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Indoor Air Quality in Two University Sports Facilities

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ABSTRACT

In July 2012, an indoor/outdoor monitoring programme was undertaken in two university sports facilities: a fronton and a gymnasium. Comfort parameters (temperature, relative humidity, and CO_2), CO and total volatile organic compounds (TVOCs) were continuously monitored. Concentrations of NO_2, carbonyl compounds and individual VOCs were obtained, after passive sampling, by spectrophotometry, high-performance liquid chromatography and gas chromatography with flame ionisation detection, respectively. Low volume samplers were used to collect particulate matter (PM_{10}). During the occupancy periods, the relative humidity values were within the comfort limits in both buildings, but frequent daytime temperatures over 30°C in the gymnasium make this indoor space rather uncomfortable. The minimum ventilation rates stipulated for acceptable indoor air quality were observed in both sports facilities. It was found that cleaning activities may have a large influence on the VOC levels. Acrolein was one of the most abundant carbonyl compounds, showing concentrations above the recommended limit. Formaldehyde was detected at levels lower than those commonly reported for other indoor environments. In the fronton, the PM_{10} concentrations obtained during the occupancy periods ranged between 38 and 43 $\mu g/m^3$. Much higher levels, from 154 to 198 $\mu g/m^3$, were registered in the gymnasium. Weekend average values lower than 20 $\mu g/m^3$ were obtained in both sports facilities, which are comparable to the outdoor levels throughout the week. The high particle levels in the gym are mainly due to the climbing chalk and the constant process of resuspension.

Keywords: Indoor air quality; Gymnasiums; Air exchange rates; VOC; PM_{10}.

INTRODUCTION

The world's global disease profile is changing: chronic, non-communicable diseases (NCD) - primarily cardiovascular disease, chronic respiratory disease, diabetes, and cancer - now account for the majority of global morbidity and mortality (Beaglehole and Yach, 2003; Yach *et al.*, 2004; Nugent, 2008; Mattke *et al.*, 2011). NCD caused an estimated 35 million deaths in 2005 and are projected to increase by a further 17% over the next ten years (WHO, 2008). The three main risk factors for chronic diseases - overnutrition, lack of physical activity, and tobacco use - are increasing generally in developing countries, just as in developed countries. The prevalence of physical inactivity, for example, rose dramatically in the first decade of the century, from a 43% increase in Indonesia (2003 to 2008) to a 188% increase in China (2002 to 2008) and a 334% increase in Russia (2003 to 2008), whereas, over the last decade, obesity rates increased by 24% in Russia, 84% in Brazil, 97% in China, and 171% in India (Mattke *et al.*, 2011). Among others, strategies for reducing risk factors due to physical inactivity should focus on improving conditions in sports, recreation and leisure facilities. However, athletes and ordinary practitioners of sports can be at risk when they are exercising or training in polluted environments due the fact that: i) the amounts of pollutants inhaled increase proportionally with increasing ventilation rates, ii) most of the air is inhaled through the mouth, bypassing the normal nasal mechanisms for filtration of large particles and soluble vapours, and iii) the increased airflow velocity carries pollutants deeper into the respiratory tract (Carlisle and Sharp, 2001). Moreover, pulmonary diffusion capacity has been shown to increase with exercise (Smith *et al.*, 1999; Zavorsky and Lands, 2005), and therefore it may be postulated that the diffusion of pollutant gases boosts with exercise (Carlisle and Sharp, 2001). Indoor air pollution may increase the risk of irritation phenomena, allergic sensitisation, acute and chronic respiratory disorders and lung function impairment (Viegi *et al.*, 2004; Annesi-Maesano and Dab, 2006).

In spite of the importance of healthy air in indoor spaces, evaluation studies have been focused almost exclusively

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on schools (e.g., Daisey *et al.*, 2003; Blondeau *et al.*, 2004; Mólnar *et al.*, 2007; Pekey and Arslanbaş, 2008; Stranger *et al.*, 2008; Pegas *et al.*, 2011; Oeder *et al.*, 2012; Pegas *et al.*, 2012), homes (e.g., He *et al.*, 2004; Parker and Ikeda, 2006; Mólnar *et al.*, 2007; Pekey and Arslanbaş, 2008), and some offices (e.g., Wood *et al.*, 2006; Pekey and Arslanbaş, 2008; Salonen *et al.*, 2009). Comparatively, indoor air quality (IAQ) evaluation programmes carried out in sports facilities are very scarce. Most of these studies have been performed in school gymnasiums and assessed a limited number of pollutants (Bruno *et al.*, 2008; Braniš *et al.*, 2009, 2011; Braniš and Šafránek, 2011; Buonanno *et al.*, 2012). The objective of the present study was to conduct a comprehensive characterisation of a vast array of indoor pollutants in two sports facilities and their relationships with outdoor air. This evaluation will be potentially useful for epidemiological studies and to develop appropriate control strategies for minimising the adverse health effects on exercise practitioners.

