Indoor air concentrations of particulate matter (PM_{10} and $PM_{2.5}$) in German schools

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Abstract

Epidemiological research has shown increases in adverse respiratory and cardiovascular outcomes related to particulate matter (PM), especially to the fine and ultrafine fraction. Numerous air quality measurements have been carried out in ambient air and in apartments; data on the occurrence of PM in classrooms, however, are still sparse. The aim of our study was to investigate the exposure of children to indoor air pollutants in German schools. Data on air quality were collected in 92 classrooms in winter (2004 / 2005) and 75 classrooms in spring / summer (2005) in 64 schools. To assess the indoor air quality, carbon dioxide (CO_2), particulate matter and volatile organic compounds were monitored on a school day in each classroom. This paper focuses on the results of particle mass measurements in schools. Realtime measurements of particle mass (PM_1, $PM_{2.5}$, PM_4, PM_{10}) were done using an optical laser aerosol spectrometer (LAS). Additionally, for each classroom descriptive data on size, number of subjects in the classroom (including the teacher) and occupancy periods were collected by a standardized form. The median PM_{10} and $PM_{2.5}$ in a classroom ranged from 16.3 to 313 µg/m³ and 2.7 to 81 µg/m³, respectively, during the winter period, whereas the PM fraction concentration in summer varied from 18.3 to 178 µg/m³ (PM_{10}) and 4.6 to 34.8 µg/m³ ($PM_{2.5}$), respectively. PM concentrations in summer were significantly lower than in winter. In 74% (PM_{10}) and 78% ($PM_{2.5}$) of the classrooms measured at both occasions, respectively, summer measurements were decreased, and the median PM was on average reduced by 36% (PM_{10}) and 35% ($PM_{2.5}$), respectively. Our results clearly show that exposure to particulate matter in school is high, and that indoor air quality is particularly poor in winter. It is, therefore, necessary to improve the ventilation of classrooms in order to provide a healthier indoor environment. For a reliable risk assessment it is also essential to characterize the chemical and, particularly, toxicological properties of both indoor and outdoor PM samples.
Keywords: schools, indoor, particulate matter, PM.

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1 Introduction

Particulate matter is defined as any non-gaseous material (solid and/or liquid) suspended in the air. Biological contaminants such as fungi, bacteria, mites and pollen contribute to indoor PM, especially in buildings with moisture problems. Indoor PM originates from both indoor and outdoor sources. Prominent indoor sources are cigarette smoking, combustion processes like burning of wood and candles, housecleaning and all physical activities which resuspend particles from room surfaces.

PM is generally classified by the size range of the sampling system. $PM_{2.5}$ and PM_{10} are typically measured fractions, which refer to all particles separated from a sampler with a penetration efficiency of 50% at an aerodynamic diameter of 2.5 or 10 µm, respectively (EPA [1]).

Numerous epidemiological studies have been carried out during the last decades which demonstrated the correlation between the pollution of outside air with toxic substances and the occurrence of health related problems and / or illness. On the background of these findings, particularly in recent years the focus of indoor air research has clearly shifted towards particulate matter, notable fine or ultra fine particles with diameters of < 100 nm (EPA [1], WHO [2]).

With short term exposure to PM the aggravation of acute respiratory diseases, characterised by more intense symptoms and increased use of medication, has been observed. Various effects on the cardiovascular system including a decreased heart rate variability, increased plasma viscosity, increased risk of arrhythmia and a heightened risk of atherosclerosis have also been noted. Other effects associated with fine particles are an increased frequency of medical consultations associated with a rise in the number of hospital admissions and an increase in cardiopulmonary mortality (Peters et al [3], Samet et al [4], Le Tertre et al [5], Pekkanen et al [6], Delfino et al [7]).

Findings of several extensive cohort studies suggest that long-term exposure to PM is associated with increased mortality and morbidity, especially with morbidity attributable to pulmonary or cardiovascular conditions. In the Cancer Prevention II study of the American Cancer Society (ACS), in which some 552,000 participants were monitored for over 16 years, a significant increase in cardiovascular mortality of 8 % to 18 % for every 10 µg/m³ increase in $PM_{2.5}$ was observed (Pope et al [8]).

Numerous measurements for PM in the outside air are available, but only few data on air pollution in residential indoor air are available, especially regarding schools and similar facilities (Fromme et al [9]). As school-aged children spend approximately 30% of their daytime in school and may be regarded as particularly vulnerable to potential health hazards, more precise data on exposure to air pollution in this setting is urgently required.

