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PAPER

Reducing dust exposure in indoor climbing gyms†

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As users of indoor climbing gyms are exposed to high concentrations (PM_{10} up to 4000 μg m^{-3}; $PM_{2.5}$ up to 500 μg m^{-3}) of hydrated magnesium carbonate hydroxide (magnesia alba), reduction strategies have to be developed. In the present paper, the influence of the use of different kinds of magnesia alba on dust concentrations is investigated. Mass concentrations, number concentrations and size distributions of particles in indoor climbing gyms were determined with an optical particle counter, a synchronized, hybrid ambient real-time particulate monitor and an electrical aerosol spectrometer. PM_{10} obtained with these three different techniques generally agreed within 25%. Seven different situations of magnesia alba usage were studied under controlled climbing activities. The use of a suspension of magnesia alba in ethanol (liquid chalk) leads to similar low mass concentrations as the prohibition of magnesia alba. Thus, liquid chalk appears to be a low-budget option to reduce dust concentrations. Magnesia alba pressed into blocks, used as powder or sieved to 2–4 mm diameter, does not lead to significant reduction of the dust concentrations. The same is true for chalk balls (powder enclosed in a sack of porous mesh material). The promotion of this kind of magnesia alba as a means of exposure reduction (as seen in many climbing gyms) is not supported by our results. Particle number concentrations are not influenced by the different kinds of magnesia alba used. The particle size distributions show that the use of magnesia alba predominantly leads to emission of particles with diameters above 1 μm.

1. Introduction

In the last decade, indoor climbing became a very popular sport in many countries. For example, in summer 2011 there were 79 indoor climbing gyms with more than 1000 m^2 climbing area and 430 gyms with more than 100 m^2 climbing area (*i.e.*, area of the climbing wall) in Germany, and additional 2400 smaller facilities. Based on a member survey and an analysis of climbing gym visits, it is estimated by the German Alpine Club that in Germany alone more than 400 000 people are engaged in indoor climbing regularly.[1] The strong increase in artificial climbing walls can also be illustrated by figures from the United Kingdom,[2] where 40 facilities were reported in the year 1988, 122 in the year 1995 and 169 in the year 1996. Despite the fact that exact data for the number of indoor climbers worldwide are not available, it can be expected that several million people are engaged in this sport.

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Environmental impact

Worldwide, several million people are exposed to high dust concentrations in indoor climbing gyms, due to the use of hydrated magnesium carbonate hydroxide (magnesia alba) for drying the hands. In some cases, occupational limit values are exceeded. In addition, vulnerable groups (*e.g.*, children, elderly, persons with respiratory diseases) are engaged in this leisure activity. Therefore, significant reduction of the dust concentrations is required. The present paper investigates the potential of low-budget reduction strategies to reduce dust concentrations in indoor climbing gyms. The results of this investigation do not only apply to indoor climbing, rather, the reduction strategies studied may also be implemented in other indoor sports using magnesia alba, as for example apparatus gymnastics or weightlifting.

The use of hydrated magnesium carbonate hydroxide (magnesia alba) for drying the hands and a better grip leads to high dust concentrations in indoor climbing gyms. PM_{10} concentrations up to 1000–4000 μg m^{-3} were found in a recent investigation[3] in nine German indoor climbing gyms. $PM_{2.5}$ concentrations were also strongly elevated with maximum values on the order of 100–500 μg m^{-3}. The total particle number concentrations (electric mobility diameter between 3.7 nm and 10 μm) measured in one indoor climbing gym were generally lower (8000–12 000 cm^{-3}) than European urban background values,[4] showing that there are no strong indoor sources for ultrafine particles.[3] Scanning electron microscopy and energy-dispersive X-ray microanalysis revealed that most particles with diameters above approximately 200 nm found in indoor climbing gyms are hydrated magnesium carbonate hydroxide.[3]