METHODOLOGY

Characterisation of Sports Facilities

Two sports facilities belonging to the University of Léon, Spain, were chosen to carry out the monitoring programme: a fronton and a gymnasium. A fronton is a court used as playing area for a variant of paddleball. It is made up of a rectangular floor and three vertical walls, named *frontis*; the front wall is the main one, where the hits are directed according to the rules. The University of Léon fronton building is a closed court. Part of the fourth wall (the one that is not part of the court) is windowed and has a 4 tiered wooden bench seating. The global dimensions of the building are 36 m length × 20 m width × 27 m height. A total of 16 vents are evenly distributed at the top of the front and opposite walls to provide permanent natural air exchange. During the sampling campaign, 2-h long matches were organised, between 10:00 and 14:00 and between 16:00 and 20:00, involving 4 players. The games took place without or with only few spectators (up to 6).

The gymnasium is 15 m wide, 27 m long and has a height of 10.6 m. It has no windows and a half-cylinder skylight (5 m diameter and 20.3 m length) centred on the roof. The vinyl flooring is practically coated with gym mats and safety mattresses. The sports equipments included asymmetric bars/high bar, rings, parallel bars, beams, pummel horse, tumble track, trampolines, wall bars, and dug pit with foam cubes. Due to the high temperatures reached after the late morning hours, a side gate was frequently open when the gymnasium was busy. The gym does not have any mechanical ventilation system. During the sampling campaign, it was occupied by college athletes between 9:00 and 14:00 and between 17:00 and 19:00. A much higher attendance was observed until mid-morning, because sports activities were included in the summer academy for kids sponsored by the university.

Sampling Campaign

The monitoring campaign was carried out between 8 and 22 July, 2012. During the first week, measurements took place in the fronton. In the second week, equipments and samplers were deployed in the gymnasium. Continuous measurements of temperature, relative humidity (RH), CO_2, CO and total volatile organic compounds (TVOCs) were performed with an Indoor Air IQ-610 Quality Probe (Gray Wolf® monitor) in both sports facilities. The same measurements, excepting TVOCs, were continuously carried out outside using an IAQ-CALC monitor (model 7545) from TSI. From Monday to Friday, VOCs and carbonyls were sampled in parallel, both indoors and outdoors, using Radiello® diffusive passive tubes (cartridge codes 130 and 165, respectively). NO_2 was monitored, also from Monday to Friday, using diffusion tubes supplied by Gradko. On working days, during the occupancy periods, simultaneous indoor and outdoor sampling of particulate matter with equivalent aerodynamic diameter less than 10 µm (PM_{10}) was performed. At weekends, a 24-h sampling schedule was adopted. The PM_{10} samples were collected onto pre-baked (6 h at 500°C) 47 mm diameter quartz filters using Echo TCR Tecora samplers, following the EN 12341 norm.

Analytical Methodologies

VOCs were extracted from the exposed samplers with 2 mL carbon disulphide (CS_2 from Aldrich) containing 2-fluorotoluene (from Aldrich) as internal standard. The glass vials were shaken for approximately 30 min. The analyses of the extracts were performed by gas chromatography (Thermo Scientific Trace GC Ultra) coupled to a flame ionisation detector. Carbonyls, in the form of 2,4-dinitrophenylhydrazines (DNPH), were extracted with 2 mL acetonitrile (Fisher Scientific). The glass vials were shaken for approximately 30 min. The extracts were filtered through 0.45 µm disc membrane filters (filtration kit RAD 174) and analysed by high-performance liquid chromatography (HPLC). The analyses of VOC and carbonyls were described in detail by Pegas *et al.* (2010). NO_2 was analysed by Gradko (Gradko Laboratories, UK), using a 50% triethanolamine (TEA) in acetone method.

