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Particle filtration in energy efficient housing with MVHR

Highly energy efficient buildings are very airtight and usually require the installation of a mechanical ventilation with heat recovery (MVHR). But which ambient air filter class is a reasonable choice in terms of indoor air quality and energy use when also considering indoor generation?

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Study objectives & methodology

Highly energy efficient buildings have very airtight building envelopes and use mechanical ventilation systems to ensure sufficient air exchange. E.g. the Passive House standard, a certification scheme for very energy efficient buildings, requires the installation of mechanical ventilation with heat recovery (MVHR) (PHI n.d.). When using a MVHR fresh air is supplied into bedrooms (and living rooms). The same amount of air is extracted from the wet rooms, i.e. kitchen, bathroom and toilet, and exhausted to the ambient once it has passed the heat exchanger. In European homes with MVHR, no air is recirculated within the dwelling (in contrast to North American homes). To protect the heat exchanger from fouling, filters are needed. For this purpose, a rather coarse filter class, e.g. G4 or equivalent, is sufficient. To reduce the exposure of the occupants to outdoor-originated particulate matter (PM), many MVHR units foresee the installation of a higher filter class for supply air. E.g. the Passive House standard requires the use of an supply air filter with an efficiency rating of minimum F7 according to EN 779 (EN 2012) or ePM_1>50% according to the more recent ISO 16890. Note, that EN 779 classified filter media by its average filtration efficiency for particles with a diameter of 0.4 µm, while ISO 16890 considers filtration efficiency over the entire particle size spectrum. Typically, the supply air filter is positioned at the ambient air intake, this way it also protects the ventilation system from fouling. Since the potential health effects of fine and ultrafine particle exposure are receiving growing attention, the question arises what filter class should be recommended for highly airtight homes with MVHR. Is the current Passive House requirement reasonable or would it make more sense to recommend a higher or lower filter class? What is the effective filtration performance, i.e. the effective occupant exposure and what are the associated energy costs?

To answer these questions a number of aspects have to be considered: e.g. in-/exfiltration through the building envelope, particle deposition (e.g. gravitational settling, adhesion) and opening of doors and windows by the occupants influence the indoor particle concentration. Additionally, indoor particle sources like cooking (considered the major indoor source) can substantially contribute to occupant exposure.

To estimate exposure depending on outdoor concentration, cooking activity and ventilation concept a computer simulation study was performed using the software CONTAM. A model representing a typical Austrian residential dwelling with two bedrooms was generated incorporating all of the aforementioned aspects (**Figure 1**). Part of the challenge is that particles of different sizes behave very differently, so that the entire relevant particle size spectrum has to be modelled and that the respective model parameters have to be provided size-dependent. The necessary parameters were extracted from reports and publications of other experimental studies (Liu and Nazaroff 2003; Riley et al. 2002; Shi 2012)even though most human exposure to PM of outdoor origin occurs indoors. In this study, we apply a model and empirical data to explore the indoor PM levels of outdoor origin for two major building types:

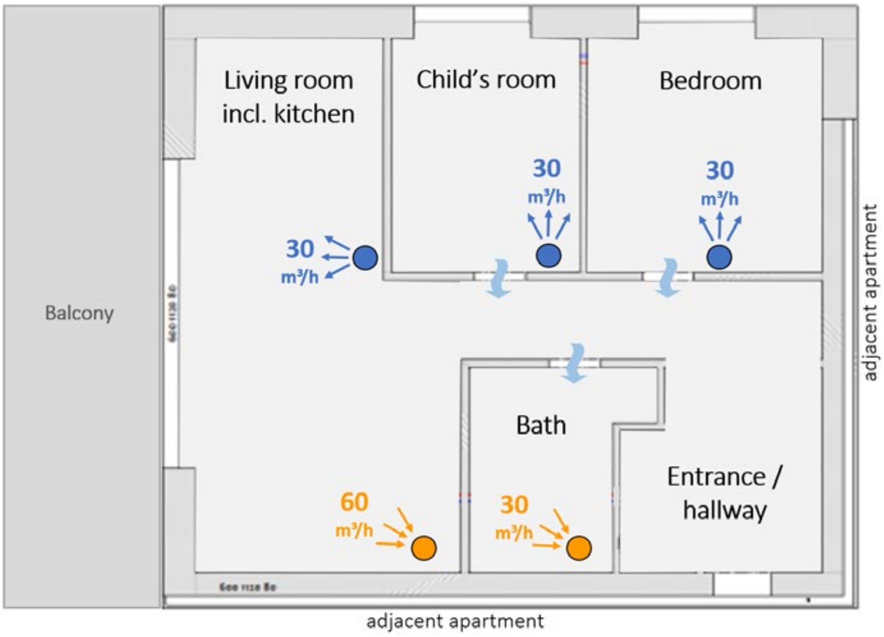

Figure 1. Sketch of the simulated floor plan representing a typical new Austrian residential dwelling.

offices and residences. Typical ventilation rates for each building type are obtained from the literature. Published data are combined with theoretical analyses to develop representative particle penetration coefficients, deposition loss rates, and ventilation-system filter efficiencies for a broad particle size range (i.e., 0.001-10 mum. A sensitivity analysis was performed for relevant model parameters to ensure that a variation on the assumed parameters will not totally change the results and therefore the conclusions, see (Rojas 2019) for more details.

Main results

Figure 2 shows the simulated particle size distribution for four distinct hours of a winter day: (a) night times: only outdoor-originated particles are present;

