

Exposure of children to indoor and outdoor particles in Baden-Wuerttemberg / Germany

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Abstract

PROBLEM STATEMENT:

In Germany, concentration of outdoor particulate matter decreased considerably during the last decade. Data on indoor exposure to particulate matter are rare and opinions differ about the influence of various sources on indoor particle concentration. In addition, little is known about the size distribution of indoor particles.

OBJECTIVES:

Characterisation of children's exposure to particulate matter in outdoor and indoor air at dwellings and at schools. Determination of main sources for indoor air pollution, investigation of particle size distribution and concentration range according to indoor activities.

METHOD OR APPROACH:

Fine particles (PM_{2.5}) were collected weekly and determined gravimetrically. Black carbon (soot) in PM_{2.5} was measured by an optical method (immersion technique). Coarse particles (>2.5 µm) were weekly collected by sedimentation on adhesive collection plates and analysed microscopically. Ultra fine particle concentrations were recorded continuously by condensation particle counters over periods of 10 hours. Activities during measuring intervals were recorded via questionnaires.

RESULTS:

In a study with 10-year-old children living in cities (Mannheim and Stuttgart) and rural regions (Aulendorf/Bad Waldsee, Kehl) weekly average concentrations of PM_{2.5} were measured in 126 dwellings and 113 classrooms. Outdoor PM_{2.5} concentrations were low and differed only marginally between urban and rural areas. In contrast to outdoor air and schools,

higher PM_{2.5} concentrations were found in most dwellings. No correlation was found between outdoor and indoor PM_{2.5}. Soot content in PM_{2.5} was higher outdoors and was correlated to corresponding PM_{2.5} concentrations. Total coarse particle concentration was found higher indoors while the concentration of a black component typically originating from tire wear was higher outdoors. Outdoor ultra fine particle concentrations were higher in Mannheim than in Aulendorf. Inside the dwellings combustion processes such as cooking, frying, and particularly smoking were proved to be the main origin of ultra fine particles. Stratification of the households according to smoking habits of family members showed a clear correlation between smoking and indoor PM_{2.5} concentration.

CONCLUSIONS:

Indoor and outdoor particles usually are of different origin. Therefore measures for their reduction have to consider these differences. For indoor particulate matter, environmental tobacco smoke (ETS) is the most important source. In addition, activities such as cooking and frying can particularly contribute to ultra fine particle concentrations in dwellings.

1) **Introduction**

Numerous epidemiological studies have shown an association between increased ambient PM₁₀ concentration and respiratory and cardiovascular health effects (Peters et al., 2002; Heinrich et al.; 2002; Kappos et al., 2003). In Baden-Wuerttemberg in South-West Germany, concentrations of outdoor particulate matter, determined gravimetrically as PM₁₀, decreased during the last decade due to measures for reduction of particle emissions in industry and also in traffic (UMEG, 2003). But there is limited information about the concentration of fine and ultra fine particulate matter in outdoor and especially in indoor air and about the associations between indoor and outdoor particle concentrations.

2) **Objectives**

The objectives of our study were to characterise children's exposure to particulate matter

- at different regions with different industrial and traffic pollution, in the cities as well as in rural areas,
- at different locations: at home, at school, indoors and outdoors,
- and under different indoor activities in the dwellings of the children.

3) Methods

Study design:

A cross sectional study was carried out including 126 children at the age of 10 years in four regions of Baden-Wuerttemberg (Mannheim, Stuttgart, Kehl, Aulendorf/Bad Waldsee). Mannheim and Stuttgart represent urban regions with high industrial concentration and traffic density. The district of Offenburg is an industrial area in a rural setting with high industrial density at Kehl. The study area of Aulendorf / Bad Waldsee in the district of Ravensburg represents a rural area with low pollution. For the voluntary examination, about 30 children were selected in each area according to the traffic density at the homes of the children (15 dwellings with the highest and 15 dwellings with the lowest traffic density of participating children).

Measurement of the particulate matter

Characterisation of particulate matter concentration was carried out continuously during winter 2001/2002 at stationary sites as daily averages of PM₁₀ and PM_{2.5} using Digital high volume samplers in Mannheim, in Aulendorf and in Bad Waldsee. In Mannheim, the samplers stood next of a school near the centre of the city. In Aulendorf, the samplers were located at a country farm house. The determination was carried out gravimetrically after deposition on quartz or glass fiber filters.

For individual exposure, samples of PM_{2.5} were collected with small filter equipments (Derenda) over a period of one week in the indoor air of the dwellings, in the outdoor air in front of the dwellings and in schools of the participating children; the concentrations were determined gravimetrically after deposition on teflon coated glass fibre filters.

Coarse particles (> 3 µm) were collected by sedimentation on transparent collection plates according to VDI 2119, part 4, over a period of one week. The plates were exposed to ambient air in the sedimentation sampler Sigma-2 in case of outdoor sampling and in an open device for indoor sampling, respectively. Subsequently, deposited individual particles were microscopically analysed providing a size segregated number deposition rate; the corresponding mass deposition rate was calculated by assuming spherical shape and unit density of particles.