Ventilation Rates

The ventilation Eq. (1) has been used to calculate the fresh air ventilation rate (Griffiths and Eftekhari, 2008). For a well-mixed space the change in CO_2 concentration with time is given by:

$$C_t = C_{ext} + \frac{q_{CO_2} \times 10^6}{Q} - \left(C_{ext} - C_0 + \frac{q_{CO_2} \times 10^6}{Q} \right) e^{\left(-Qt/V\right)} \quad (1)$$

where C_t is the indoor concentration of CO_2 at time t (ppm), C_{ext} the outdoor concentration of CO_2 (ppm), C_0 the concentration of CO_2 in the indoor air at time 0 (ppm), Q the volume flow rate of air entering the space (m^3/s), q_{CO_2} the volumetric indoor emission rate of CO_2 (m^3/s), V the volume of the classroom (m^3) and t is the interval since t = 0 (s). When the classroom is unoccupied there is no CO_2 emission from the occupants, and $q_{CO_2} = 0$. Thus, Eq. (1) can be rearranged to give the following expression, which allows the ventilation rate (Q) to be calculated from measured concentration values time t apart:

$$Q = -\frac{V}{t} \times ln\left(\frac{C_t - C_{ext}}{C_0 - C_{ext}}\right) \tag{2}$$

RESULTS AND DISCUSSION

Comfort Parameters and air Exchange Rates

High relative humidity and thermal amplitudes between nighttime and daytime highs were registered outdoors (Table 1). For summer (light clothing), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends maintaining indoor temperature in the ranges 24.5–28°C and 23–25.5°C for RH values of 30 and 60%, respectively. In general, during the occupancy periods, the RH values were within the comfort limits in both buildings. However, frequent daytime temperatures over 30°C in the gymnasium make this environment rather uncomfortable and fatiguing. Working in heat can lead to sports practitioners, especially children, suffering serious illness (Binkley *et al.*, 2002; Grubenhoff *et al.*, 2007; Racinais *et al.*, 2012). The temperatures should be kept in the comfortable range through the use of engineering controls, such as air conditioning, air circulating fans, insulating or shielding sources of heat, roofs or walls, reducing heat gain via windows or skylights by reflective film or blinds, and ducting hot exhausts outside the sports space.

Carbon monoxide, a pollutant from incomplete combustion of carbonaceous fuels, was present only at minor or undetectable levels, never exceeding the WHO guidelines (15 min - 81 ppm, 1 h - 28 ppm, 8 h - 8.1 ppm, 24 h - 5.7 ppm). The primary source of CO_2 in indoor spaces is respiration of the building occupants. In this study, the ASHRAE standard of 1000 ppm was never surpassed, which can be considered a benchmark of good ventilation.

In the fronton, the air exchange rate (AER) remained unchanged, around 1 h^{-1}, from day to day. The AER values for the gymnasium ranged from 0.3 to 0.5 h^{-1}. Taking into account the dimensions of both spaces, the supplied flow rates of primary air were estimated to be 4.72 and 1.00–1.67 L/s per m^2 of floor area for the fronton and gymnasium, respectively. These values generally exceed the minimum ventilation rates recommended by ASHRAE for acceptable IAQ either in sports arenas, stadiums and gymnasiums (1.5 L/s per m^2), or in health clubs and aerobics rooms (0.3 L/s per m^2).

Air Pollutants

The NO_2 concentrations were higher outdoors than indoors, probably as a result of vehicular exhaust emissions from nearby traffic. The average levels obtained inside the fronton and gymnasium were, respectively, 8.8 and 10.5 µg/m^3. The corresponding I/O ratios were 0.88 and 0.79. A guideline value of 40 µg/m^3 (annual mean) has been set by the World Health Organisation (WHO, 2010) to protect public health. Either at the gym or in the fronton, TVOCs reached maximum values around 2300 ppb coincident with the cleaning activities, decaying to 30–40 ppb during nighttime. Individual VOCs in the fronton were found at I/O ratios up to 0.22, suggesting that the low indoor concentrations arise predominantly from the transport of outdoor air into the indoor environment (Table 2). The high VOC concentrations obtained outdoors during the monitoring period in the fronton may be associated with sanitising, cleaning and general maintenance activities carried out at the end of the academic year in a neighbouring building. The application of protective waxes and brightening liquids to the surfaces of the pavements is among those activities. VOC release through the air vents of that building, which were located a few meters from the outdoor sampling point, is probably the main cause for the observed levels. An I/O ratio of 7 obtained for acetone in the gymnasium indicates the presence of

Table 1. Concentrations of total volatile organic compounds and comfort parameters.

