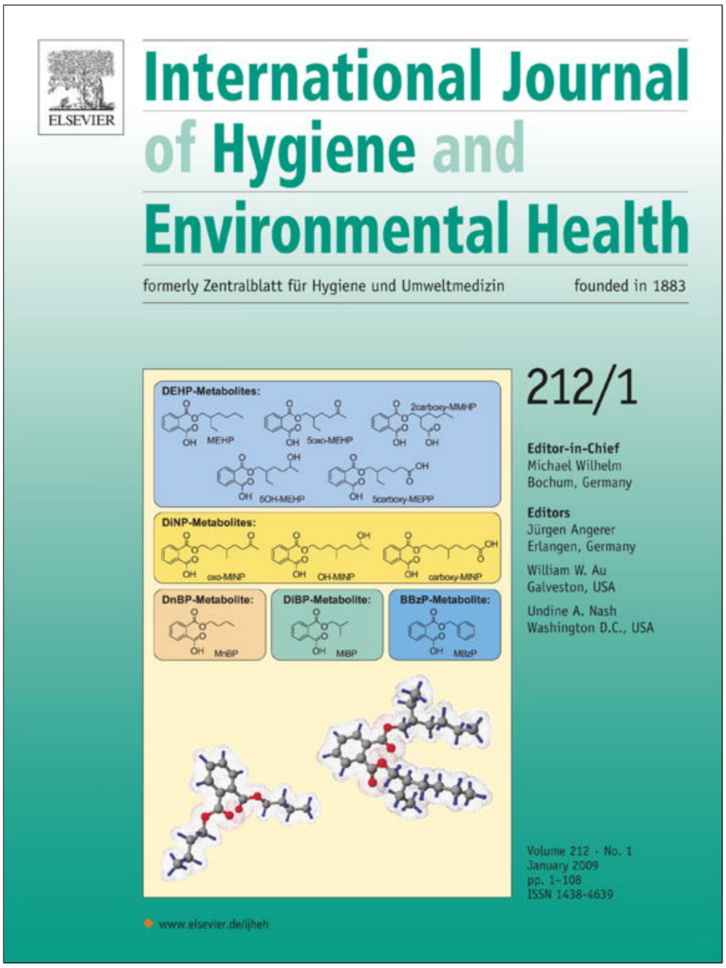
ELSEVIER
International Journal of Hygiene and Environmental Health
formerly Zentralblatt für Hygiene und Umweltmedizin
founded in 1883
212/1
DEHP-Metabolites:
DiNP-Metabolites:
DnBP-Metabolite:
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Volume 212 · No. 1
January 2009
pp. 1–108
ISSN 1438-4639
www.elsevier.de/ijheh

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Int. J. Hyg. Environ. Health 212 (2009) 45–55
International Journal of Hygiene and Environmental Health
www.elsevier.de/ijheh

Particulate matter and carbon dioxide in classrooms – The impact of cleaning and ventilation

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Received 9 November 2006; received in revised form 20 June 2007; accepted 10 September 2007

Abstract

The objective of the study was to measure the indoor air quality in classrooms with special emphasis on particulate matter (PM 10) and carbon dioxide (CO_2) and the impact of cleaning and ventilation.

Material and method: PM 10 was analysed via gravimetric method and by laser beam technology. CO_2 was analysed by infrared sensors. Measurements were collected for 3 weeks; first week: "normal" cleaning (twice a week) and ventilation; second week: intensified cleaning (five times a week); third week: intensified cleaning and intensified ventilation.

Results: Levels of PM 10 in the classrooms during the 3 weeks were $69 \pm 19\,\mu g/m^3$ and they were dominated by occupancy and the persons' activity. Intensified cleaning showed a significant decrease in all classrooms (79 ± 22 to $64 \pm 15\,\mu g/m^3$). The effect of ventilation on levels of PM10 was inconsistent – levels of CO_2 were very high in all schools and could be diminished by intensified ventilation (mean 1459 to 1051 ppm).

Conclusion: Although further investigation is needed to study detailed characteristics of the PM 10 (size distribution, chemical identity) the data are sufficient to improve the cleaning and the ventilation in schools.

Keywords: Air quality; Schools; Particulate matter PM 10; Carbon dioxide; Cleaning; Ventilation

Introduction

Health impacts of ambient air pollution are dominated by particulate matter (PM). PM10 levels are associated with an increased mortality as well as an increased morbidity. In the European Union, in the year 2000, about 3 million life years were lost due to PM 10, which amounts to a decrease of 8.6 months for every citizen in Europe (CAFE CBA, 2005). Based on an extensive amount of epidemiological data, WHO states that an increase of $10\,\mu g/m^3$ per year results in a 6% increase in total mortality; a short-term increase of $10\,\mu g$ PM $10/m^3$ for several days is associated with more coughing, lower respiratory symptoms, an increase in hospital admissions due to respiratory problems, bronchodilator use and even mortality (WHO, 2000). Therefore, the EU has established a European Guideline with new threshold values for the ambient air. In many German cities, measurements, such as closing

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1438-4639/$ - see front matter
doi:10.1016/j.ijheh.2007.09.011

busy streets for Diesel cars without special particle traps, have become necessary.

However, people spend much more time indoors than outdoors. Indoor air quality in private homes and in public places, especially in schools, has therefore caught the interest not only of scientists, but of the general public as well. Good air quality in classrooms benefits children in their learning ability, helps keep teachers and staff productive, and also is beneficial to their health (USEPA, 1996; Shendell et al., 2004a, b; Mendell and Heath, 2005). Indoor air quality is affected by outdoor pollution from traffic, industrial construction and combustion activities, but also by ventilation, furnishings and the indoor activities of humans. In private homes, cooking, particularly frying, as well as smoking is among the most important sources of particles indoors (Wallace et al., 2003, 2004; Wallace, 1996).