Finally, the particle mass concentration was computed by approximating particle deposition velocity by their individual terminal settling velocity according to Stokes' law. The particle concentration was determined for total particle fraction as well as for a black elemental

carbon containing particle fraction (soot content). Particle fractions of diameters from 3 to 6 μm , 6 to 12 μm , 12 to 24 μm , 24 to 48 μm , and 48 to 96 μm were distinguished.

Particle number concentration was recorded continuously during a period of about 8 hours by means of condensation particle counters (CPC, TSI) indoors and outdoors.

4) Results

Outdoor and indoor $\text{PM}_{2.5}$

Daily average concentrations of outdoor $\text{PM}_{2.5}$, collected with stationary high volume samplers from December 2001 till May 2002 in the centre of Mannheim and at a country farm house near Aulendorf, are shown in figure 1. The concentration primarily depended on the meteorological situation. The time course was similar at both monitoring sides, despite the distance between the two regions of more than 100 kilometres. Concentrations were higher in Mannheim in January during inversion weather as well as in April and May, but the mean values were not much different: The half year average was about $22 \mu\text{g}/\text{m}^3$ in Mannheim and $17 \mu\text{g}/\text{m}^3$ in Aulendorf.

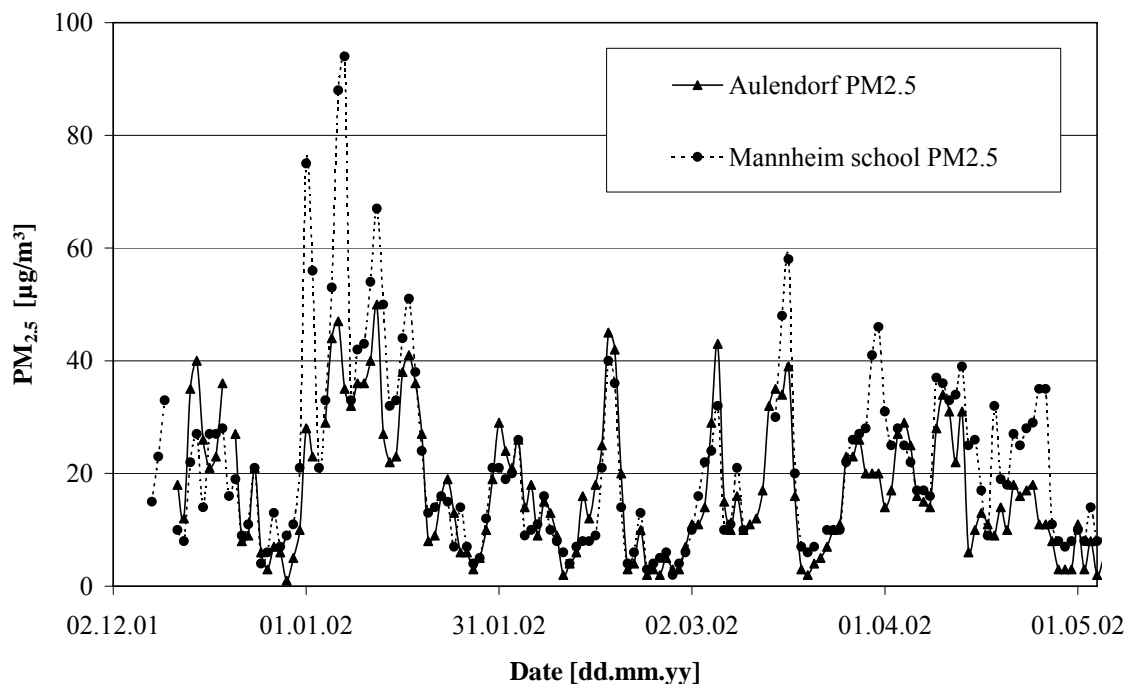


Figure 1: Daily average values of outdoor $\text{PM}_{2.5}$ in the centre of a city (Mannheim school) and in a rural area (country farm house near Aulendorf)

For individual particle exposure, concentrations of PM_{2.5} were measured over a period of one week in the dwellings of 126 children (child's room), in front of the dwellings and in the classrooms of the schools. The results are illustrated in fig. 2. While outdoor PM_{2.5} concentrations at the dwellings varied between 6 and 33 µg/m³, high indoor PM_{2.5} variations were found in the dwellings, with a maximum of more than 200 µg/m³. In the classrooms of schools, PM_{2.5} concentrations normally were below the concentrations found in outdoor air.