The purpose of the study was to determine the quality of the indoor air in schools in different seasons. Thus, as part of a lager study, various parameters of indoor air climate, carbon dioxide (CO_2), various volatile organic compounds (VOC) and some fractions of particulate matter (such as PM_{10} and $PM_{2.5}$), were measured in classrooms. This paper focuses on the results of particle mass measurements in schools.

2 Methods

Sixty-four primary and secondary schools located in the northern part of the city of Munich and in a neighbouring rural district took part in the study, thus allowing data collection from city, rural and small town areas. In the winter measurement period (December 2004 to March 2005) 92 classrooms, and in the summer measurement period (May to July 2005) 75 classrooms, respectively, were included. For each classroom descriptive data on size, number of subjects in the classroom (including the teacher) and occupancy periods were collected by a standardized form.

The measuring equipment was located at the back of the rooms, away from the doors and blackboards at approximately 1 meter above the floor level, thus avoiding disturbance resulting from air currents.

Realtime measurements of particle mass (PM_1, $PM_{2.5}$, PM_4, PM_{10}) were done using an optical laser aerosol spectrometer (LAS) (Dust monitor 1.108, Grimm Aerosol Technik GmbH, Ainring, Germany). The spectrometer works by constantly drawing the air sample via a volume controlled pump (1.2 l/min.) through a flat beam of laser light. All scattered signals generating while the particles cross this beam are detected with a high speed photo diode, analysed by an integrated pulse height analyser and counted. LAS measures particle concentrations in 16 nominated size bins from 0.23 to 20 µm. For our purposes the continuous measurements were stored minute-by-minute on a data logger. Carbon dioxide was measured using a continuously monitored infrared sensor (Testo, Germany).

To describe the air quality in one classroom the median minute-by-minute PM concentration for this room was derived. Only data collected in time periods when classrooms were occupied were used in analysis. Differences between summer and winter measurements were calculated for classrooms measured at both occasions and the t-statistic used to determine statistical significance.

3 Results and discussion

The size of the classrooms ranged between 47 – 98 m^2 (median: 68 m^2) and the volume between 160 – 437 m^3 (median: 222 m^3). During the measurement period (ca. 5 school hours daily) the classrooms were occupied by 9 – 35 subjects (median: 24). The attendance (number of pupils) in winter did virtually not differ from attendance in summer. The statistical parameters describing temperature, humidity and PM in indoor and outdoor air at both measurement periods are shown in Table 1.

Median particle mass concentrations in classrooms were on average higher in winter than in summer. In winter, the $PM_{2.5}$ and PM_{10} ranged between 2.7 and 80.8 µg/m^3 (median: 19.8 µg/m^3) and 16.3 and 313 µg/m^3 (median: 91.5 µg/m^3) respectively. In summer, concentrations of $PM_{2.5}$ and PM_{10} between 4.6 and

34.8 µg/m³ (median: 12.7 µg/m³) and 18.3 and 178 µg/m³ (median: 64.9 µg/m³), respectively, were measured.

Table 1: Descriptive statistics in indoor and outdoor air using daily medians.

	Min	10^{th} P.	Median	90^{th} P.	Max	Mean
winter indoors (n = 92)						
Temperature (°C)	18	20	22	23	25	22
Relative humidity (%)	22	28	38	49	60	38
PM_1 (µg/m³)	1.1	2.9	7.8	32.2	42.0	13.0
$PM_{2.5}$ (µg/m³)	2.7	8.3	19.8	44.9	80.8	23.0
PM_4 (µg/m³)	12.3	27.2	63.4	120.0	243.8	71.9
PM_{10} (µg/m³)	16.3	43.2	91.5	168.8	313.2	105.0
winter outdoors (n = 20)						
Temperature (°C)	-8	-6	-0.6	5	12	-3
Relative humidity (%)	42	46	66	81	82	65
summer indoors (n = 75)						
Temperature (°C)	21	22	24	27	29	25
Relative humidity (%)	32	41	51	62	70	51
PM_1 (µg/m³)	1.4	3.3	6.7	14.0	19.3	7.2
$PM_{2.5}$ (µg/m³)	4.6	7.1	12.7	21.0	34.8	13.5
PM_4 (µg/m³)	15.5	20.0	42.9	77.0	121.5	44.8
PM_{10} (µg/m³)	18.3	31.8	64.9	124.1	178.4	71.1
summer outdoors (n = 38)						
Temperature (°C)	10	12	18	24	26	19
Relative humidity (%)	49	52	65	85	94	66

Table 2: Mean difference in particle mass between winter and summer in 58 classrooms measured in both measurement periods.