	TVOC (ppb)	CO_2 (ppm)	CO (ppm)	T (°C)	HR (%)
			FRONTON - INDOOR		
Average	82.4	413	0.17	21.1	38.7
Maximum	2300	565	12.6	32.5	49.8
Minimum	30.0	370	< d.l.	15.9	22.0
			FRONTON - OUTDOOR		
Average	n.m.	409	0.02	18.4	52.4
Maximum	n.m.	503	1.00	30.9	89.8
Minimum	n.m.	375	< d.l.	5.1	11.3
			GYMNASIUM - INDOOR		
Average	53.0	468	0.01	29.0	25.8
Maximum	2318	787	2.10	36.6	37.3
Minimum	35.0	397	< d.l.	20.4	10.8
			GYMNASIUM - OUTDOOR		
Average	n.m.	418	4.9	22.8	43.2
Maximum	n.m.	458	0.50	37.0	90.9
Minimum	n.m.	379	< d.l.	7.70	7.50

n.m.- not measured; d.l. - detection limit

Table 2. Concentrations of volatile organic compounds (μg/m^3).

VOCs	FRONTON		GYMNASIUM	
	Indoor	Outdoor	Indoor	Outdoor
Methanol	< d.l.	16.4 ± 3.0	0.33 ± 1.06	< d.l.
Acetone	2.85 ± 0.43	207 ± 10.9	23.5 ± 1.94	3.41 ± 0.51
Pentane	0.90 ± 0.13	103 ± 5.44	0.87 ± 0.10	1.05 ± 0.08
Dichloromethane	5.30 ± 3.11	24.1 ± 4.03	2.24 ± 0.21	4.39 ± 0.50
n-Hexane	0.44 ± 0.07	19.9 ± 0.97	0.81 ± 0.15	0.50 ± 0.03
Benzene	0.58 ± 0.13	8.71 ± 0.44	0.71 ± 0.02	0.58 ± 0.09
n-Heptane	0.96 ± 0.36	7.23 ± 0.16	1.43 ± 0.08	1.26 ± 0.11
Toluene	0.94 ± 0.22	97.2 ± 3.48	1.53 ± 0.08	1.50 ± 0.03
Ethylbenzene	0.55 ± 0.64	14.1 ± 0.52	< d.l.	0.98 ± 0.10
n-Nonane	< d.l.	7.79 ± 0.40	< d.l.	< d.l.
n-Decane	< d.l.	24.4 ± 0.55	0.59 ± 1.18	< d.l.

d.l. - detection limit

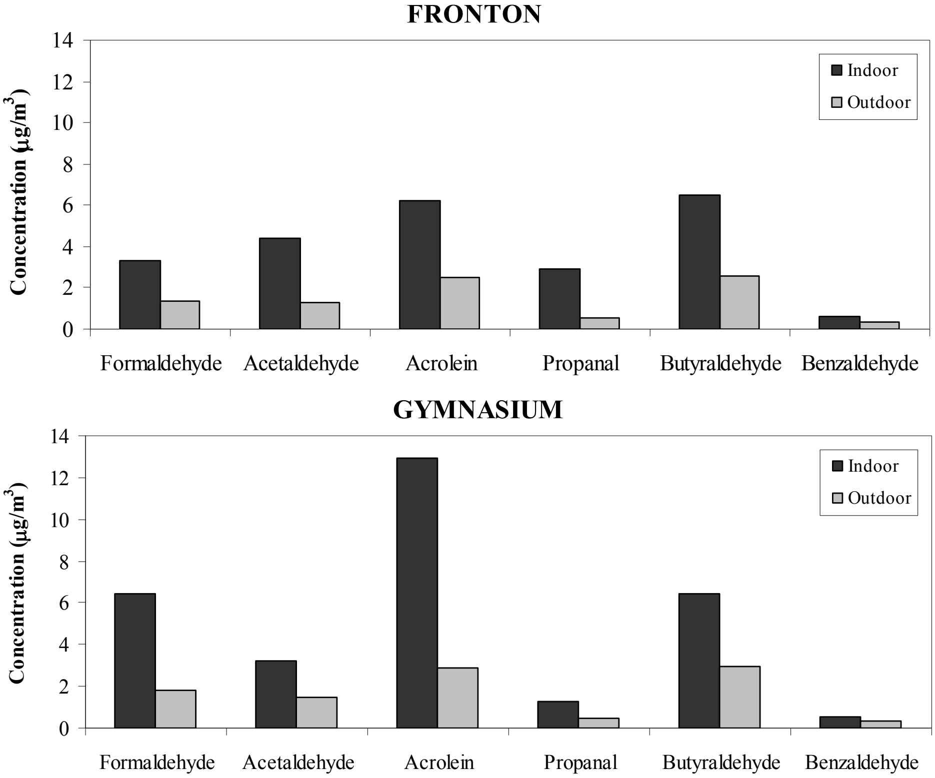

Fig. 1. Average concentrations of carbonyl compounds.

