePM1 60 % grade filters (F7) used in the building. In both cases, the particle size dependent filtration efficiency had similar characteristics, i.e., the filtration efficiency was high for the smallest and largest particles and the MPPS was approximately 200 nm. In this study we aimed to characterize the benefit recirculation has on air quality. However, it should be kept in mind that there are also several drawbacks regarding ventilation systems utilizing indoor air recirculation; gaseous compounds such as CO_2 are not removed by particulate filters, which means that it is not as quickly removed from offices and other indoor spaces, and during a pandemic, aerosols containing harmful viruses which originate from the occupants will also have a chance to re-enter room air (Lidia Morawska et al., 2020). The former could be resolved by adding carbon dioxide scrubbers to the recirculated air, and the latter by using higher efficiency filters for supply air. Unfortunately, the savings in energy consumption would most likely be lost due to increased flow resistance. In buildings with considerable indoor pollution sources, even the benefit in reduced particle concentration may vanish. Thus, recirculation of indoor air should always be utilized carefully, keeping in mind these potential problems. In low occupancy spaces, recirculation may improve indoor air quality and energy efficiency.

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