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The correlation between amount of carpet and deposition of particles

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SUMMARY

This paper presents some of the results of an air filtration-based intervention study carried out in 21 apartments situated near busy traffic streets. The aim of the study was to identify positive health effects of air filtration in an elderly population. The air change rates and indoor particle concentrations were measured continuously during two consecutive periods of 48 hours. Each apartment was equipped with two filter units, one located in the bedroom and one in the living room. Particles were removed by filtration during one of the exposure periods. Periods without filtration during which candle-burning was the only significant indoor source of particles were identified; this occurred in three apartments. The deposition rates of particles were calculated based on air change rate and the decay period after the candles had been put out and related to the fraction of floor area covered with carpets. Results showed that the amount of carpet on the floor was significantly correlated with particle deposition in the apartments.

KEYWORDS

Carpet, Deposition, Sink rate, Particles, Filter units

INTRODUCTION

Particle deposition to indoor surfaces has a beneficial effect on indoor air quality, as it results in reduced inhalation exposures. One approach to improving indoor air quality is to select surface materials with the ability to remove indoor particles through increased particle deposition. Particle deposition phenomena provide useful information about human exposure indoors. Particle deposition mechanisms onto indoor surfaces are complex and vary according to particle size and surface roughness. The deposition rate for each particle size can vary over a few orders of magnitudes (Lai and Nazaroff, 2005). For particle sizes larger than 1 µm, gravitation is dominant, while diffusion is dominant for particles of sizes smaller than 0.1 µm. For particle sizes between 0.1 and 1 µm, a mixture of both mechanisms may be assumed (Lai, 2004).

The levels of indoor particle deposition rates have been investigated in theoretical modelling and experimental studies. The experimental studies included both chamber studies and real life building studies. The chamber studies have shown that both the surface properties of the materials and the particle sizes have an effect on the deposition rates. In addition, the effect of particle size is much larger than the effect of surface properties (Afshari et al., 2007; Abadie et al., 2000).

The previous studies have also provided further information about the deposition of fine particles onto rough and smooth vertical surfaces in small and full-scale chambers (Lai et al., 2002). However, few if any studies have examined deposition of ultrafine particles from ambient air in residential buildings in relation to the fraction of floor area covered with carpets. The aim of the present study is to quantify the deposition rates of fine and ultrafine particles onto carpet-covered floor areas in residential buildings and investigate whether this was correlated with carpet surface area.

METHODS

The study was performed in 21 apartments situated near busy streets in central Copenhagen. The air change rates and indoor particle concentrations were measured continuously during two consecutive periods of 48 hours. Each apartment was equipped with two filter units (Airshower from Airsonett AB in Sweden with an airflow of 540 m^3/h), one located in the bedroom and one in the living room. Particles were removed during one of the exposure periods. Exposure periods without filtration during which candle-burning was the only significant indoor source of particles were identified; this was possible in only three apartments. Apartment A was covered by 100% wall-to-wall carpet, Apartment B by 65% and Apartment C by 20%.

The deposition rates of particles were calculated and related to the fraction of floor area covered with carpets. The concentration measurements of particles were made in the living room of the apartments at 1.10 m above floor level. The PFT technique (Per Fluorocarbon Tracer) was used to measure air change rates in the apartments. The technique is a multiple tracer-gas method based on passive sampling. Temperature and relative humidity were recorded during the experiments. See Table 1.

A Differential Mobility Particle Sizer (DMPS) consisting of a 28 cm Vienna-type Differential Mobility Analyser (DMA, Winklmayr et al., 1991) that uses a re-circulating flow system (Jokinen and Mäkelä, 1997) in connection with a TSI Model 3010 Condensation Particle Counter was used for measuring particle number concentrations in 15 electrical geometrically equidistant mobility channels corresponding to one-electron charged spherical particles with diameters (d) ranging from 10-700 nm. This corresponded to DMA voltages ranging from 10 V – 11 kV. Corrections for the DMA transfer function efficiency and for zero and multiple electron charging (Wiedensohler, 1988) were made by matrix inversion based on a 15-point spline function of the differential inlet particle number concentration as function of the particle mobility. Using the known relation between mobility and diameter of spherical particles, differential particle number concentrations as function of particle diameter were calculated (dN/dlogd). Corrections were made for the particle counter efficiency drop below 15 nm (Mertes et al., 1995). The scanning time for each spectrum was 2 min 30 sec. Integrated concentration values over the whole measured size range (10-700 nm) of number (N), surface area (A) and volume (V), have been calculated assuming spherical particle shape for the surface and volume estimates.

Table 1. Air change rate, relative humidity and temperature in the apartments during the experiments.