There is an abundance of studies showing high contamination levels of carbon dioxide in classrooms (Lee and Chang, 1999; Blondeau et al., 2005; Scheff et al., 2000a, b; Grams et al., 2003; Fromme and Dietrich, 2006; Shendell et al., 2004a, b; Erdmann and Apte, 2004). In recent years, several studies were published on particulate matter contamination in classrooms (Fromme et al., 2005; Lee and Chang, 1999, 2000; Blondeau et al., 2005; Lahrz, 2006; Scheff et al., 2000a, b; Liu et al., 2004; Lahrz et al., 2005) as well as in private homes and in public places other than schools (Fromme et al., 2005; Lee et al., 1999; Liu et al., 2004; Li et al., 2001; Cao et al., 2005).

In Germany, mean current levels of particulate matter were about 27 μg/m^3 in non-smokers' apartments, whereas in smokers' apartments 57 μg/m^{3}could be detected (Fromme et al., 2005). In nursery schools and in schools, PM levels were found comparable to apartments of smokers with mean levels of 53 and 59 μg/m^3 (Fromme et al., 2005; Lahrz et al., 2005). A preliminary intervention study in two classrooms in Berlin in the winter 2004/5 indicated that intensified cleaning and ventilation helped to significantly reduce the indoor particulate matter. Unfortunately, intensified cleaning was done only in one classroom correctly, which limits the representativeness of this statement (Lahrz et al., 2005).

Therefore, the objective of the study presented here was to measure and evaluate the indoor air quality in two primary schools in Frankfurt/M., with special emphasis on particulate matter and carbon dioxide and the impact of cleaning and ventilation.

Materials and methods

Two primary schools in Frankfurt/M. were selected for this study. School A was located in a rural area while school B was selected from an inner city area of Frankfurt/M. with typical high outdoor air contamination. In both schools, indoor and outdoor pollution was measured. Gravimetric analysis for particulate matter was used as reference, but particulate matter was analysed as well by laser beam technology, so that data on PM could be obtained in small time intervals. This was done to enable the assessment of influence factors such as number of persons present in the classroom, their activity, the ventilation of the rooms, etc. At the same time, carbon dioxide was analysed by infrared sensors. In addition, temperature, humidity, and air velocity (only outdoor) were recorded (data not presented here). In school A, measurements were done by the Fresenius Institute in Taunusstein. For school B, the TÜV Süd Industrie Service GmbH conducted the measurements. Both institutes followed identical study protocols, which were defined by the city of Frankfurt/M.

All these data – except particulate matter via gravimetric method – were recorded in 5 min increments from 8 am to 2 pm. A continuous documentation of the number of persons present in the room, their activity and ventilation was done parallel to this. For the purpose of recording the data on the person's activity and the ventilation, special scores had been developed. These included the activity score: break or nobody in the room = 1, face to face lessons = 2, activities such as making handicrafts, working with different materials = 3, romping, gambolling = 4; and the ventilation score: door and windows closed = 0; one window or door completely open = 1; window or buttom-hung window tilted = 0, 5. This score was obtained by addition.

Measurements were collected during school time for a period of 3 weeks (February 20–24, March 6–10 and March 13–17, 2006). During the first week, the normal school situation was analysed, i.e. the classrooms were ventilated as usual and were cleaned by wet wiping twice a week. During the second and third weeks, the rooms were cleaned every day, so that the effect of intensified cleaning could be studied. In addition, during the third week, teachers and pupils were to follow a protocol for intensified mechanical ventilation by opening the windows during every break.

Analytical methods

Dust measurements (indoor and outdoor)

Gravimetric method

Standard procedure according to BIA 6068 (BIA = Berufsgenossenschaftliches Institut für Arbeitsschutz – BGIA). Sampling on cellulose nitrate filters, diameter

70 mm, pore diameter 8 μm. Conditioning of the filters 72 h at 20 °C and 52% relative humidity. Predeposition according to "Johannesburger Convention" (7.1 μm cut).

School A: Sampling on glass fibre filter, diameter 47 mm with MPG II (Dr. Ing. Georg Wazau GmbH, Berlin). Conditioning of the filters 48 h at 20 °C and 52% relative humidity (according to BGI 505.41). Analytical method: gravimetric determination (Sartorius, Göttingen, Germany). Reading precision: 0.1 mg absolutely. Determination limit: 0.3 mg and 0.004 mg/m^3, respectively.

School B: The sampling device used was a stationary measurement with a Gravikon PM4-sampler (Ströhlein Company, D-41546 Kaarst, Germany). Analytical method: single-pan balance (Sartorius, Göttingen, Germany), type A200S, limit of quantitation 0.3 mg. Reading precision: 0.1 mg absolutely. Determination limit of the method: 0.004 mg/m^3 particle mass at 24 m^3 sampling of air volume.

Laser photometry

Principle of measurement: A random sampling head collects the dust in accordance to the Johannesburger Convention and EN 481, respectively, and leads the particles into the optical chamber. Each particle is counted there and classified according to its size using 90° laser light scattering. The mass concentration strongly depends on the dust concentration and on the particle size. Calibration of the system is performed with the gravimetric method described above, as well with reference latex particles 1 μm and Micro Dolomit DR80.

The data analysis is done using the WINDOWS-Software (Grimm).

School A: The particulate matter was sampled with DUSTTRAK Aerosol Monitor (Typ.: 5820, SN: 85201226/85201228). The particulate matter was separated with the Cyclone and afterwards detected by a laser photometer. The calibration took place 2 weeks before test start.

School B: Monitors: portable dust monitor and aerosol spectrometer, Type 1.106 and 1.107 (Grimm Aerosol Technik GmbH&Co.KG, D-83401 Aining, Germany). Limit of quantification: 0.5 μg/m^3. Reading precision: 0.1 μg/m^3.

Carbon dioxide

Principle of measurement: Infrared sensor with a measuring range of 0–100 vol%. Standard procedure according to BIA 9070. The calibration is performed by a test gas containing a 3.05 vol% carbon dioxide concentration and pure nitrogen for zero balance. The detection limit of the method is 0.01 vol% of carbon dioxide.

School A: Carbon dioxide concentrations were sampled in school A with QTRAK CN50274 (Typ.: IAQ Monitor) from TSI (TSI Incorporated, USA) and determined with continuous NDIR-analyzer. The calibration with the test gas (CO/CO_2) took place 1 week before test start.

School B: Measuring device: Dräger X-am 7000 for simultaneous and continuous detection of up to five gases (Dräger safety AG & Co. KGaA, D-23560 Lübeck, Germany).