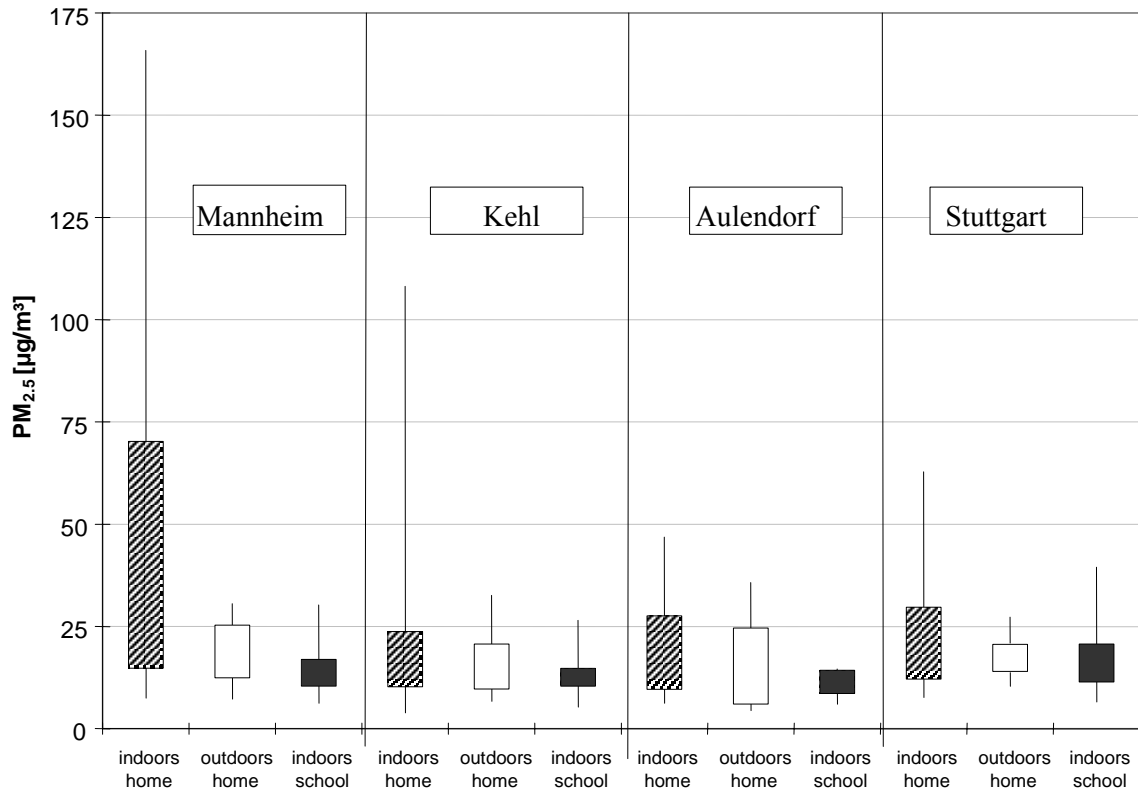


Figure 2: Concentration of PM_{2.5} in the dwellings, in front of the dwellings, and in the schools of the children (5th, 25th, 75th, and 95th percentiles of distribution)

For all areas, the weekly averaged concentration is characterised by the following statistical parameters: 19 µg/m³ (median), 6 µg/m³ (5th percentile), and 111 µg/m³ (95th percentile) indoors of the dwellings, 16 µg/m³ (median), 6 µg/m³ (5th percentile), and 33 µg/m³ (95th percentile) in the front of the dwellings and 13 µg/m³ (median), 6 µg/m³ (5th percentile), and 30 µg/m³ (95th percentile) indoors of the schools.

Indoor and outdoor PM_{2.5} concentrations did not show any association (fig. 3). Therefore, the sources of high PM_{2.5} must exist in the indoor environment of the dwellings. Looking for the reasons of these high particle concentrations, we determined the soot content in indoor PM_{2.5}. As shown in fig. 4, high soot contents were found when PM_{2.5} concentrations in the dwellings were high.