Place	Air change rate (h^{-1})	Relative humidity (%)	Temperature (^0C)
Apartment A	0.33	28.6	19.7
Apartment B	0.52	36.4	21.7
Apartment C	0.36	28.8	19.8

Calculation of deposition rate

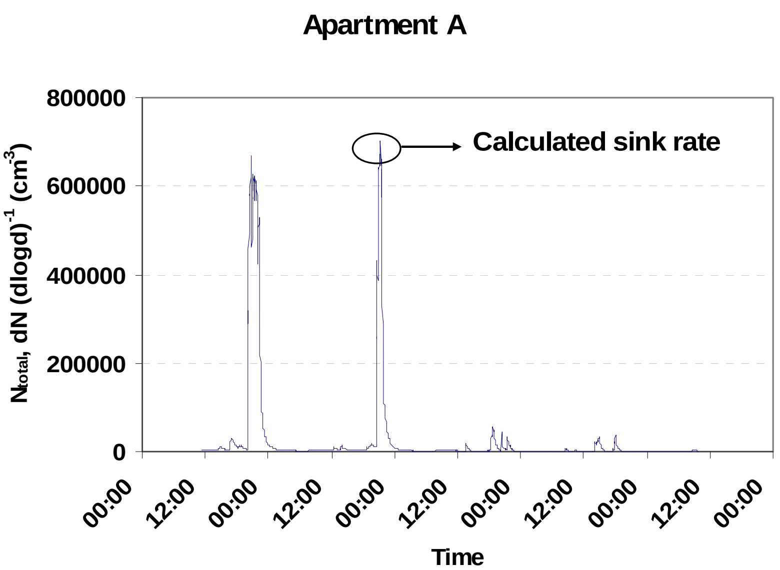
Analyses of the particle concentration during the step-change of the surface materials with different properties provide information both on the particle concentration and the quantity of deposition effects. The particle decay observed after the concentration of fine and ultrafine particles reached predetermined levels was used to assess the time constant for the particle decay, T_P. The time constant was obtained through regression of the measured particle concentration decay. The ventilation time constant, T_V, was obtained by tracer-gas measurements. The difference between the inverse values of the ventilation time constant and the particle decay time constant represents the particle deposition rate constant, r, which is given in the figures using the unit h^{-1}.

$$C_{(t)} = C_{(0)} \times e^{-\left(r+\frac{1}{T_V}\right)\times t} = C_{(0)} \times e^{-\frac{t}{T_P}}, \qquad (1)$$

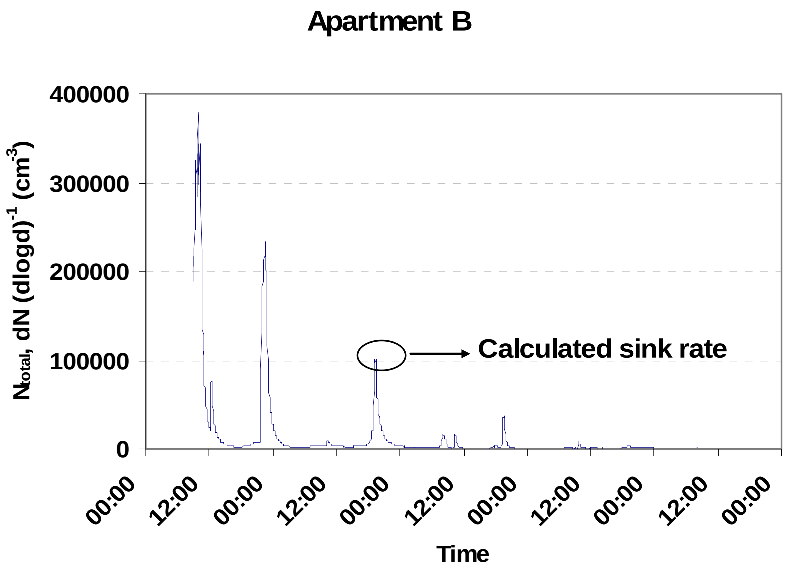
where *C(t)* is concentration at time t (particles/cm^3), and *C(0)* is concentration at time zero (particles/cm^3). This method has been used earlier in another study (Abt et al., 2000).