strong indoor sources for this compound. Acetone is present in products such as paint removers, waxes, polishes, certain detergents and cleansers, cosmetics and some glues (Bruno *et al.*, 2008). Whereas indoor VOC levels may increase due to the entry and accumulation of compounds from outdoor sources, the presence of dominant VOC sources is illustrated by the magnitude of the I/O ratio. Other VOCs, such as hexane (I/O = 1.6), benzene (I/O = 1.22) and heptane (I/O = 1.13), also present in household products, were detected at slightly higher concentration in the indoor gym environment than outdoors.

Several carbonyl compounds were detected both indoors and outdoors (Fig. 1). The I/O ratios ranged from 1.5 to 5, which indicate the presence of indoor sources. Formaldehyde is one of the most important indoor air pollutants due to its human health effects and the fact that it is the compound normally present in highest concentrations (Alves and Acioli, 2012). Formaldehyde could originate from composite wood and other products with urea-formaldehyde resin, some architectural finishes, tobacco smoke and other combustion processes. Also, pressed wood products use adhesive containing urea formaldehyde that can break down, releasing formaldehyde into the air (Alves and Aciole, 2012). In spring and summer, outdoor formaldehyde levels increase due to acceleration of photochemical activity (Lee *et al.*, 2001), while the opposite trend is observed indoors, since the

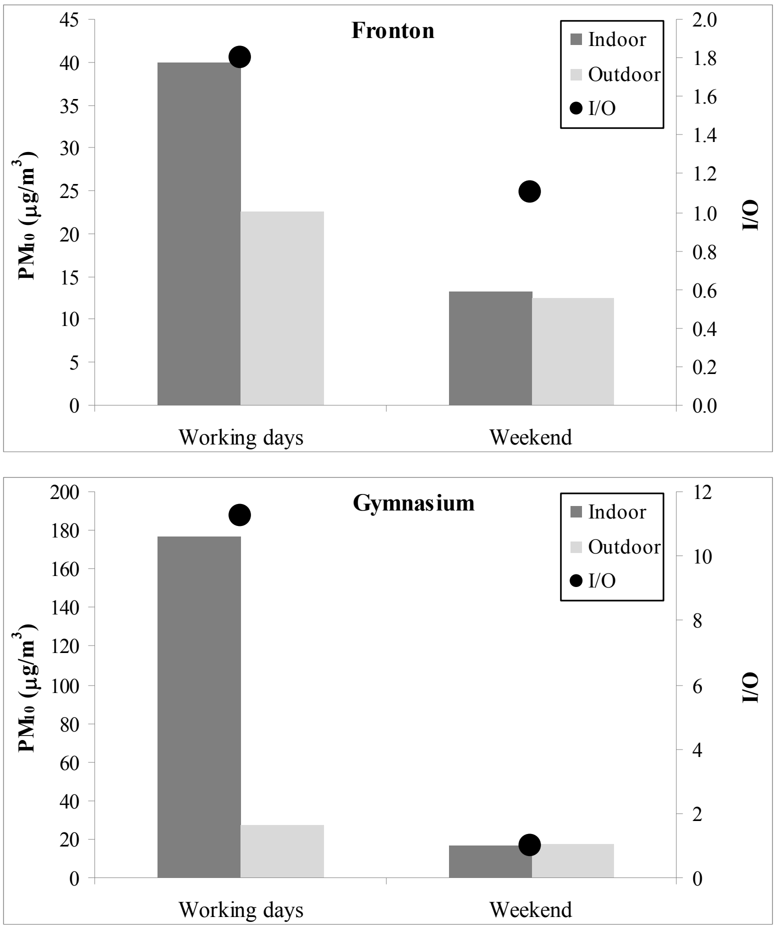

Fig. 2. PM_{10} concentrations and indoor/outdoor ratios.

interchange rate between indoor and outdoor air is higher due to open windows (Pilidis *et al.*, 2009). In a recent assessment, it was concluded that a formaldehyde indoor air limit of 132 µg/m^3 should protect even particularly susceptible individuals from both irritation effects and any potential cancer hazard (Golden, 2011). A large review of formaldehyde concentrations worldwide in several types of indoor environments has been summarised by Salthammer *et al.* (2010). Concentrations range from values close to zero to levels exceeding 2000 µg/m^3. However, no measurement was reported for sports facilities. Compared to other indoor environments, the formaldehyde concentrations were relatively low in both sports buildings.