Results

In Table 1 a description of the classroom facilities, the activity as well as of the number of occupants, and the ventilation score are presented. School A is a small primary school in the rural area of Frankfurt/M. Classroom A1 is located in a building built in 1916, and classroom A2, is in a building built in 2005. School B built in 1899 is located in an inner city area of Frankfurt/M., whereby classroom B1 is located on the 1st floor and classroom B2 on the 3rd floor. Classrooms in school A were much smaller than those in school B and they had fewer windows. Furthermore the windows in school A were buttom-hung windows. Thus, the maximum ventilation index was 11 in school B and 8 in school A. The usage of the classrooms in school A was lower than in school B with regard to the number of children taught and the lessons given there.

Table 2 shows the data on particulate matter in ambient and indoor air, integrated samples for 6 h which were analysed by the gravimetric method. As expected, levels of particulate matter in ambient air were lower in school A than in school B. An increase in ambient air pollution could be seen from weeks 1 to 3; however, it was only significant for school B and not for school A.

Table 3 shows the levels of particulate matter obtained by means of the laser method, and the levels of carbon dioxide in the four classrooms separately for the 3 different weeks. With regard to the mean values in all classrooms combined, there is a decrease in particulate matter levels from weeks 1 to 2 (increased cleaning), followed by an increase in week 3 (intensified cleaning and improved ventilation). A comparison of week 1 ("normal cleaning") to the weeks 2 + 3 combined (intensified cleaning) showed a significant decrease in all classrooms, as well as in classroom A1, B1 und B2, but a significant increase in classroom A2. Great differences between the days could be found (as well) (Fig. 1(a–d)).

Carbon dioxide levels were very high in all schools, with mean values of 1437 ppm (by volume) in week 1, 1479 ppm in week 2, and 1051 ppm in week 3. The maximum levels measured reached 4840 ppm, which is only little less than the maximum level established by the

Table 1. General description of the rooms investigated

Location	School A Rural area		School B Inner city area	
	Room A1	Room A2	Room B1	Room B2
Floor	1st	1st	1st	3rd
Floor area (m^2)	31.5	31.5	73.5	73.5
Windows/buttom-hung window	4/4	7/0	7/6	6/6
Maximum possible ventilation index Windows + (buttom-hung window/2) + door	7	4.5	11	10
Occupants present: $X\pm$sdev (max.)[a]	12.6 ± 11.7 (32)	10.2 ± 9.7 (26)	13.8 ± 10.4 (25)	12,7 ± 10.1 (24)
Hours (lessons)/day: $X\pm$sdev (max)	3.6 ± 1.4 (6)	3.5 ± 1.2 (5)	4.5 ± 0.5 (5)	4.9 ± 1.0 (6)
Ventilation index				
1st–3rd weeks $X\pm$sdev (max.)[a]	0.4 ± 1.1 (7)	0.5 ± 1.4 (7)	2.2 ± 1.5 (8.5)	2.2 ± 1.2 (6.5)
1st and 2nd weeks $X\pm$sdev (max.)[a]	0.2 ± 0.6 (4)	0.2 ± 0.5 (3.5)	2.3 ± 1.5 (7)	1.9 ± 1.0 (5)
3rd week $X\pm$sdev (max.)[a]	0.7 ± 1.7 (7)	1.0 ± 2.2 (7)	1.9 ± 1.5 (8.5)	2.8 ± 1.5 (6.5)

[a]Mean obtained by documentation of 5 min increments.

Table 2. Levels of particulate matter (gravimetric method) in the outdoor air and in the indoor air of the classrooms – in different weeks

	Week 1 (μg/m^3) $X\pm$sdev min–median–max	Week 2 (μg/m^3) $X\pm$sdev min–median–max.	Week 3 (μg/m^3) $X\pm$sdev min–median–max.	Week 2 + 3 (μg/m^3) $X\pm$sdev min–median–max.	Sign week 1 vs. week 2 + 3
Outdoor air					
All schools, 2 schools	22 ± 10 10–20–37	25 ± 12 10–25–49	35 ± 21 10–24–73	30 ± 18 10–24–73	Sign.
School A	14 ± 6 10–10–20	14 ± 6 10–10–20	18 ± 5 10–20–20	16 ± 5 10–20–20	n.s.
School B (mean of two sites at this school)	30 ± 8 15–30–37	36 ± 6 30–33–49	53 ± 17 27–55–73	44 ± 15 27–39–73	Sign.
Indoor air					
All schools – 4 classrooms	79 ± 22 54–75–150	57 ± 11 35–59–79	70 ± 15 42–64–105	64 ± 15 35–63–105	Sign.
School A, room A1	106 ± 26 80–100–150	61 ± 6 53–61–70	75 ± 13 63–72–90	68 ± 12 53–63–90	Sign
School A, room A2	74 ± 15 60–70–90	58 ± 15 35–61–72	76 ± 12 63–81–90	67 ± 16 35–66–90	n.s.
School B, room B1	73 ± 7 62–74–81	59 ± 12 49–57–79	71 ± 19 57–65–105	65 ± 16 49–61–105	n.s.
School B, room B2	62 ± 10 54–58–75	51 ± 12 38–50–66	57 ± 9 42–58–67	54 ± 11 38–58–67	n.s.

MAK commission for industrial workplaces. For all schools combined, carbon dioxide levels decreased in week 3 (intensified ventilation) to 1051 ppm, but, again, great differences were observed between the classrooms and also from day to day (Fig. 2(a–d)).

According to the study design, ventilation was to be intensified in week 3. As expected, ventilation index increased in week 3 to 1.6, compared to 1.3 in weeks 1 and 2, in all schools. Again, great differences could be seen in the various classrooms, with very low ventilation indices in school A, compared to higher indices in school B. A significant increase in week 3 was seen in classrooms A1, A2, B2, but not in classroom B1, where in week 3 ventilation index decreased. Because of very low ambient air temperatures, this class did not follow the proposed ventilation scheme.