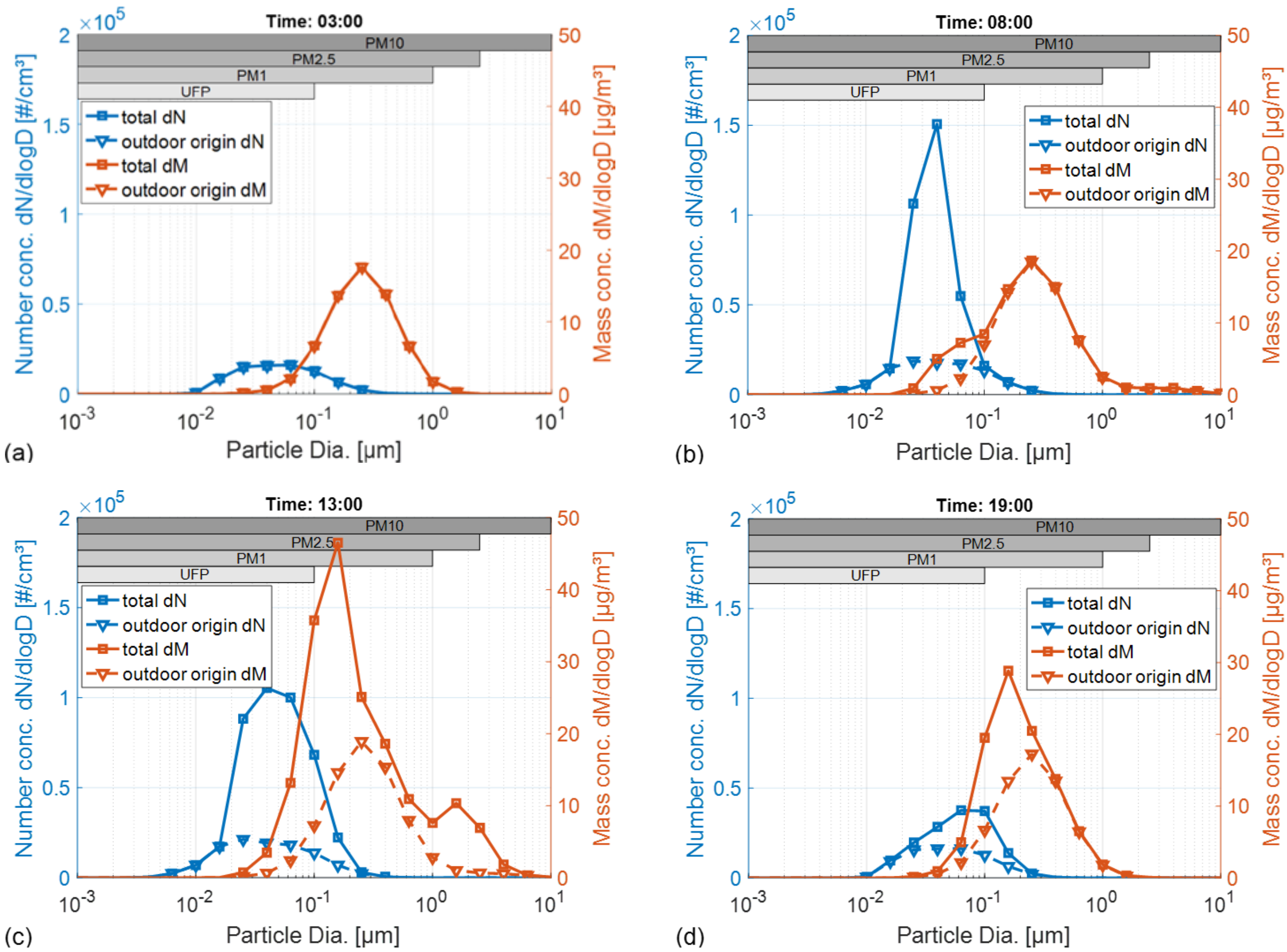

Figure 2. Log-normalized PM size distribution in the living room at four different hours of the day: during the night (a), after breakfast (b), after lunch (c), after dinner (d). The distribution of the outdoor-originated number and mass concentration is also plotted to differentiate between contributions from indoor and outdoor sources.

(b) after breakfast (with bread toasting activity): the number concentration is strongly increased by indoor-originated particles, however the mass concentration is still dominated by outdoor-originated particles (increased by morning airing event); (c) after lunch: the cooking event (frying burger) substantially increases the number and mass concentration; (d) after dinner: the number and mass concentration is notably increased by another cooking activity (heating oil). As one can also see, there is little difference between PM_1, $PM_{2.5}$ and PM_{10} values, i.e. most of the time indoor exposure is mainly dominated by sub-micrometre sized particles.

The results of the variation in air filter class show that a F7 filter (according to EN 779, roughly equivalent to MERV13 according to ASHRAE Standard 55.2 or ePM_1>50% according ISO 16890) reduces the average $PM_{2.5}$ exposure of a person (that is home all day) to outdoor-originated particles by 67% compared to outdoor air. This comes at a relatively low additional electrical energy consumption (the extra fan power needed to overcome the flow resistance created by the filter). In comparison, the use of a lower class filter like a M5 (equivalent to MERV9/10) or a higher class filter like F9 (equivalent to MERV15) would reduce the exposure by 26% or 79%, respectively. See triangles/dashed line in **Figure 3**. Note that the simulated filters were classified according to EN 779, because fractional efficiency curves for filters according to ISO 16890 were not available to the authors yet.

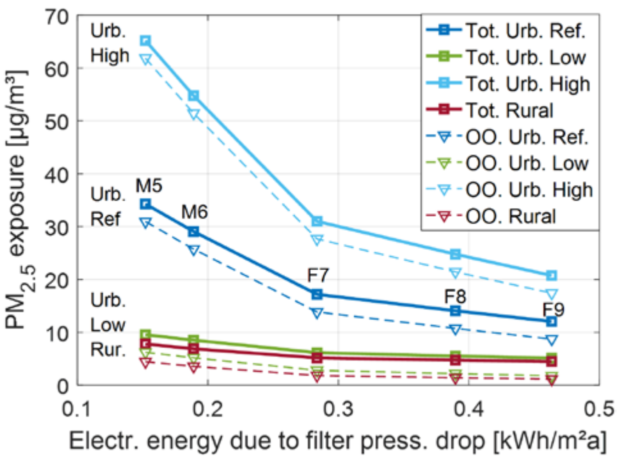

Figure 3. Average $PM_{2.5}$ exposure of a person staying home all day as a function of electric energy consumption of the fan due to the pressure drop of the filter. "Urb. High" represents highly polluted areas with daily means of ~80 μg/m³, "Urb. Ref" moderately polluted areas with means of ~40 μg/m³ and "Urb. Low" low polluted urban areas with a daily mean ~8 μg/m³. The dashed line/triangle show the exposure to outdoor-originate PM.