RESULTS

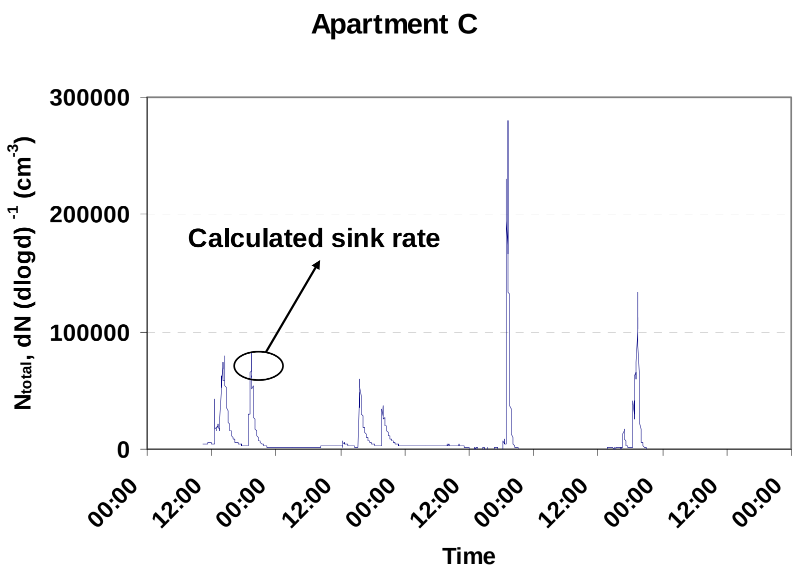
Figures 1a, b and c illustrate a plot of the total number particle concentrations versus time during the measurement in apartments A, B and C, respectively. Figures include both 48 hour periods. Filtration took place in the second 48 hour period included to illustrate the effect of filtration. The sink rates were calculated for exposure periods without filtration after which candle-burning had been the only significant indoor source of particles. Figure 1d illustrates average concentration as a function of particle size for measurement periods when filter units were on and when filter units were off in the apartments. The results showed that filtering reduced all particle fractions in the range from 10 to 700 nm.



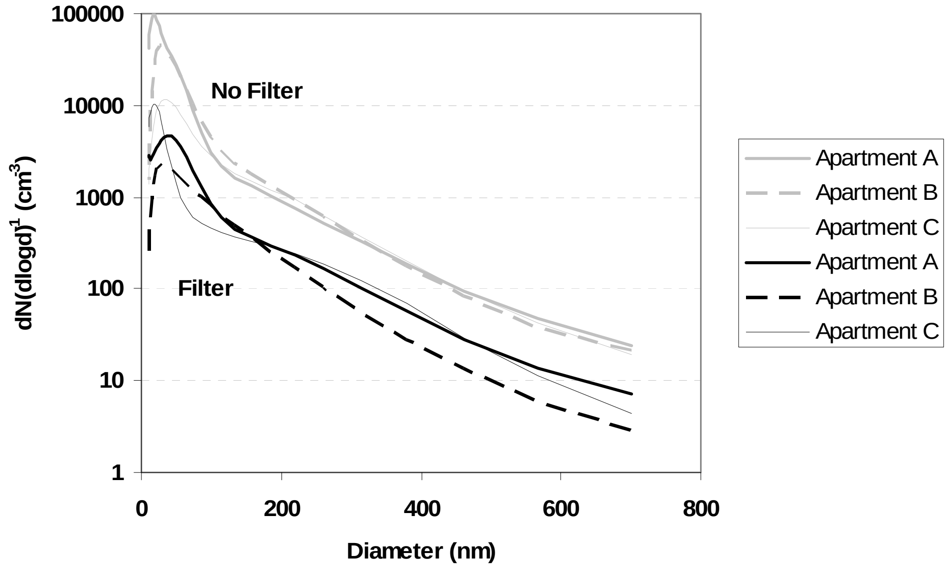
a)


Apartment B
Calculated sink rate
400000
300000
200000
100000
0
Ntotal, dN (dlogd)-1 (cm-3)
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
00:00
Time

b)


Apartment C
Calculated sink rate
300000
200000
100000
0
Ntotal, dN (dlogd) -1 (cm-3)
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
00:00
Time

c)



d)

Figure 1. a) , b) and c) Particle concentration profiles over the period of measurements in apartments A, B and C, respectively. d) Average particle concentration during measurement period as a function of particle size for filter/no filter in the apartments.

Table 2 shows the calculated total deposition rates (the deposition rate of particles on all surfaces in the living room including floor, walls, ceiling, windows and furniture) for total number concentration of particles in the fractions 10-700 nm onto the surfaces of living rooms in the apartments.

Table 2. Calculated total deposition rates for the living rooms in the apartments.

Living room	Carpet (%)	A_{Carpet} (m^2)	$V_{living\ room}$ (m^3)	$A_{Carpet}/V_{living\ room}$ (m^{-1})	Total deposition rate(h^{-1})
Apartment A	100	24.4	75.1	0.32	2.68
Apartment B	65	15.5	61.4	0.25	1.71
Apartment C	20	6.3	82.9	0.076	1.43

DISCUSSION

The total deposition rate is the additional air exchange rate on top of the actual air exchange rate that would be needed to achieve the particle loss rate actually found. This deposition is the result of deposition on all surfaces in the living room including floor, walls, ceiling, windows and furniture.