Bivariate correlations between particulate matter, carbon dioxide and persons in the classroom were significantly positive, correlations with intensity of cleaning (1st versus 2nd and 3rd weeks combined) were

Table 3. Levels of particulate matter and carbon dioxide, number of persons in the room and indices of ventilation and activity in all schools as well as in the classrooms separately – in different weeks

	Week 1	Week 2	Week 3
	Mean ± sdev (median/max)	Mean ± sdev (median/max)	Mean ± sdev (median/max)
All schools			
Particulate matter (μg/m³)	86 ± 116 (60/1090)	57 ± 80 (45/1060)	72 ± 79 (63/1280)
CO_2 (ppm)	1437 ± 994 (1100/4840)	1479 ± 1081 (1000/4850)	1051 ± 559 (1000/3610)
Ventilation index	1.3 ± 1.1 (1/5)	1.3 ± 1.5 (1/7)	1.6 ± 1.9 (1/8.5)
Persons (*n*)	12.4 ± 10.2 (16/28)	12.5 ± 11.1 (14/32)	12.2 ± 10.4 (15/29)
School A, room A1			
Particulate matter (μg/m³)	134 ± 213 (58/1090)	71 ± 146 (38/1060)	95 ± 144 (67/1280)
CO_2 (ppm)	2761 ± 1071 (2560/4840)	2861 ± 1153 (3010/4850)	1347 ± 755 (1120/3610)
Ventilation index	0.2 ± 0.4 (0–2)	0.3 ± 0.6 (0–4)	0.7 ± 1.7 (0–7)
Persons (*n*)	12.1 ± 10.9 (13–28)	13.4 ± 12. 7 (6–32)	12.4 ± 11.3 (15–29)
School A, room A2			
Particulate matter (μg/m³)	56 ± 22 (51–168)	51 ± 22 (51–120)	77 ± 27 (75–175)
CO_2 (ppm)	879 ± 422 (810–2650)	1152 ± 585 (940–3080)	827 ± 519 (600–2600)
Ventilation index	0.2 ± 0.5 (0–3.5)	0.2 ± 0.4 (0–1)	1.0 ± 2.2 (0–7)
Persons (*n*)	9.1 ± 8.9 (1–22)	11.2 ± 10.4 (5–26)	10.9 ± 9.6 (13–24)
School B, room B1			
Particulate matter (μg/m³)	87 ± 50 (79–285)	53 ± 37 (52–240)	61 ± 40 (55–475)
CO_2 (ppm)	1081 ± 321 (1000–2100)	900 ± 307 (900–2000)	1164 ± 374 (1100–2200)
Ventilation index	1.9 ± 1.1 (1.5–5.5)	2.9 ± 1.7 (2.5–7)	1.9 ± 1.5 (1–8.5)
Persons (*n*)	14.5 ± 10.0 (22–23)	13.8 ± 10.9 (21–24)	13.4 ± 10.4 (20–25)
School B, room B2			
Particulate matter (μg/m³)	68 ± 35 (62–234)	52 ± 29 (6–50–151)	53 ± 29 (12–49–197)
CO_2 (ppm)	1002 ± 299 (900–1500)	873 ± 257 (800–1500)	869 ± 288 (900–1700)
Ventilation index	1.9 ± 0.9 (2–4)	2.0 ± 1.0 (2–5)	2.8 ± 1.5 (3–6.5)
Persons (*n*)	13.9 ± 10.1 (19–24)	12.0 ± 12.2 (14–24)	12.2 ± 9.9 (15–24)

Mean ± sdev: (median–maximal value).

significantly negative in all schools altogether, as well as in every classroom – except for a non-significant correlation between particulate matter and persons present in classroom A1. Correlation between particulate matter and intensity of cleaning remained significantly negative – after controlling for persons present, ventilation index and carbon dioxide (partial correlations).

With regard to ventilation – 1st and 2nd versus 3rd weeks – however, consistent correlations with particulate matter could not be found, neither with nor without controlling for other parameters. On the other hand, as expected, correlations of carbon dioxide to persons in the room were always significantly positive and they were significantly negative to the ventilation index.

Levels of particulate matter and carbon dioxide and the impact of ventilation and persons present can be demonstrated in Fig. 3 for classrooms A1 and A2. Example 1: In classroom A1, on February 21, 2006, lessons started at high carbon dioxide levels of about 2000 ppm, and they increased during the first two lessons up to 4800 ppm. Ventilation during the break reduced the level of carbon dioxide to 3200 ppm, which increased to about 4700 ppm during the following lesson. After school, carbon dioxide levels remained constantly high, till later ventilation. Levels of particulate matter showed an increase to the end of the first two lessons and a sharp increase during break. During the next lesson, levels of particulate matter remained relatively high, only after school they decreased constantly (Fig. 3). Example 2: In classroom A2, the same day, lessons started at levels of carbon dioxide of 1000 ppm, again during the lessons increases up to 2600 ppm were to be seen; ventilation during break resulted in a sharp decrease, and during the next lessons maximum levels of CO_2 could be kept less than 2000 ppm by a short ventilation during the lesson. Pariculate matters were increasing at the end of the lessons and during ventilation. Again, after school a steady decrease was to be seen (Fig. 4). Example 3: On 14 March in classroom A1, according to the schedule, ventilation was increased. Nevertheless, levels of >2500 ppm CO_2 were seen during the lessons. Again, levels of particulate matter tend to increase versus the