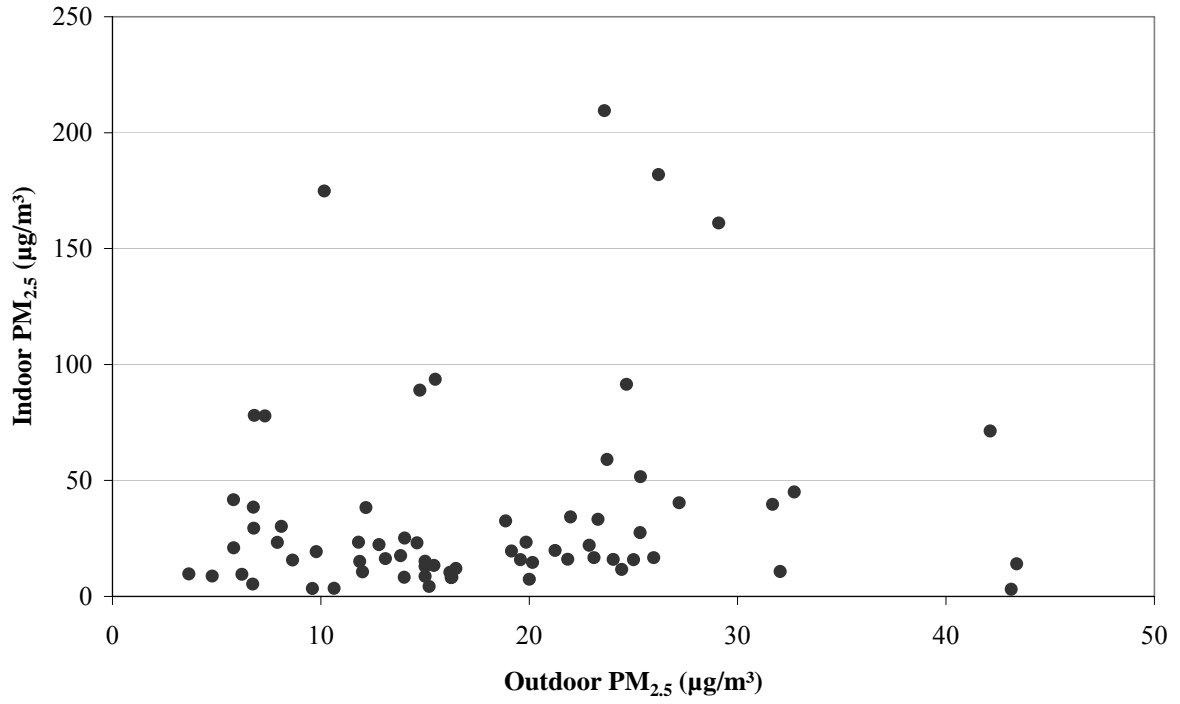


Figure 3: Comparison of PM_{2.5} in front of the dwellings (abscissa) and indoors of the dwellings (ordinate) of the children (mean of one week)

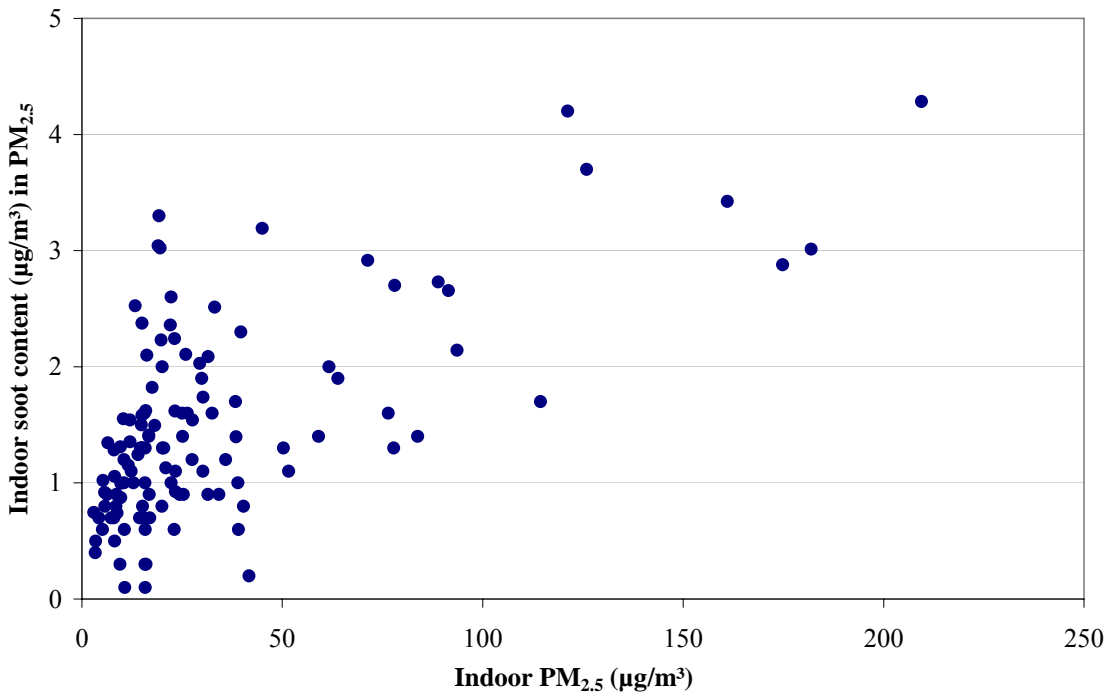


Figure 4: Comparison of indoor soot content and indoor PM_{2.5} in the dwellings of the children

Stratifying indoor PM_{2.5} concentrations according to smoking habits of the parents yields a clear association between PM_{2.5} and smoking, as illustrated in figure 5. About one quarter of all investigated dwellings exceeded concentrations of 30 µg PM_{2.5} per m³, and nearly all of these households were smoker households. Only one half of the smoker households showed concentrations below 30 µg/m³. Therefore, tobacco smoking by the parents seems to be the main cause of high PM_{2.5} exposure to children indoors of the dwellings.