Potential adverse health effects of the use of magnesia alba in indoor sports include cough, respiratory tract irritation and, in susceptible individuals, exacerbation of asthma.[5] As the toxicological properties of magnesia alba are not known, regulation of exposure has to be based on the exposure limits for respirable and inhalable dust. In Germany for example, the current occupational exposure limits for respirable (3000 μg m^{-3}) and inhalable (10 000 μg m^{-3}) dust[6] are not exceeded. However, the maximum workplace concentration (MAK) value,[7] which is the scientific basis for the occupational exposure limit for respirable dust, was recently reduced from 1500 μg m^{-3} to 300 μg m^{-3}, and it can be expected that the occupational exposure limit will be lowered accordingly. In this case, some of the observed concentrations of respirable dust in indoor climbing gyms would exceed the occupational limit value. In addition, significant reduction of the dust concentrations in indoor climbing gyms is even necessary when the occupational limit values are not exceeded, as minimizing dust concentrations to technologically feasible values is required by the current German legislation.

Air ventilation is an obvious way of reducing the dust concentrations in indoor climbing gyms. However, for older commercial climbing gyms retrofitting of modern air ventilation is often not possible at reasonable costs. For the large number of small facilities – often run by local climbing clubs, schools, and nursery schools – installation of state of the art ventilation is generally not feasible due to economic reasons. Therefore, low-budget reduction strategies have to be developed. Magnesia alba for use in rock climbing is distributed in several kinds, for example as loose powder, pressed blocks, or as suspension in ethanol. The use of chalk balls (magnesia alba enclosed in a sack of porous mesh material) is stipulated in many indoor climbing facilities to reduce the dust concentrations.

In the present paper, the influence of the different kinds of magnesia alba currently in use on the dust concentrations in indoor climbing gyms is investigated under controlled climbing activity. For comparison, the reduction potential of modern air ventilation is also evaluated.

2. Experimental

Aerosol concentrations were measured in four different indoor climbing gyms in Germany (München-Thalkirchen, Stuttgart, Hanau and Regensburg). Characteristics of the different climbing gyms are given in Table 1. The climbing gyms in München-Thalkirchen, Stuttgart and Regensburg are large facilities with a climbing area ≥1400 m^2 which are open every day of the week. The climbing gym in Hanau is much smaller (350 m^2 climbing area) and only open on two evenings a week and on Sundays. The climbing gym in München-Thalkirchen was used for instrument comparison only, and the climbing gym in Regensburg for evaluating the performance of modern air ventilation. In the climbing gyms in Stuttgart and Hanau the reduction potential of different kinds of magnesia alba was investigated. It proved to be difficult to obtain comparable terms of use during the measurement days (*e.g.*, the same number of visitors and willingness to use the same kind of magnesia alba) in the large, commercial indoor climbing facility in Stuttgart. Therefore, the climbing gym in Hanau was chosen for the systematic study of the influence of the different kinds of magnesia alba on the dust concentrations. Due to its smaller size and the corresponding much lower number of visitors, conditions during our measurements could be better controlled. In order to obtain a comparable number of visitors, the measurements in Hanau were conducted on Thursday evenings of seven consecutive weeks. By this strategy, it was also assured that mostly the same climbers were present during the seven measurement campaigns.

In all four climbing gyms, mass concentrations (PM_{10}, $PM_{2.5}$, and PM_1) were determined with an optical particle counter (OPC) and the particle size distribution in three climbing gyms (München-Thalkirchen, Stuttgart and Hanau) with an electrical aerosol spectrometer (EAS). In two climbing gyms (München-Thalkirchen and Stuttgart), PM_{10} was also measured by a synchronized, hybrid, ambient real-time particulate (SHARP) monitor to assess the accuracy of PM_{10}.

The OPC (Grimm Aerosol Spectrometer, model #1.109, Grimm Aerosol Technik GmbH, Ainring, Germany) measures particle number concentrations in the size range between 0.25 and 32 μm aerodynamic diameter (in 31 size channels). For conversion of the particle number concentrations into mass concentrations, a density of 2.2 g cm^{-3} was used, which is close to the density of magnesia alba powder (2.16 g cm^{-3}). The mass concentrations were corrected by a gravimetric factor, determined by weighing a filter that is located behind the measurement chamber of the instrument. The time resolution of the instrument was six seconds.