	Mean difference (95% confidence interval)	p-value*
PM_1 (µg/m³)	6.80 (3.54, 10.06)	0.0001
$PM_{2.5}$ (µg/m³)	10.37 (6.30, 14.45)	<0.0001
PM_4 (µg/m³)	26.18 (16.55, 35.80)	<0.0001
PM_{10} (µg/m³)	31.77 (20.03, 43.51)	<0.0001

* p-value for mean difference not equal 0

The data on particle mass were collected in both winter and summer in 58 classrooms. Among these classrooms, a reduction in PM_{10} and $PM_{2.5}$ in the summer period was observed in 74% and 78% cases, respectively. The median reduction potentials of all classrooms were 36% (PM_{10}) and 35% ($PM_{2.5}$). On average, PM concentrations were decreased by 6.8 µg/m³ (PM_1), 10.4 µg/m³

($PM_{2.5}$), 26.2 µg/m³ (PM_4) and 31.8 µg/m³ (PM_{10}) in summer compared to winter (Table 2). These differences were highly statistical significant.

Figure 1 shows CO_2 and mass concentrations measured during a typical school day. The data clearly demonstrate that indoor particle counts are highly variable with some large short-term peaks. These events could be attributed to elevated indoor activities of the pupils during the beginning and end of the teaching time and during school breaks (for example at 9:30).

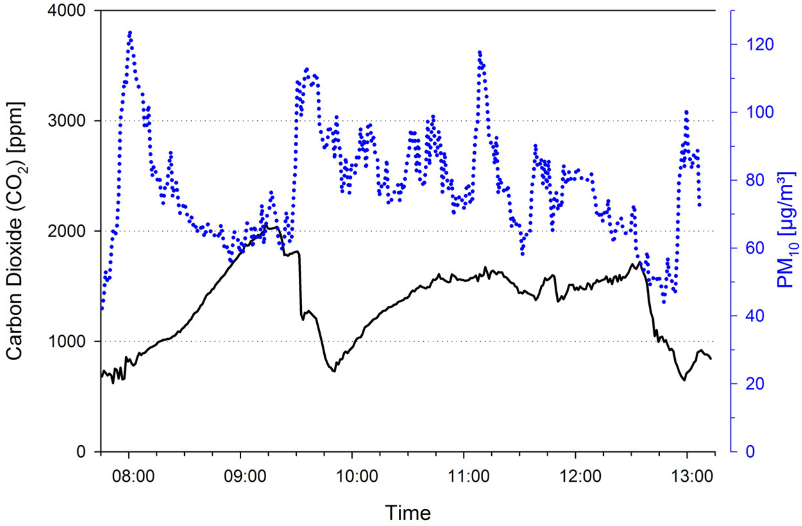

Figure 1: Measurement of carbon dioxide and PM_{10} in a classroom. (PM_{10}: dotted line; CO_2: solid line).

Table 3: PM (µg/m³) in indoor air in schools and similar facilities in Europe.

Source	**Fraction**	**Median (range)**	**Mean**	**Number of facilities, year**
Janssen [10]	PM_{10}	81 (57, 234)	157	3; 1994/95
Roorda-Knape [11]	PM_{10}	73 (51, 166)	92	12; 1995, *
Janssen [12]	$PM_{2.5}$	20 (17, 27)	20	24; 1997/98
Fromme [9]	PM_4	54 (13, 128)	55	73; 2000/01
Link [13]	$PM_{2.5}$	10 (5, 40)	15	4; 2001/02
Lahrz [14]	PM_4	60 (24, 106)	62	33; 2003
this study	PM_{10}	92 (16, 313) 65 (18, 178)	105 71	79 ; winter 2004/05 74 ; summer 2005
	$PM_{2.5}$	20 (3, 81) 13 (5, 35)	23 13	79 ; winter 2004/05 74 ; summer 2005

*: computed from means of the school buildings

Only limited data on indoor particle mass concentration from schools and similar buildings are at present available. Results obtained in previous European studies are summarized in Table 3. Taken into account that different fractions of PM were measured in the aforementioned studies, the majority found a high concentration of particulate matter during the school day.

Our results clearly show that exposure to particulate matter in school is high, and that indoor air quality is particularly poor in winter.

It is, therefore, necessary to improve the ventilation of classrooms in order to provide a healthier indoor environment. For a reliable risk assessment it is also essential to characterize the chemical and, particularly, toxicological properties of both indoor and outdoor PM samples.

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