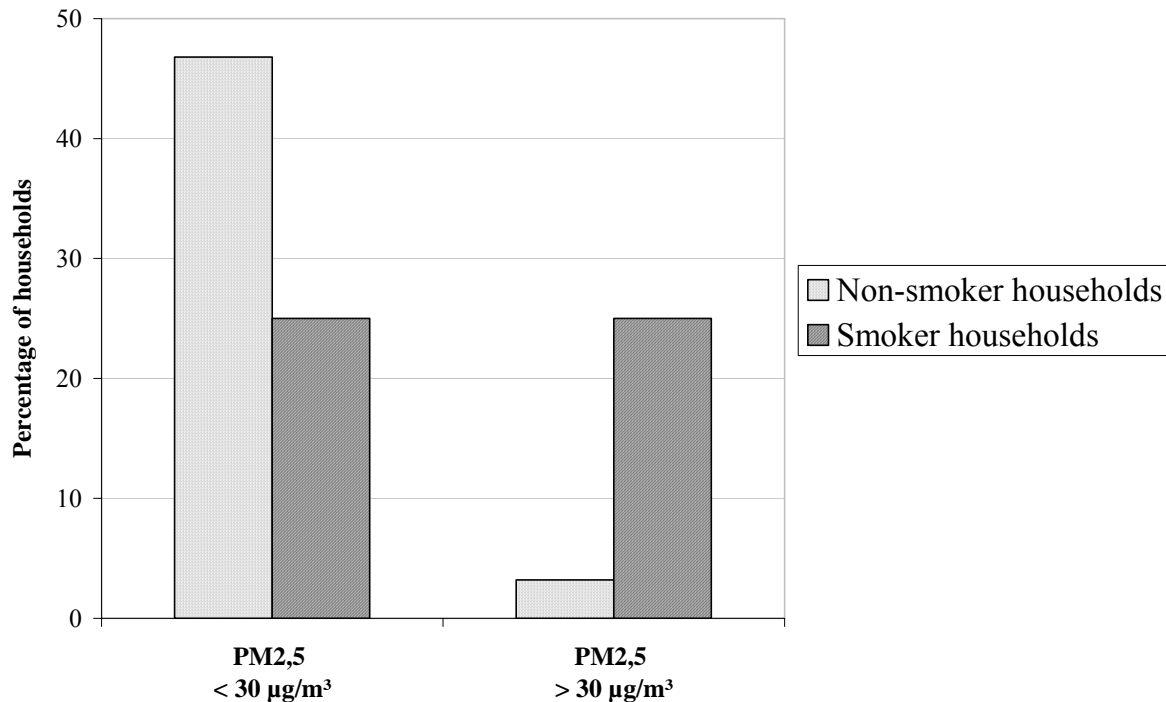


Figure 5: Indoor concentrations of PM_{2.5} in non-smoker and smoker households

Coarse particles

Coarse particles were collected in outdoor and indoor air for one week in the dwellings from the middle of November 2001 to the beginning of May 2002. Automated microscopic analysis provided a size fractionated particle mass concentration (fig. 6). Maximum outdoor particle concentrations were found in the fraction from 6 to 24 µm, reflecting the particle formation by mechanical processes. The indoor air showed substantially higher particle concentrations in the fractions below 12 µm. In these indoor particle fractions, a high amount of epithelia and other material of biologic origin was found.