The SHARP monitor (Thermo Electron dust monitor, model 5030 SHARP, Thermo Electron GmbH) combines nephelometry with beta attenuation (^{14}C source) measurements. The instrument calibrates continuously the nephelometer data with a reference mass determined from the attenuation of beta radiation. The time resolution was 30 minutes. Comparisons of mass concentrations measured by OPS and the SHARP monitor in ambient air are given in several publications.[8–10]

The particle size distribution between 3.7 nm and 10 μm electrical mobility diameter was measured by an Electrical Aerosol Spectrometer (EAS). Technical details of the instrument are given elsewhere.[11] Each size distribution is measured within 4 minutes followed by a one minute calibration cycle leading to a time resolution of 5 minutes. The PM_{10} mass concentrations were calculated from the size distribution measurements. First, the electrical-mobility diameters measured by the EAS were converted to aerodynamic diameters assuming spherical shape and a density equivalent to magnesia (2.2 g cm^{-3}). Second, the

Table 1 Characteristics of the indoor climbing gyms investigated

Climbing gym	München-Thalkirchen	Stuttgart	Hanau	Regensburg
Climbing area (indoor only)	2000 m^2	1950 m^2	350 m^2	1400 m^2
Building volume (climbing area only)	≈ 5600 m^3	≈ 5600 m^3	≈ 1800 m^3	≈ 5500 m^3
Annual number of visitors	≈ 160 000	≈ 100 000	≈ 5800	≈ 50 000
Ventilation system	Yes	Yes	No	Yes
Measurement period	May 2008	Nov. 2008	Oct.–Dec. 2009	Feb. 2010
Temperature[a] [°C]	20–21	16–21	18–21	19–21
Relative humidity[a] [%]	25–35	30–53	35–53	26–30
Air exchange rate[a]	4000 $m^3 h^{-1}$	2600 $m^3 h^{-1}$	—	8100 $m^3 h^{-1}$

[a] During the measurements.

size distribution channels were weighted with the PM_{10} collection efficiency function (Hinds,[12] p. 255) for their calculated aerodynamic diameters. Third, the mass concentrations were achieved by integrating the resulting weighted volume concentrations for each channel over the size spectrum and multiplying by the magnesia alba bulk density.

The aerosol concentrations were measured at a height of approximately 1.5 m (OPC, SHARP) or 1.2 m (EAS). The instruments were placed at a distance of approximately 3–4 m from the climbing wall for safety reasons and to prevent damage by climbers or falling equipment. We have monitored the dust concentrations during the complete opening hours of each climbing gym (up to 16 hours a day). All windows and doors were closed during the measurements in Stuttgart, Hanau and Regensburg in order to reduce natural ventilation to a minimum. The air ventilation system in Stuttgart was operated with similar conditions during the three measurement days to assure that the observed differences in dust concentration are caused by the different kinds of magnesia alba used. In the climbing gym in Hanau, no air ventilation system is installed.

For the detailed investigation of the influence of different kinds of magnesia on dust concentrations in the climbing gym in Hanau, seven situations were distinguished: no restriction on the use of magnesia alba, the use of magnesia alba prohibited, block chalk (magnesia alba pressed into blocks), powdered chalk, sieved chalk (2–4 mm diameter), chalk balls (powdered magnesia alba enclosed in a sack of porous mesh material) and liquid chalk (a suspension of magnesia alba in ethanol). Product data on the different kinds of magnesia alba used in our study are listed in the ESI†.

Statistical calculations (95% confidence intervals, analysis of variance) were performed with STATGRAPHICS® (version 5, Warrenton, VA, USA). Statistical significance was assumed for p-values below 0.01.