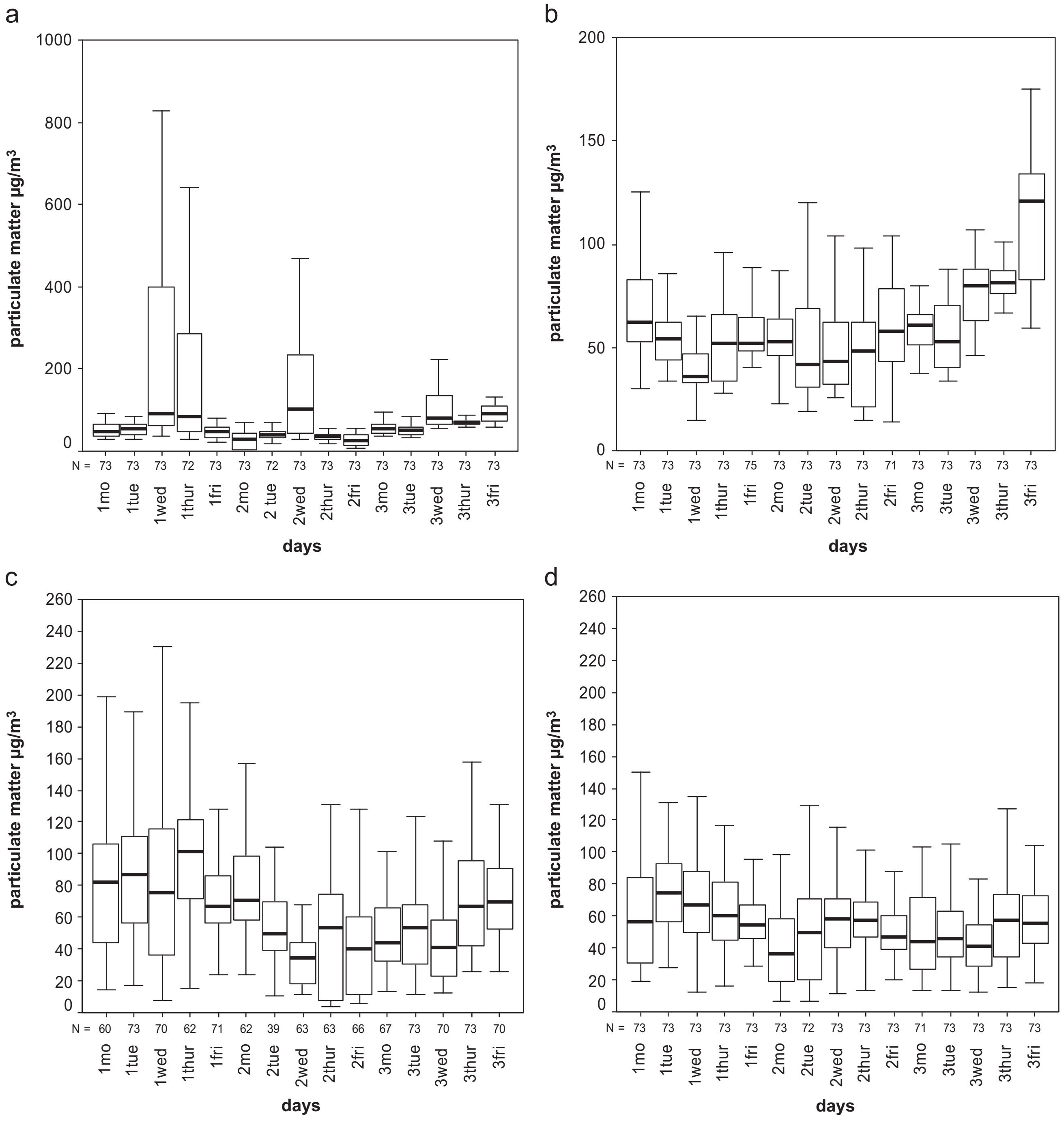


Fig. 1. Levels of particulate matter (laser method) in classrooms. School A – rural environment – classrooms 1 and 2 (top), School B – inner city area – classrooms 1 and 2 (bottom).

ends of the lessons, but sharp increases were seen during ventilation periods as well, regardless of the presence or absence of persons in the room (Fig. 5).

Discussion

Indoor air quality in schools, especially the levels of particulate matter in classrooms, have become a great public concern in Germany, particularly because published levels of particulate matter in classrooms were found to exceed the guideline levels for ambient air and revealed concentrations comparable to those in apartments of smokers (Lahrz et al., 2005). Though threshold values do not exist for particulate matter in indoor air, reducing chemical substances and particulate matter was demanded by parents and the public as well as by hygienists and experts for environmental medicine.