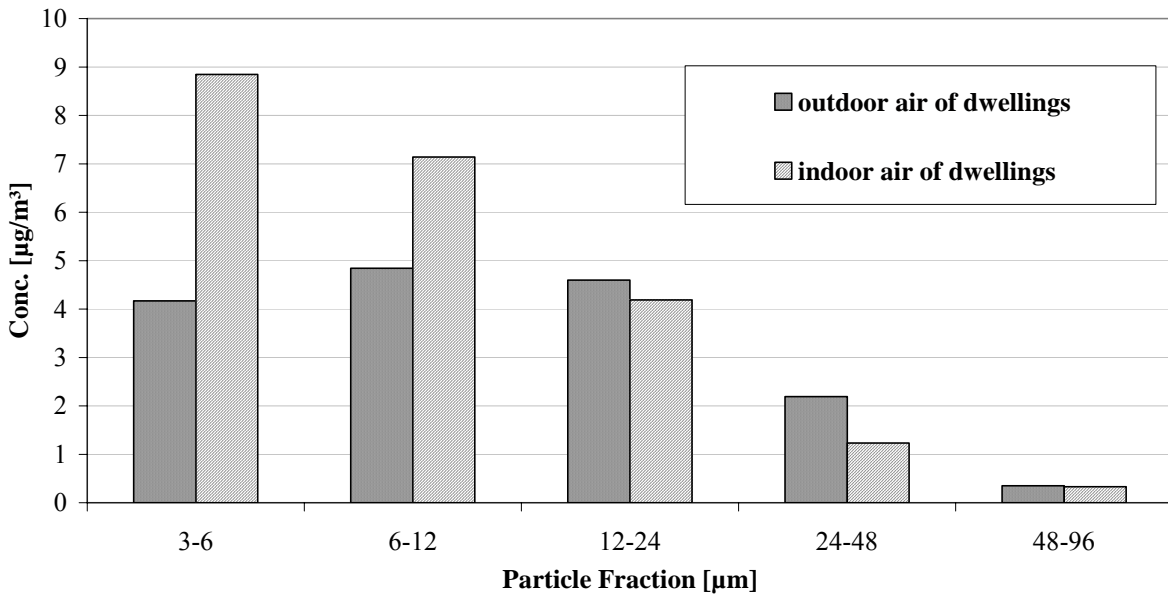


Figure 6: Coarse particles in indoor and outdoor air of dwellings

A different situation was detected for the black component in the coarse particle range (fig. 7). Higher concentrations of black particles were found outdoors than indoors with a maximum in the range of 6 to 24 μm , while in the indoor air the maximum was between 3 and 6 μm . The black particles greater 6 μm in diameter are mostly rubber fragments typically originating from tire wear. These particles were higher in Stuttgart and Mannheim than at the rural areas of Kehl and Aulendorf and can be used as an indicator for a traffic induced particle load.

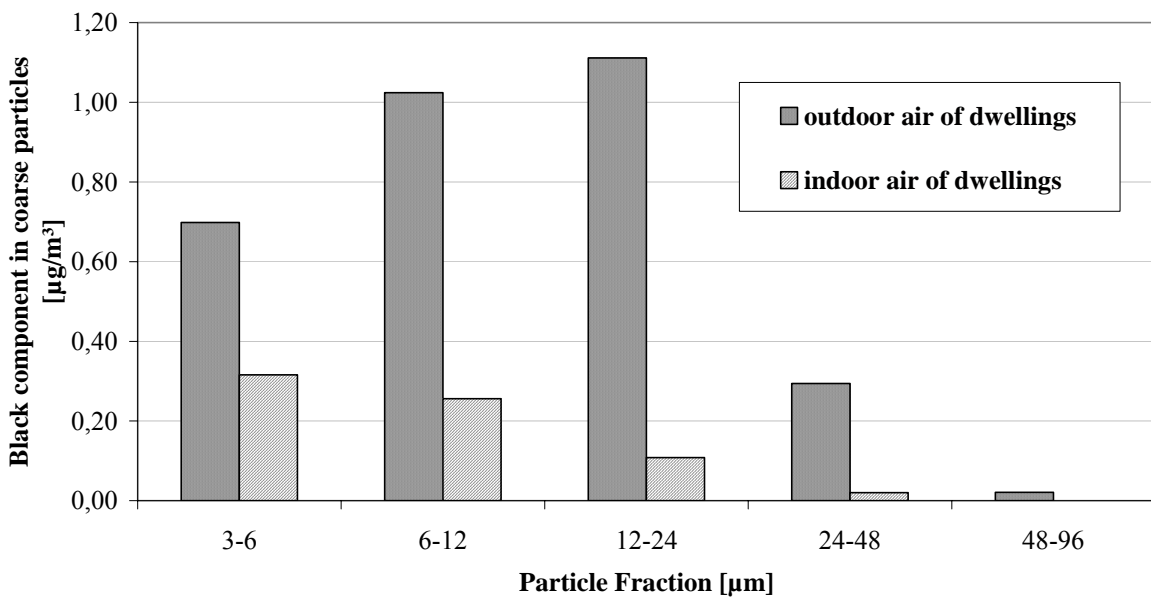


Figure 7: Black component in coarse particle fractions of indoor and outdoor air

Particle number concentrations

Fine and ultra fine particles in the range of about 100 nm were measured in a number of dwellings by counting the particle number concentration continuously over a period of approx. 10 hours at the same time indoors and outdoors. Results are shown in fig. 8. Outdoor particle number concentration depended primarily on traffic influences and were higher in the city of Mannheim than in the rural area of Aulendorf. Indoors these regional differences are smaller.