3. Results

3.1. Accuracy of mass concentrations

PM_{10} determined with the OPC, the SHARP monitor and the EAS generally show a good agreement. The variation of PM_{10} during a day, which mainly depends on the number of climbers present, is well recorded by all three instruments. Typical examples of the daily variations are shown in Fig. 1. The mean coefficient of variation (standard deviation/arithmetic mean) for the different measurement days varies between 0.12 and 0.22. The reasons for the discrepancies in PM_{10} are currently not known. It should be kept in mind that the results of three different measurement techniques are compared. Thus, some systematic differences can be expected. However, as the relative order of the three instruments changed from day to day and even during the same day (Fig. 1), the differences seem not to be systematic instrumental artefacts. The differences of PM_{10} observed in the present study are of the same order of magnitude as those reported in a long term (eight month) comparison of 23 different instruments in which an accuracy between 12 and 39% (relative to the results of gravimetric mass determination of filters of low volume samplers) was obtained for continuous measurement techniques.[8]

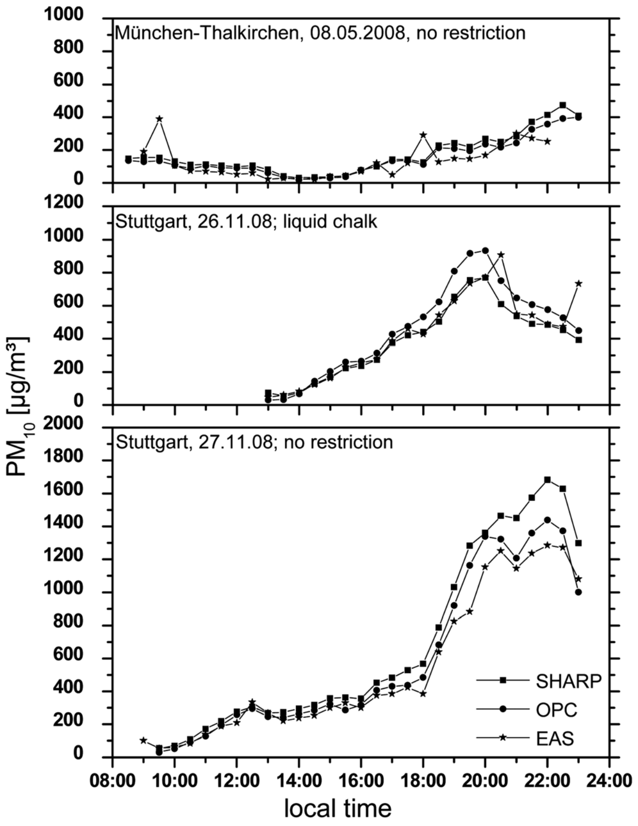

Fig. 1 Comparison of PM_{10} measured by an optical particle counter (OPC), a synchronized hybrid ambient real-time particulate (SHARP) monitor, and an electrical aerosol spectrometer (EAS).

3.2. Reduction potential

The reduction potential of the different kinds of magnesia alba can be estimated best from the measurements in the climbing gym in Hanau because the experimental conditions (*e.g.*, number of climbers, use of the different types of magnesia, and climbing activity) were well controlled at this location. The PM_{10} mass concentrations for the seven different days are shown in Fig. 2. As the number of climbers and its time dependence were quite similar for the seven days, only the average number of climbers is displayed in this figure. In accordance with previous work,[3] the mass concentrations strongly increase with the number of climbers present. The average number of climbers as well as mass and number concentrations are summarized in Table 2 for the periods of high activity. In order to estimate the reduction potential, the dust concentrations were normalized to the number of climbers present (Table 3). As the number of climbers was only counted every 15 (Hanau, Regensburg) or 30 minutes (Stuttgart), the normalized concentrations were obtained by dividing the mean values of the dust concentrations of 15 minute (in the case of Stuttgart 30 minutes) time intervals by the number of climbers present during the particular time period.