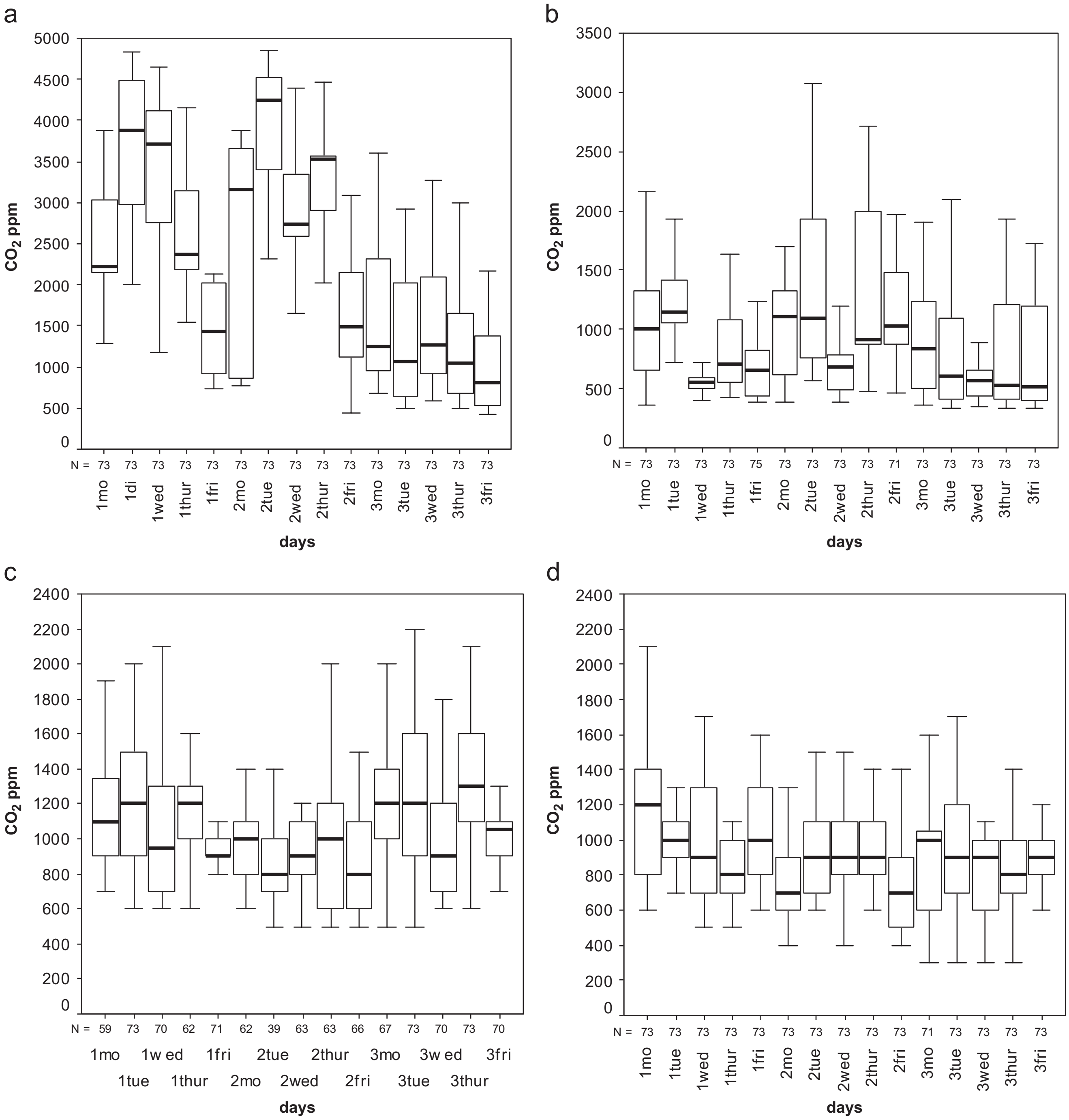


Fig. 2. Levels of carbon dioxide in classrooms. School A – rural environment – classrooms 1 and 2 (top), School B – inner city area – classrooms 1 and 2 (bottom).

Therefore, our study aimed to assess indoor air quality with respect to particulate matter and carbon dioxide, as well as to find out appropriate measures to reduce those contaminations.

Consistent with other studies published (Lee and Chang, 1999; Blondeau et al., 2005; Scheff et al., 2000a, b; Grams et al., 2003; Fromme and Dietrich, 2006; Shendell et al., 2004a, b; Erdmann and Apte, 2004) levels of carbon dioxide were very high, sometimes extremely high. Guideline level 1000 ppm (Pettenkofer 1858) was exceeded in more than 50% of the measurements and more than 25% of the measurements stayed above 1500 ppm. When children stayed indoors, the percentage of measurements exceeding 1000 and 1500 ppm were 70%, and 30%, respectively. In the US EPA 100 office-building BASE study, statistically significant, dose-dependent associations for combined mucous membrane, dry eyes, sore throat, nose congestion,

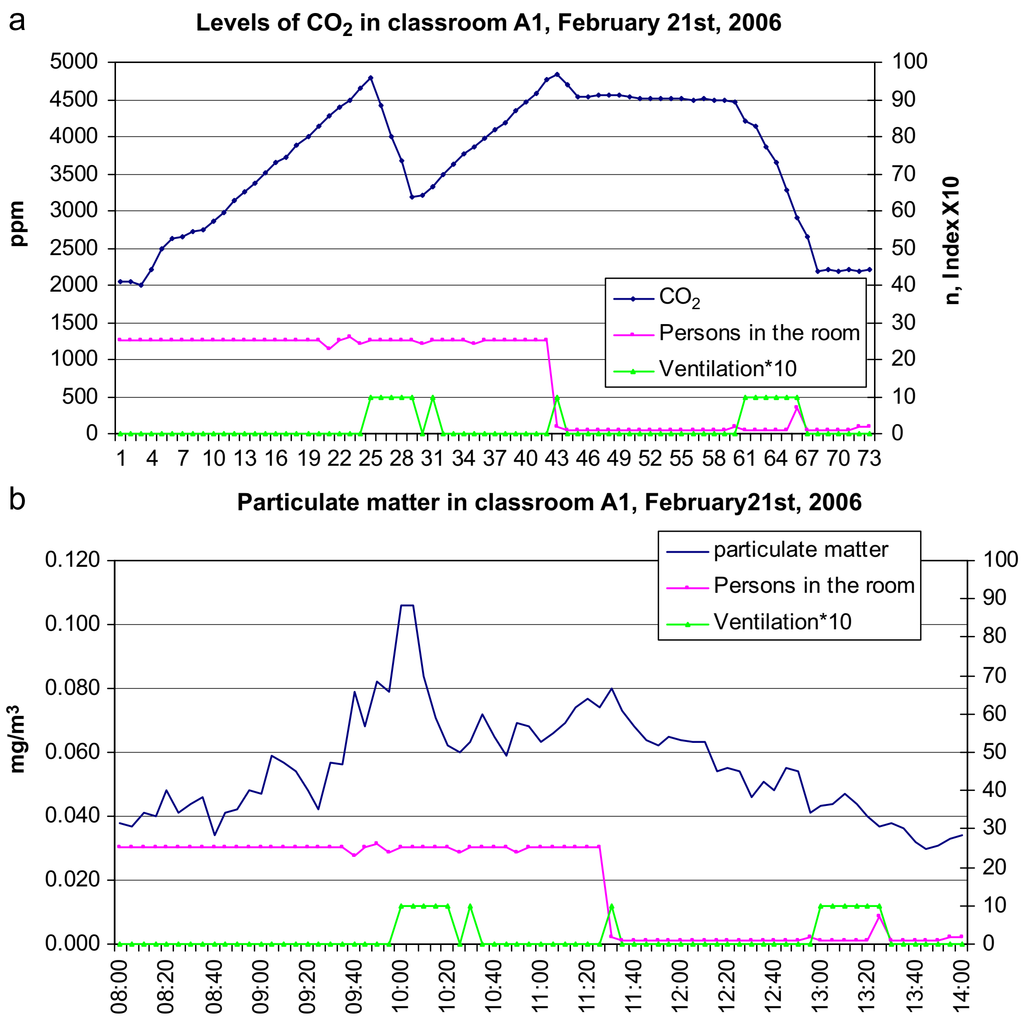


Fig. 3. (a, b) Levels of PM 10 and of carbon dioxide (CO_2) in classroom A1 with regard to ventilation by opening the windows and to occupancy by pupils, February 21, 2006.

sneeze and wheeze symptoms were found with increase in indoor carbon dioxide levels (Erdmann and Apte, 2004). In a recently published study from Washington and Idaho, USA, an increase of 1000 ppm carbon dioxide was associated with a 0.5–0.9% decrease in annual average daily attendance, corresponding to a relative 10–20% increase in student absence (Shendell et al., 2004a, b). As a good indicator of adequacy of ventilation, elevated levels of CO_2 reflected the deficiency of ventilation. Based on this, improving ventilation should improve the well being of the occupants and their ability to work and study as well.