Depending on the outdoor air PM concentration and the level of cooking activities by the occupants, the exposure to indoor generated particles might become a substantial or even dominant fraction of the total PM exposure. To assess the exposure to cooking related PM, different cooktop ventilation strategies (no cooker hood, a recirculating cooker hood with carbon filter and an extracting cooker hood) were simulated. When operating extracting cooker hoods in airtight buildings the inflow of make-up air has to be provisioned, e.g. by a dedicated make-up air opening or an open window. This is the reason that the use of an extracting device is not necessarily beneficial when the outdoor concentration is high or moderate and the particle generation from cooking is low or moderate. However, for low outdoor air concentrations, the use of an extracting cooker hood will greatly reduce exposure to particles from cooking, in particular for strongly emitting activities like frying.

Conclusions

This is a simulation study and therefore its results are affected by assumed boundary conditions. Nevertheless, this study gives insights and trends for the exposure to PM in highly energy efficient homes, which help the selection of sensible PM filtration systems. The results confirm that the use of a F7 filter (roughly equivalent to ePM_1 50% or MERV13) makes sense as a general precautionary recommendation, since the relation between exposure reduction and associated

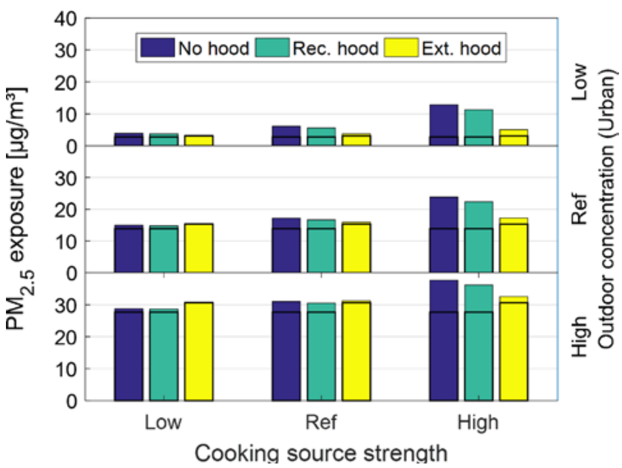

Figure 4. Average $PM_{2.5}$ exposure of a person staying home all day for different outdoor concentrations, different cooking source strength and different cooktop ventilation strategies (no hood, recirculating hood and extract hood). Horizontal lines show exposure to outdoor-originate PM.

energy penalty is good. The results also show that for outdoor air concentrations as typically encountered in urban areas in well developed countries (labelled "low" in this study, see also (WHO 2016)), the total PM exposure may be dominated by indoor sources like cooking (**Figure** 4). Here, effective measures, like the use of extracting cooker hoods, are recommendable for high cooking activities. For locations with moderate or high outdoor PM concentrations, as often encountered in Asian cities, the use of higher filter classes like F9 or equivalent are recommendable. They will further reduce the exposure to outdoor-originated PM. In those cases, the use of extracting cooker hoods may not be advisable due to the introduction of outdoor particles with the make-up air. For conditions with high outdoor PM concentrations and high cooking source strength as often encountered in Asian households, a need for new product developments, such as recirculating cooker hoods or make-up air openings with particle filtration, is identified. ■

References

EN. 2012. "EN 779:2012 Particulate Air Filters for General Ventilation - Determination of the Filtration Performance."

Liu, De Ling and William W. Nazaroff. 2003. "Particle Penetration through Building Cracks." *Aerosol Science and Technology* 37(7):565–73.

PHI. n.d. "About Passive House - What Is a Passive House?" Retrieved September 29, 2018 (https://passiv.de/en/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm).

Riley, William J., Thomas E. McKone, Alvin C. K. Lai, and William W. Nazaroff. 2002. "Indoor Particulate Matter of Outdoor Origin: Importance of Size-Dependent Removal Mechanisms." *Environmental Science and Technology* 36(2):200–207.

Rojas, Gabriel. 2019. "Ambient Air Filter Efficiency in Airtight, Highly Energy Efficient Dwellings – A Simulation Study to Evaluate Benefits and Associated Energy Costs." in *AIVC Proceedings 2019*, AIVC.

Shi, Bingbing. 2012. "Removal of Ultrafine Particles by Intermediate Air Filters in Ventilation Systems - Evaluation of Performance and Analysis of Applications Ventilation Systems." Chalmers University of Technology, Göteborg, Sweden.

WHO. 2016. "Concentration of PM2.5 in Nearly 3000 Urban Areas, 2008-2015." Retrieved May 9, 2019 (http://gamapserver.who.int/mapLibrary/Files/Maps/Global_pm25_cities_2008_2015.png).