The PM_{10}/climber values obtained in the climbing gym Hanau are shown in Fig. 3. It is obvious that the use of liquid chalk leads to a similar reduction as the prohibition of magnesia alba. In both cases, PM_{10}/climber is approximately 30% of the value observed for climbing without any restriction. All other types of magnesia alba do not reduce the normalized dust concentrations significantly (Fig. 3). A similar result is obtained for $PM_{2.5}$/climber (Table 3). According to analysis of variance (ANOVA), these results are highly significant (p-value < 10^{-4}). For PM_1/climber, the different kinds of magnesia alba used do not show such a simple pattern (Table 3). As the use of magnesia alba predominantly leads to emission of particles with diameters above 1 μm (see below), the PM_1/climber values vary in a more random way. The particle number concentrations (Table 2) are not influenced in a systematic way by the different types of magnesia alba. The particle size distributions (Fig. 4a) show that the use of magnesia alba mainly leads to emission of particles with diameters above approximately 1 μm.

In the climbing gym Stuttgart, the use of liquid chalk also leads to a significant reduction of the normalized mass concentrations (Table 3), although less pronounced as in Hanau. The use of chalk balls did not reduce the normalized mass concentrations; even higher values compared to the day without restrictions were observed (Table 3). The particle number concentrations (Table 2) show no significant differences between the three measurement days. The particle size distributions also exhibit for Stuttgart that the use of magnesia alba mainly leads to emission of particles with diameters above approximately 1 μm (Fig. 4b).

The efficiency of modern air ventilation was estimated from the climbing gym in Regensburg. All three normalized mass concentrations are significantly lower (by a factor of 2–2.5) if the ventilation system is operating (Table 3).

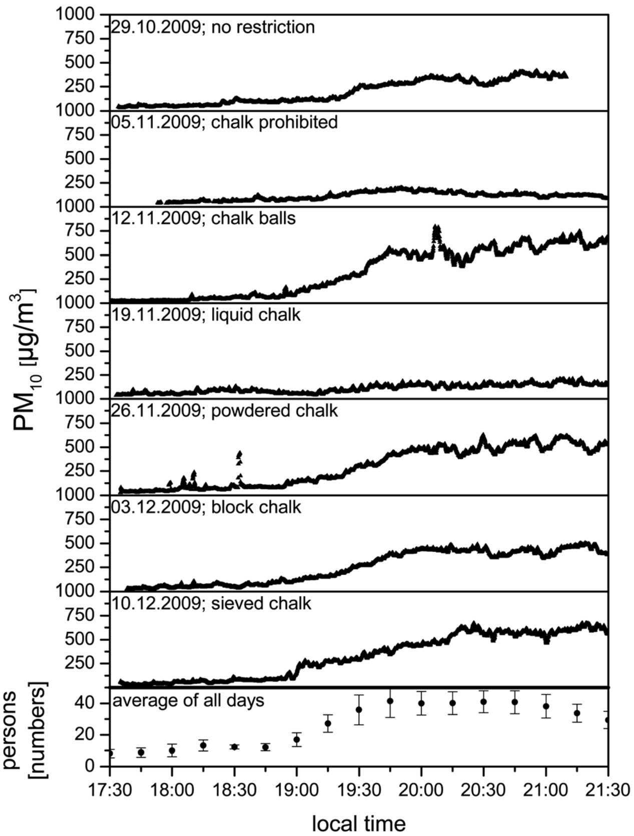

Fig. 2 PM_{10} as a function of time for the different kinds of magnesia alba used in the climbing gym Hanau. The error bars for the number of climbers represent ±1 standard deviation.

4. Discussion

4.1. Efficiency of reduction strategies

A significant reduction of the particle mass concentrations was only observed for the use of liquid chalk. As the mass concentrations were as low as during times when the use of magnesia alba was prohibited (Fig. 3), liquid chalk appears to be a reasonable means to reduce dust exposure in indoor climbing. However, it has to be emphasized that possible adverse effects of ethanol on the skin after prolonged use are not regarded here. Another drawback of liquid chalk is the fact that – at least in the present form – both hands are needed for application. Therefore, liquid chalk can be only applied prior to climbing and is not well suited for longer routes where magnesia alba is usually applied on the hands again during the same climb. However, liquid chalk appears to be a reasonable low cost option to reduce dust exposure significantly in bouldering gyms.