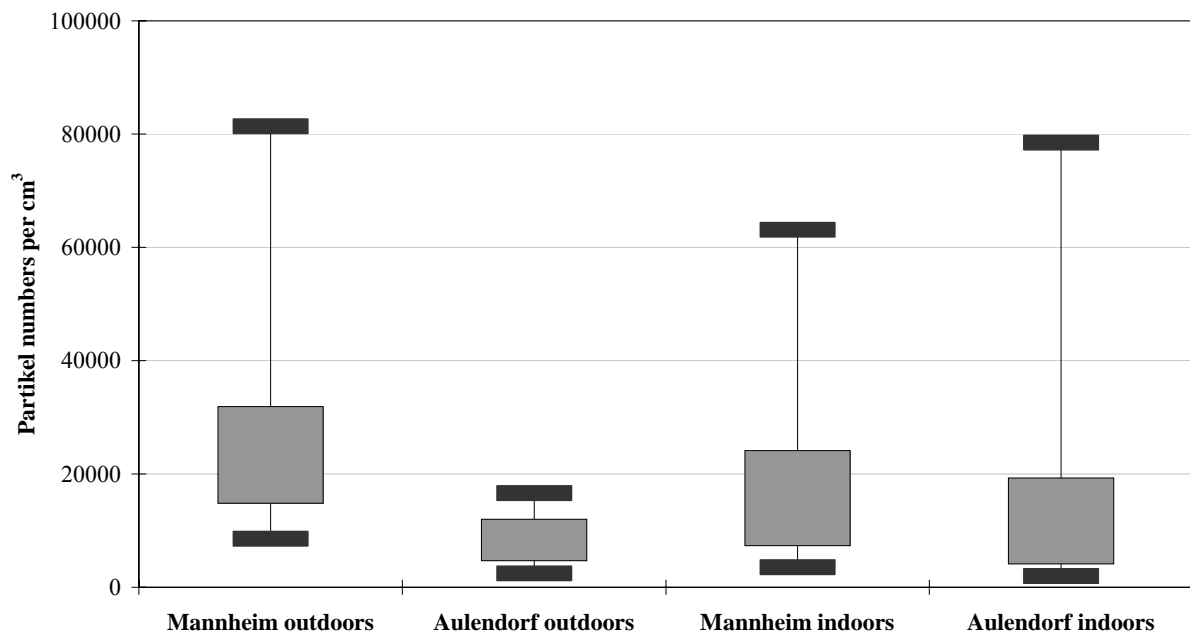


Figure 8: Particle number concentration in Mannheim and Aulendorf (5th, 25th, 75th, and 95th percentiles are indicated)

In the time course, there was no correlation between indoor and outdoor particle number concentration: only a small portion of outdoor particles reached the indoor air and contributed to the particle load. High indoor concentrations appeared as transient peaks, as demonstrated in figure 9 in a smoker household, where each peak was caused by smoking of a cigarette.

Other indoor activities with high particle number concentrations are kitchen activities like cooking, frying, and baking and other high temperature processes (fig. 10). But we don't know, if there are differences in the toxicological effects of the fine particles from different sources.

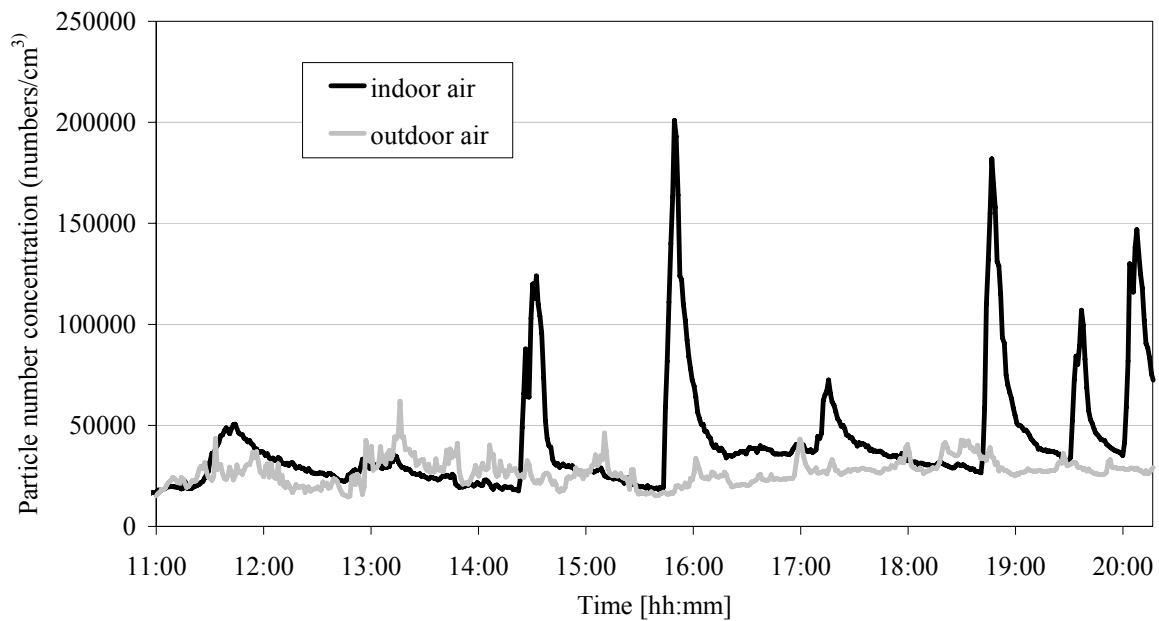


Figure 9: Particle number concentration indoors and outdoors of a room with environment tobacco smoke