The experimental data reveal that the total deposition rate was higher in apartment A than in apartments B and C. The results also showed that the amount of carpet on the floor correlated with the total particle deposition rates in the apartments. It seems that the amount floor area covered with carpets has a significant influence on deposition rates of particles and it is a positive phenomenon from the perspective of human health and material damage. Therefore, one approach to reduce particle levels indoors is to use active surfaces in buildings such as carpets, curtains, etc, which may increase deposition of ultrafine particles onto the surfaces.

Previous experiments in a climate chamber (Afshari et al., 2007) showed that carpets had approximately twice the deposition rate of unpainted gypsum and approximately 10 times the deposition rate on more smooth surfaces like glass, aluminum and laminate (Abadie et al., 2000). One guesstimate of the increased deposition on 1 m^2 of room surface area if that area was replaced by carpet is an increase by a factor 4. The ratio between floor area and all other surfaces in the living rooms has been estimated at around 1/5.

On this basis we would expect the total deposition rate to vary from 100% to 100 + 1/5 x 4 x 100% = 180% when flooring was changed from lacquered wood to wall-to-wall carpets. From Figure 2 it may be seen that going from 20 % carpet to 100% carpet resulted in an increase in deposition rate from 1.43 h^{-1} to 2.68 h^{-1}. This is equal to an increase of 187% of the value at 20%, see Figure 1.

These identifications of real-life events in normal apartments seem to give a somewhat higher difference between deposition on carpets and other surfaces that would be expected from the chamber experiments.

From the energy consumption point of view, the requirements for energy use in buildings will in the coming years be tightened considerably (more than 75% until 2020) and the energy use for ventilation will relatively be of much larger importance for the total energy use than it is today. Reducing the air pollution with smooth surfaces may result in a reduction in the air-flow rate and energy consumption. In addition, the use of carpet can be an effective alternative to filtration of building air intake for cleaning of polluted outdoor air.

However, deposited larger particles may be resuspended from the carpets and good removal of particles containing allergens by cleaning procedures may be difficult from carpets. Because of this the Danish Asthma and Allergy Federation does not recommend carpets as air cleaners. They still recommend smooth surfaces for better protection against allergic symptoms among people with asthma and allergy. There is a need for more research in this field to improve knowledge and better evaluate any possible health risk.

The experimental data also reveal that the filtering reduced all particle fractions in the range from 10 to 700 nm, see Figure 1d. It seems that one effective measure for reduce exposure to smaller particles fall into removal control. It should be noted that in many cases source control and ventilation control together form an effective control strategy. However source control is not always feasible or practical and for ventilation control the use of large amounts of outdoor dilution air is neither cost-effective nor energy-efficient. Therefore, other methods of reducing exposure to particles and other contaminants, such air cleaning must be employed.

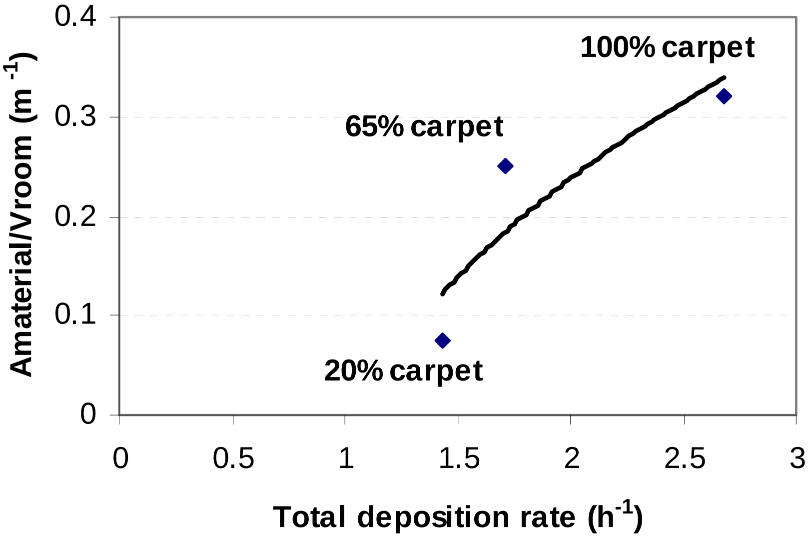


Figure 2. Particle deposition rates onto the surfaces in three apartments, each with different surface area coverage of carpet.

CONCLUSIONS

- Results showed that the surface area of carpet on the floor correlated with the particle deposition in the apartments
- The results showed that filtering reduced all particle fractions in the range from 10 to 700 nm

ACKNOWLEDGEMENT

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