PM_{10} and $PM_{2.5}$ were not reduced by chalk balls; in the climbing gym in Stuttgart even higher values were observed. Therefore, the use of chalk balls does not offer any advantage with respect to the airborne dust concentrations and should no longer be promoted as a means of exposure reduction. Powdered chalk (which is prohibited in many climbing gyms), block chalk and sieved chalk lead to similar dust concentrations as chalk balls. All four kinds of magnesia alba do not exhibit a significant reduction potential, as the normalized dust concentrations are similar to the values observed without restriction of magnesia alba use (Fig. 3).

Air ventilation leads – of course – to substantial reduction of the mass concentrations. In the climbing gym Regensburg,

Table 2 Mass and number concentrations as function of the type of magnesia alba used

Date	Time[a]	Kind of magnesia	Climbers[b]	PM_{10}[b] [μg m⁻³]	$PM_{2.5}$[b] [μg m⁻³]	PM_1[b] [μg m⁻³]	Particle number[b,c] [1 cm⁻³]
Stuttgart							
26.11.2008	18:00–20:30	Liquid chalk	177 ± 6	806 ± 126	127 ± 21	18 ± 2	14 679 ± 4845
27.11.2008	18:00–22:00	No restriction	183 ± 42	1179 ± 254	160 ± 34	22 ± 5	14 002 ± 4599
28.11.2008	17:00–20:00	Chalk balls	113 ± 3	965 ± 130	152 ± 17	23 ± 2	12 303 ± 1628
Hanau							
29.10.2009	20:00–21:09	No restriction	28 ± 1	342 ± 36	49 ± 4	10 ± 1	n.m.
05.11.2009	20:00–21:30	Chalk prohibited	37 ± 7	129 ± 20	19 ± 2	3.0 ± 0.2	7721 ± 1352
12.11.2009	20:00–21:30	Chalk balls	45 ± 4	584 ± 78	75 ± 11	12 ± 1	7707 ± 1172
19.11.2009	20:00–21:30	Liquid chalk	40 ± 6	155 ± 23	19 ± 3	5 ± 1	27 534 ± 1295
26.11.2009	20:00–21:30	Powdered chalk	42 ± 5	513 ± 53	65 ± 7	8 ± 1	15 070 ± 3952
03.12.2009	20:00–21:30	Block chalk	34 ± 9	428 ± 36	62 ± 5	8 ± 1	4069 ± 378
10.12.2009	20:00–21:30	Sieved chalk	39 ± 3	572 ± 55	77 ± 11	10 ± 1	3335 ± 148
Regensburg							
10.02.2010	18:00–21:30	No restriction ventilation on	90 ± 13	660 ± 80	81 ± 10	17 ± 1	n.m.
11.02.2010	18:30–21:30	No restriction ventilation off	72 ± 13	962 ± 146	159 ± 24	33 ± 2	n.m.

[a] Period of high activity. [b] Mean value and standard deviation of period of high activity. [c] Particles with electrical mobility diameter between 3.7 nm and 10 μm; n.m. = not measured.