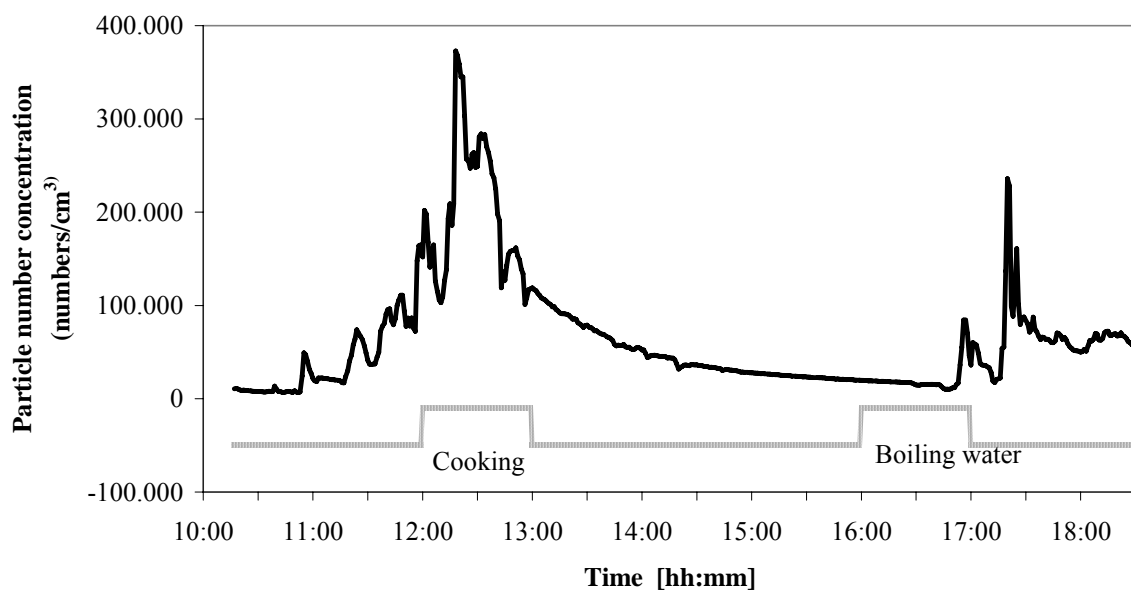


Figure 10: Particle number concentration in the indoor air of a kitchen

5) Discussion of results

The exposure of children to particulate matter to a high degree depends on the activity of children themselves due to abrasion and resuspension processes of particles they provoke in their rooms at home. However, total particle load children are exposed to, consists of indoor air load at home, at school and during outdoor activities as well. Lowest average

concentrations of PM_{2.5} were found in the classrooms of the schools; particle concentrations in the outdoor air were in general a little higher. For outdoor PM_{2.5}, regional differences are small in Baden-Wuerttemberg. This can be explained by the obviously very effective dispersion and the resulting homogenous distribution of these particles in the outdoor air (Brüggemann, Franck et al., 2000). According to our investigations, the main exposure is at home in the children's playroom or living room, with a high variation in the concentration levels. No correlation was found in our study between the concentration of indoor and outdoor PM_{2.5}. This is in contrary to some publications, ascertaining a similar course of indoor and outdoor particle concentrations (Jannssen et al., 1997; Jannssen et al., 1999). However, other studies don't show such a close correlation (Brauer et al., 2000; Oglesby et al., 2000).

Our measurement of the coarse particles demonstrate, that relevant sources for this particle fraction exist in interiors. As a major component in the coarse particle fraction, biological particles were identified originating from the abrasion of human epithelia, from animals, and from clothes, furnishing and other fabrics. Windows and doors form a barrier for particles with diameters $\geq 24 \mu\text{m}$. Elemental carbon containing particles predominate in the outdoor air. These coarse black particles are typically generated by tire wear and mostly occur in the particle range from 6 to 24 μm particle diameter.

Sources for the fine particles in dwellings are tobacco smoke but also kitchen activities like cooking and frying. Similar results are described in other studies (Abt et al., 2000; Wigzell et al., 2000; Wallace et al., 2003). Typically no continuous exposure but short peak concentrations during these activities arise in the dwellings. Traffic influences from the outdoor air seem to be of minor importance for fine dust concentrations inside rooms.

6) Conclusions

In Baden-Wuerttemberg, highest PM_{2.5} concentrations appear in the dwellings of the children, where tobacco smoking by the parents is the most important source of indoor air particle exposure for children. Therefore, further reduction of tobacco smoke, especially in the presence of children, is an important public health challenge.

Tobacco smoke is responsible for high numbers of ultra fine particles in the indoor air, too. But also other high temperature processes like cooking and frying are associated with high ultra fine particle load. Further research is needed for investigation of the toxicological relevance of these particles .

On the other hand, black components in coarse particles occur predominantly outdoors and can be used as an indicator for a traffic induced particle load.

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