The most abundant carbonyl compounds were butyraldehyde and acrolein. No occupational exposure limit has been set for butyraldehyde. Acrolein is a known respiratory toxicant and one of the 188 most hazardous air pollutants identified by the U.S. EPA. This volatile and unsaturated aldehyde is a common constituent of both indoor and outdoor air. The contribution of hitherto known indoor sources of acrolein (heated cooking oil, cigarette smoke, incense, candles, and wood-burning fireplaces) seems, in the case of the two sports facilities, unlikely. The formation of acrolein by the oxidation of VOCs which off-gas from furnishings, building materials, carpeting, wood finish, glues and adhesives, and paints has been pointed out as a probable mechanism to justify the occurrence of acrolein indoors (Seaman *et al.*, 2007). The Office of Environmental Health Hazard Assessment (California Environmental Protection Agency) has adopted an acute non-cancer reference exposure level (REL) of 0.19 µg/m^3 and a chronic REL of 0.06 µg/m^3 for acrolein (OEHHA, 2001), which were largely surpassed, either in the fronton or in the gymnasium.

In the fronton, the PM_{10} concentrations obtained during the occupancy periods ranged between 38 and 43 µg/m^3, decreasing to average values of 13 µg/m^3 on weekend (Fig. 2). Much higher levels, from 154 to 198 µg/m^3, were registered in the gymnasium. A weekend average value of 17 µg/m^3 was obtained in this sports facility, which is comparable with the outdoor level. On working days, I/O ratios close to 2 and from 7 to 57 were, respectively, attained for the fronton and the gymnasium. There is no consensual threshold limit for PM_{10} in indoor spaces. Some departments of public health in the U.S. have developed guidelines for acceptable IAQ, recommending that PM_{10} should be maintained at less than the Environmental Protection Agency air quality standard of 150 µg/m^3 during a 24-h time period. The Government of the Hong Kong Special Administrative Region established two levels of IAQ guideline values for PM_{10}: 20 µg/m^3 (8-h mean) for an excellent IAQ class and

180 μg/m^3 (8-h mean) for a good IAQ class. The Finnish Society of Indoor Air Quality and Climate recommends a more restrictive standard (8-h mean) of 20 μg/m^3. The steering group assisting WHO in designing the IAQ guidelines concluded that there is no convincing evidence of a difference in the hazardous nature of particulate matter from indoor sources as compared with those from outdoors. Therefore, the ambient air quality guideline for PM_{10} is also applicable to indoor spaces (50 μg/m^3, 24-hour mean). This latter value coincides with that in the Spanish norm UNE 171330-2: 2009, which defines the IAQ inspection procedures. Regardless of which guideline is used, it can be concluded that sports practitioners are exposed to potentially harmful concentrations of PM_{10} in the gym. The main reason for the high particle levels is the climbing chalk (hydrated magnesium carbonate hydroxide or magnesia alba) used by the athletes as drying agent for hands. Moreover, the physical activities contribute to a constant process of resuspension of sedimented material. 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 (Weinbruch *et al.*, 2008). Magnesium carbonate is not a known carcinogen, and is given a "slight" hazard rating by various government organisations, although the effects of long-term exposure are unknown. According to the U.S. Department of Labour, magnesium carbonate can be a skin and respiratory irritant, but is not considered toxic. Breathing clouds of chalk, such as inside a poorly ventilated gym, could cause us to cough and wheeze, and we might experience some tightness in our chest. Breathing in chalk dust for a number of years can create or trigger respiratory problems (Majumdar and William, 2009). Weinbruch *et al.* (2012) investigated the influence of the use of different kinds of magnesia alba on dust concentrations. 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.

CONCLUSIONS

The consistently high temperatures in the gymnasium were outside the comfortable ranges stipulated by international organisations, which can cause heat stress and heat-related illness to sports practitioners. Thus, the use of engineering controls (e.g., air conditioning) is recommended. Relatively low CO_2 levels and high outdoor air infiltration rates indicate efficient ventilations in both sports facilities. Taking into account that VOC spikes were observed during cleaning activities and that cleaning products are ever more being recognised as risk factors for respiratory health, low-emitting agents and "green" practices should be adopted. Especially due to the use of climbing chalk, exposure to particulate matter in gymnasiums is high. Reduction strategies, such as the use of liquid chalk instead of the common magnesia alba, have to be developed. Despite the fact that a scientifically well defined limit value is not available for magnesia alba, the large number of exposed people requires a practical guiding value for the dust concentrations in indoor gyms.