Table 3 Normalized mass concentrations

Date	Time[a]	Kind of magnesia	PM_{10}/climbers[b] [(μg per m³)per person]	$PM_{2.5}$/climbers[b] [(μg per m³)per person]	PM_1/climbers[b] [(μg per m³)per person]	*n*
Stuttgart						
26.11.2008	18:00–20:30	Liquid chalk	4.5 (2.8–6.1)	0.7 (0.5–0.9)	0.10 (0.07–0.13)	6
27.11.2008	18:00–22:00	No restriction	6.7 (5.3–8.0)	0.9 (0.7–1.1)	0.12 (0.10–0.15)	9
28.11.2008	17:00–20:00	Chalk balls	8.1 (6.6–9.7)	1.3 (1.1–1.5)	0.19 (0.16–0.22)	7
Hanau						
29.10.2009	20:00–21:09	No restriction	12.2 (10.7–13.8)	1.7 (1.5–2.0)	0.36 (0.33–0.40)	5
05.11.2009	20:00–21:30	Chalk prohibited	3.5 (2.1–5.0)	0.5 (0.3–0.8)	0.08 (0.05–0.11)	6
12.11.2009	20:00–21:30	Chalk balls	12.4 (11.0–13.9)	1.6 (1.3–1.8)	0.25 (0.22–0.28)	6
19.11.2009	20:00–21:30	Liquid chalk	3.8 (2.3–5.2)	0.5 (0.2–0.7)	0.11 (0.08–0.14)	6
26.11.2009	20:00–21:30	Powdered chalk	11.8 (10.4–13.3)	1.5 (1.3–1.7)	0.18 (0.15–0.21)	6
03.12.2009	20:00–21:30	Block chalk	12.0 (10.6–13.5)	1.7 (1.5–2.0)	0.23 (0.19–0.26)	6
10.12.2009	20:00–21:30	Sieved chalk	14.1 (12.7–15.6)	1.9 (1.6–2.1)	0.24 (0.21–0.27)	6
Regensburg						
10.02.2010	18:00–21:30	No restriction ventilation on	7.3 (6.0–8.6)	0.9 (0.7–1.1)	0.19 (0.15–0.23)	15
11.02.2010	18:30–21:30	No restriction ventilation off	13.7 (12.3–15.0)	2.3 (2.0–2.5)	0.48 (0.44–0.52)	13

[a] Period of high activity. [b] Mean value and 95% confidence interval (in parenthesis) of period of high activity derived from 15 (Hanau; Regensburg) or 30 minutes (Stuttgart) time intervals; *n* = number of time intervals used for calculation of mean values and 95% confidence intervals.

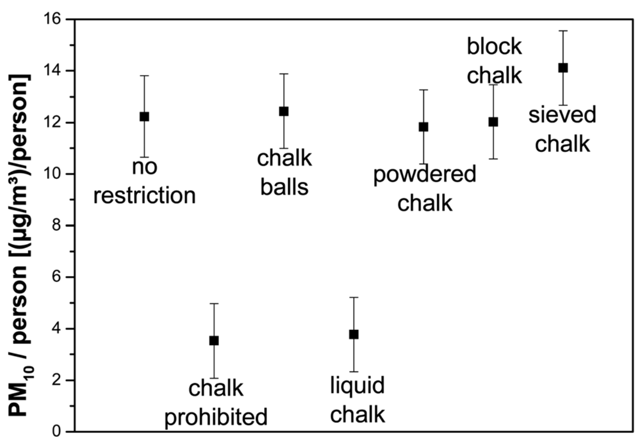

Fig. 3 PM_{10} normalized to the number of climbers (mean value and 95% confidence interval) in the climbing gym in Hanau.

PM_{10}/climber was reduced by ≈45%, $PM_{2.5}$/climber by ≈60%, and PM_1/climber by ≈60% (Table 3). As current legislation requires ventilation or air conditioning in sports gyms in many countries (Germany for example: 60 m³ per h per athlete plus 20 m³ per h per spectator place[13]), installation of modern ventilation systems is indispensable for large commercial climbing gyms. However, many older indoor climbing gyms and many small facilities cannot retrofit such equipment for economic reasons. For such facilities, liquid chalk or prohibition of the use of magnesia alba are the most obvious options for dust reduction.

During the time period of high activity (usually evening hours), particle number concentrations varied between approximately 3300 and 27 500 cm⁻³ similar to the findings of Weinbruch *et al.*[3] The particle number concentrations were not correlated with the different types of magnesia. As strong indoor sources for ultrafine particles were not present, it is concluded that they originate outdoors. The particle number concentrations in indoor climbing gyms are similar to classrooms in the Munich