Levels of particulate matter in the classrooms during the 3 weeks were high as well. Mean level was $69 \pm 19\,\mu g/m^3$ and thus well above the levels of ambient air which were sampled at the schools parallel to this. Though levels of particulate matter in the classrooms presented here were below those detected in schools in China (median $\geqslant 100\,\mu g/m^3$) (Lee and Chang, 1999, 2000; Liu et al., 2004), they were comparable to those in schools and nursery schools as well as in apartments of smokers in Germany and they exceeded limit values for ambient air (50 μg/24 h to be exceeded less than 35 times a year in 2005). It should be emphasised, however, that limit values for ambient air cannot be applied to indoor air, because the distribution of the particulate matter may be very different.

However, a detailed look at the data obtained in the Frankfurt/M. schools appears mandatory in order to avoid drawing false conclusions. First, contrary to the hypothesis that high ambient air levels are associated with high indoor air levels in classrooms, indoor air levels in the two classrooms of the inner city school B were lower than those in school A located in a rural environment though levels of particulate matter in ambient air were higher in school B than in school A. Obviously, the impact of ambient air on levels of indoor contamination was dominated by indoor factors, such as occupancy and activity of the persons in the room.

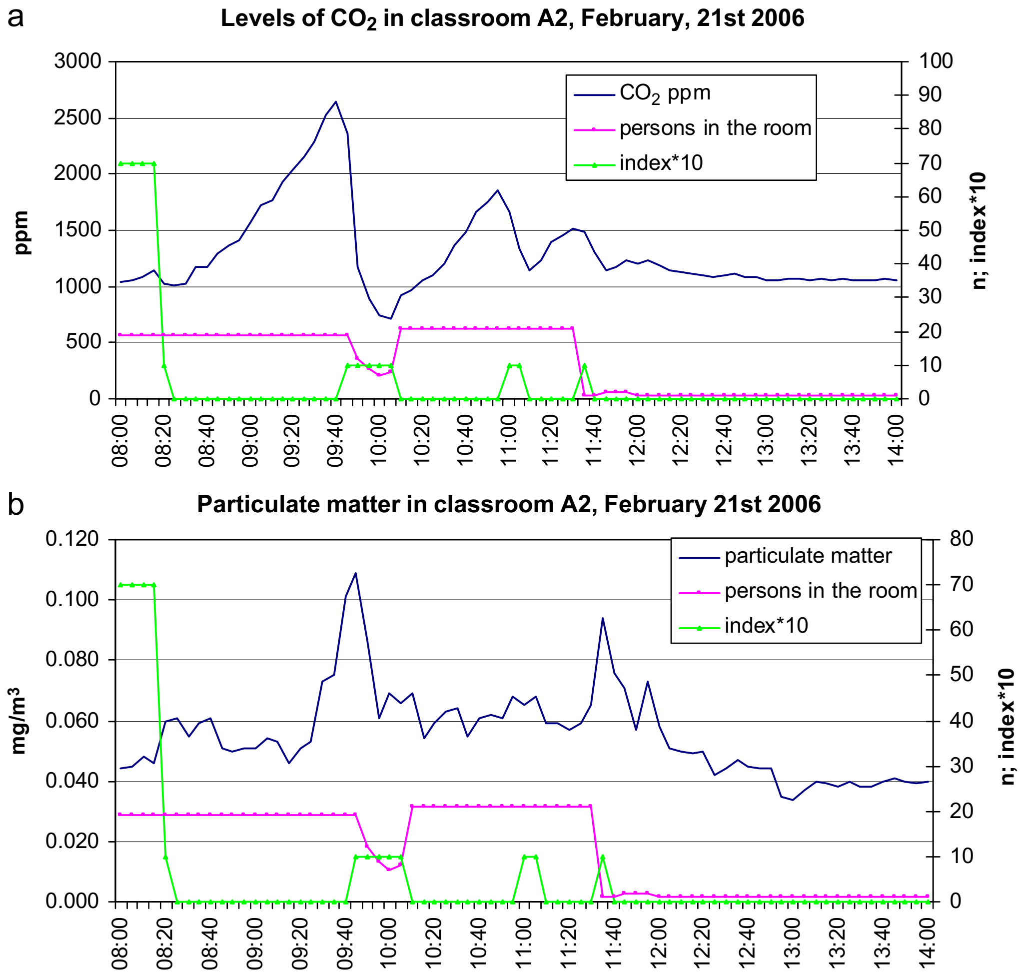
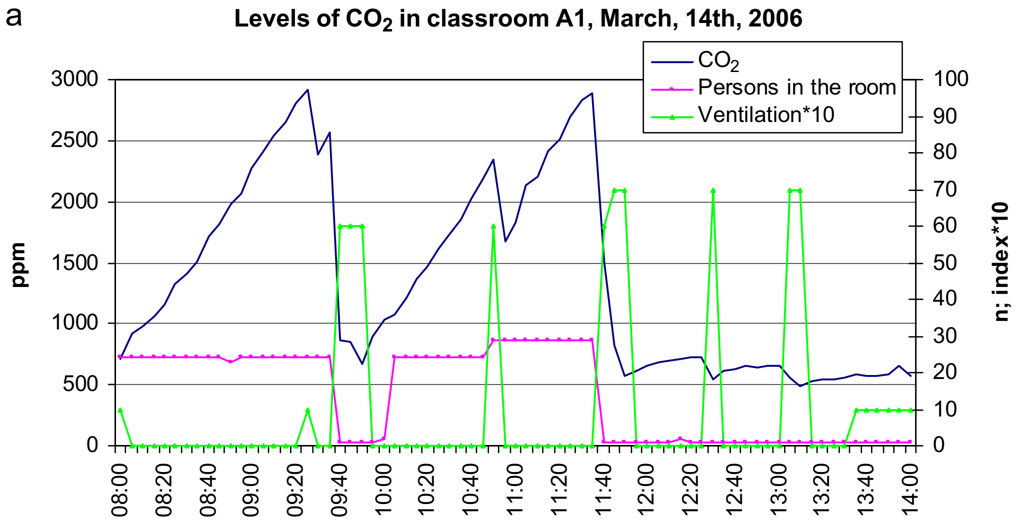


Fig. 4. (a, b) Levels of PM 10 and of carbon dioxide (CO_2) in classroom A2 with regard to ventilation by opening the windows and to occupancy by pupils, February 21, 2006.