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REFERENCES

Alves, C.A. and Aciole, S.D.G. (2012). Formaldehyde in Schools: A Review. *Quim. Nova.* 35: 2025–2039.

Annesi-Maesano, I. and Dab, W. (2006). Air Pollution and the Lung: Epidemiological Approach. *Med. Sci. (Paris).* 22: 589–594.

Beaglehole, R. and Yach, D. (2003). Globalisation and the Prevention and Control of Non-Communicable Disease: the Neglected Chronic Diseases of Adults. *Lancet* 362: 903–908.

Binkley, H.M., Beckett, J., Casa, D.J., Kleiner, D.M. and Plummer, P.E. (2002) National Athletic Trainers' Association Position Statement: Exertional Heat Illnesses. *J. Athl. Training* 37: 329–343.

Blondeau, P., Iordache, V., Poupard, O., Genin, D. and Allard, F. (2004). Relationship between Outdoor and Indoor Air Quality in Eight French Schools. *Indoor Air* 15: 2–12

Braniš, M., Šafránek, J. and Hytychová, A. (2009). Exposure of Children to Airborne Particulate Matter of Different Size Fractions during Indoor Physical Education at School. *Build. Environ.* 44: 1246–1252.

Braniš, M. and Šafránek, J. (2011). Characterization of Coarse Particulate Matter in School Gyms. *Environ. Res.* 111: 485–491.

Braniš, M., Safránek, J. and Hytychová, A. (2011). Indoor and Outdoor Sources of Size-Resolved Mass Concentration of Particulate Matter in a School Gym-Implications for Exposure of Exercising Children. *Environ. Sci. Pollut. Res. Int.* 18: 598–609.

Bruno, P., Caselli, M., De Gennaro, G., Iacobellis, S. and Tutino, M. (2008). Monitoring of Volatile Organic Compounds in Non-Residential Indoor Environments. *Indoor Air* 18: 250–256.

Buonanno, G, Fuoco, F.C., Marini, S. and Stabile, L. (2012). Particle Resuspension in School Gyms during Physical Activities. *Aerosol Air Qual. Res.* 12: 803–813

Carlisle, A. and Sharp, N. (2001). Exercise and Outdoor Ambient Air Pollution. *Br. J. Sports Med.* 35: 214–222.

Daisey, J.M., Angell, W.J. and Apte, M.G. (2003). Indoor Air Quality, Ventilation and Symptoms in Schools. *Indoor Air* 13: 53–64

Golden, R. (2011). Identifying an Indoor Air Exposure Limit for Formaldehyde Considering both Irritation and Cancer Hazards. *Crit. Rev. Toxicol.* 41: 672–721.

Griffiths, M. and Eftekhari, M. (2008). Control of CO_2 in a

Naturally Ventilated Classroom. *Energ. Buildings* 40: 556–560.

Grubenhoff, J.A., du Ford, K. and Roosevelt, G.E. (2007). Heat-Related Illness. *Clin. Pediatr. Emerg. Med.* 8: 59–64.

He, C., Morawska, L., Hitchins, J. and Gilbert, D. (2004). Contribution from Indoor Sources to Particle Number and Mass Concentrations in Residential Houses. *Atmos. Environ*. 38:3405–3415.

Lee, S.C., Li, W.M. and Chan, L.Y. (2001). Indoor Air Quality at Restaurants with Different Styles of Cooking in Metropolitan Hong Kong. *Sci. Total Environ*. 279: 181–193.

Majumdar, D. and William, S.P.M. (2009). Chalk Dustfall during Classroom Teaching: Particle Size Distribution and Morphological Characteristics. *Environ. Monit. Assess.* 148: 343–335.

Mattke, S., Haims, M.C., Ayivi-Guedehoussou, N., Gillen, E.M., Hunter, L., Klautzer, L. and Mengistu, T. (2011). *Improving Access to Medicines for Non-Communicable Diseases in the Developing World,* RAND Coorporation, USA.

Molnár, P., Bellander, T., Sällsten, G. and Boman, J. (2007). Indoor and Outdoor Concentrations of $PM_{2.5}$ Trace elements at Homes, Preschools and Schools in Stockholm, Sweden. *J. Environ. Monit*. 9:348–357.

Nugent, R. (2008). Chronic Diseases in Developing Countries Health and Economic Burdens. *Ann. N.Y. Acad. Sci.* 1136: 70–79.