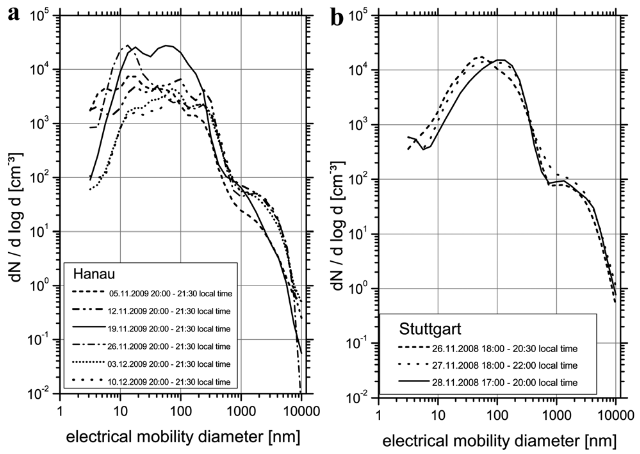

Fig. 4 Particle size distributions for the climbing gyms in Hanau (a) and Stuttgart (b).

(Germany) area which also contain no strong indoor sources for ultrafine particles.[14]

In the climbing gym in Hanau, higher particle number concentrations (compared to the rest of the measurement days) were observed on November 19th and 26th 2009 (Table 2). Based on the evolution of the size distribution with time (not shown) it appears that distinct nucleation events occurred on these days, *i.e.* a large number of particles with diameters below 10 nm was formed within a few minutes. These particles grew to a larger size within hours. As there were no strong sources for ultrafine particles within this climbing gym, it is concluded that they originated outdoors. We have no indications of special outdoor sources (*e.g.*, combustion processes and smoking) for these particles during the measurements. An alternative explanation would be that evaporating alcohol from liquid chalk contributes to secondary particle formation indoors. Indeed, in the climbing gym in Hanau by far the highest particle number concentrations were measured on the day when liquid chalk was used (Table 2). However, in the climbing gym in Stuttgart the particle number concentrations were not substantially increased during the use of liquid chalk (Table 2).

4.2. Practical considerations

As discussed earlier,[3] the toxicological properties of magnesia alba are not known. Magnesium carbonate is the material with the closest chemical composition for which health hazards have been assessed. However, even for this substance a health-based occupational exposure limit could not be defined due to the limited database. Instead, the occupational exposure limits for respirable and inhalable dust (for The Netherlands: 5 and 10 mg m^{-3} respectively) were considered adequate for regulation purposes in The Netherlands.[15] For inhalable dust, the observed dust concentrations in indoor climbing gyms are well below the current occupational exposure limits in The Netherlands and in Germany. However, the concentrations of respirable dust may exceed the future occupational exposure limit in Germany. In addition, the observed dust concentrations exceed current guidelines in Germany for workplaces without the use of hazardous substances (for details see Weinbruch *et al.*[3]). Some employers may be exposed to high dust concentrations the whole workday, as in many gyms the climbing area is not separated from service areas. For most climbers, the exposure time is much lower (most likely between 3 and 8 hours a week).

Despite the fact that a scientifically well defined limit value is currently not available for magnesia alba, the large number of exposed persons calls for a practical guiding value for the dust concentrations in indoor climbing gyms. With modern air ventilation equipment, PM_{10} and $PM_{2.5}$ concentrations around 650 and 80 μg m^{-3}, respectively, were obtained in the climbing gym in Regensburg during time periods of high climbing activity. As the maximum number of athletes that can be active at the same time in this climbing gym (≈ 140) was not reached during our measurements, higher dust concentration can be expected under complete utilization. With the mass concentrations normalized to the number of climbers (Table 3), PM_{10} values of ≈ 1000 μg m^{-3} and $PM_{2.5}$ values of ≈ 125 μg m^{-3} are estimated during complete utilization. As the climbing gym in Regensburg was equipped with the best ventilation system of all climbing gyms of the German Alpine Club, it is concluded that these mass concentrations are technologically feasible and economically justifiable, and may, thus, serve as a practical guideline for indoor climbing gyms. These values are considerably lower than the maximum concentrations measured in older commercial climbing gyms.[3] Thus, application of the proposed practical guiding values would lead to substantial reduction of dust exposure. For PM_1 and the particle number concentration, no recommendation is given, as both parameters are not much affected by the use of magnesia alba.

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