Statistical analysis showed best and consistent correlations between particulate matter contamination and persons present in the room or to their activity. Mean levels of particulate matter during occupancy was $85\pm104\,\mu g/m^3$ compared to $55.6\pm77.3\,\mu g/m^3$ when classrooms were not occupied. This result is consistent with the data of eight French schools, where only in occupied rooms indoor/outdoor ratios of particles were greater than unity, the larger the particles the higher the ratios. In unoccupied rooms, however, the I/O ratios were smaller or slightly greater than unity. The authors came to the conclusion that occupancy is the most likely dominant source of particulate matter indoor (Blondeau et al., 2005).

With regard to the time series in individual classrooms, a sharp increase in levels of particulate matter was always seen during times of high physical activity, such as several minutes before the start of school and during breaks. This may be caused by import of particles by children entering the room or by re-suspension of previously deposited particles because of the children's activities during breaks. This result is in concordance with the data of the eight French schools, where indoor concentrations of particles showed peaks within the time slots when the rooms were occupied (Blondeau et al., 2005).

One objective of our study was to assess the impact of intensified cleaning on indoor particulate matter contamination. It should be mentioned that in Frankfurt/M., as in many other German cities, the frequency of cleaning schools was reduced during the 1990s due to a lack of sufficient public finances. In consequence, parents of school children and hygienists complained in many cities about the hygienic situation in schools (Eikmann and Herr, 2005). In classroom A1, a great reduction in PM concentrations from week 1 (cleaning twice per week) to weeks 2 and 3 (intensified cleaning, five times per week) was found, suggesting a very good effect of increased cleaning. However, this "effect" was probably caused by an unusually extremely high level in week 1, due to intense indoor activities (casting candles, etc.). On the other hand, in classroom A2, the increase in levels of particulate matter in week 3 compared to week 1 may be caused by low indoor PM levels due to the low



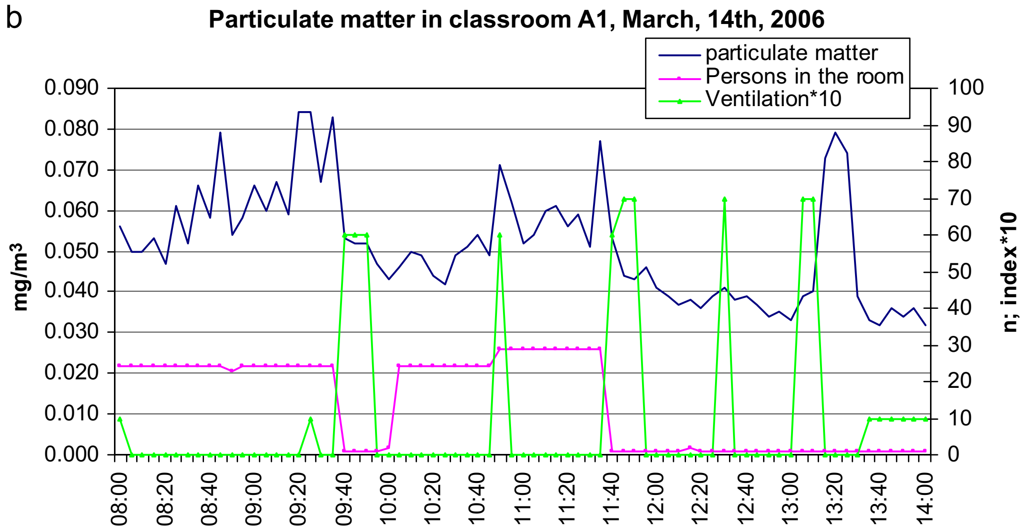


Fig. 5. (a, b) Levels of PM 10 and of carbon dioxide (CO_2) in classroom A1 with regard to ventilation by opening the windows and to occupancy by pupils, March 14, 2006.

occupancy in week 1 (median 1, mean 9 persons) compared to the other weeks (medians 5 and 11, mean 11). On the other hand, PM10 increase during week 3 could also have been caused by working with wool during that time. In school B, where occupancy and activities did not vary very much during the three weeks, a consistent decrease in particulate matter contamination was seen with intensified cleaning, for both the gravimetric and the laser method. The positive effect of cleaning was consistent, especially after controlling for the other parameters influencing indoor PM levels, such as occupancy, activity and ventilation.

The effect of ventilation on PM levels in the indoor air (week 3 versus weeks 1 and 2) was not consistent in the different classrooms tested, even when controlling for other parameters. The decrease of the level of particulate matter in the indoor air after school may mainly be caused by sedimentation. These deposited particles can be removed by wet wiping and cleaning, and in this way cannot be re-suspended by the occupants during the following day.

Although further investigation is needed to study the detailed characteristics of the particulate matter (size distribution, chemical identity) for the exact health assessment of the persons exposed in classrooms, the data – particulate matter and CO_2 – are sufficient to initiate programs on improving air quality in schools. Therefore, the city of Frankfurt/M. has decided to improve the cleaning of the classrooms in order to diminish levels of particulate matter. Beginning with November 1, classrooms will be cleaned five times per week in winter and three times per week in the summer. With regard to levels of CO_2 in the classrooms, a ventilation programme was started. Information on correct ventilation was given to teachers and pupils via a leaflet.

Acknowledgements

We thank the Department for School and Education of the City of Frankfurt/M for funding the study. We also thank Dipl. Ing. Walter Schweitzer (TÜV SÜD Industrie Service) for realization of the measurements in school B.

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