Oeder, S., Dietrich, S., Weichenmeier, I., Schober, W., Pusch, G., Jörres, R.A., Schierl, R., Nowak, D., Fromme, H., Behrendt, H. and Buters, J. (2012). Toxicity and Elemental Composition of Particulate Matter from Outdoor and Indoor Air of Elementary Schools in Munich, Germany. *Indoor Air* 22: 148–158.

OEHHA (Office of Environmental Health Hazard Assessment) (2001). Air Toxics "Hot Spots" Program Risk Assessment Guidelines. Part III. Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Pegas, P.N., Evtyugina, M.G., Alves, C.A., Nunes, T., Cerqueira, M., Franchi, M., Pio, C.A., Almeida, S.M. and Freitas, M.C. (2010). Outdoor/Indoor Air Quality in Primary Schools in Lisbon: A Preliminary Study. *Quim. Nova* 33: 1145–1149.

Pegas, P., Alves, C.A., Evtyugina, M., Nunes, T., Cerqueira, M., Franchi, M., Pio, C., Almeida, S.M., Cabo Verde, S. and Freitas M.C. (2011). Seasonal Evaluation of Outdoor/Indoor Air Quality in Primary Schools in Lisbon. *J. Environ. Monit.* 13: 657–667.

Pegas, P.N., Nunes, T., Alves, C.A., Silva, J.R., Vieira, S.L.A., Caseiro, A. and Pio, C. (2012). Indoor and Outdoor Characterisation of Organic and Inorganic Compounds in City Centre and Suburban Elementary Schools of Aveiro, Portugal. *Atmos. Environ.* 55: 80–89.

Pekey, H. and Arslanbaş, D. (2008). The Relationship between Indoor, Outdoor and Personal VOC Concentrations in Homes, Offices and Schools in the Metropolitan Region of Kocaeli, Turkey. *Water Air Soil Pollut.* 191: 113–129.

Pilidis, G.A., Karakitsios, S.P., Kassomenos, P.A., Kazos, E.A. and Stalikas, C.D. (2009). Measurements of Benzene and Formaldehyde in a Medium Sized Urban Environment. Indoor/Outdoor Health Risk Implications on Special Population Groups. *Environ. Monit. Assess.* 150: 285–294.

Racinais, S., Mohr, M., Buchheit, M., Voss, S.C., Gaoua, N., Grantham, J. and Nybo, L. (2012). Individual Responses to Short-Term Heat Acclimatisation as Predictors of Football Performance in a Hot, Dry Environment. *Br. J. Sports Med.* 46: 810–815.

Salonen, H.J., Pasanen, A.L., Lappalainen, S.K., Riuttala, H.M., Tuomi, T.M., Pasanen, P.O., Bäck, B.C. and Reijula, K.E. (2009). Airborne Concentrations of Volatile Organic Compounds, Formaldehyde and Ammonia in Finnish Office Buildings with Suspected Indoor Air Problems. *J. Occup. Environ. Hyg*. 6: 200–209.

Salthammer, T., Mentese, S. and Marutzky, R. (2010). Formaldehyde in the Indoor Environment. *Chem. Rev.* 110: 2536–2572.

Seaman, V.Y., Bennett, D.H. and Cahill, T.M. (2007). Origin, Occurrence, and Source Emission Rate of Acrolein in Residential Indoor Air. *Environ. Sci. Technol*. 41: 6940–6946.

Smith, A.A., Cowburn, P.J., Parker, M.E., Denvir, M., Puri, S., Patel, K.R. and Cleland, J.G.F. (1999). Impaired Pulmonary Diffusion during Exercise in Patients with Chronic Heart Failure. *Circulation* 100: 1406–1410.

Stranger, M., Potgieter-Vermaak, S.S. and Van Grieken, R. (2008). Characterization of Indoor Air Quality in Primary Schools in Antwerp, Belgium. *Indoor Air* 18: 454–463.

Viegi, G., Simoni, M., Scognamiglio, A., Baldacci, S., Pistelli, F., Carrozzi, L. and Annesi-Maesano, I. (2004). Indoor Air Pollution and Airway Disease. *Int. J. Tuberc. Lung Dis*. 8: 1401–1415.

Weinbruch, S., Dirsch, T., Ebert, M., Hofmann, H. and Kandler, K. (2008). Dust Exposure in Indoor Climbing Halls. *J. Environ. Monit*. 10: 648–654.

Weinbruch, S., Dirsch, T., Kandler, K., Ebert, M., Heimburger, G. and Hohenwarter, F. (2012). Reducing Dust Exposure in Indoor Climbing Gyms. *J. Environ. Monit*. 14: 2114–2120.

WHO (World Health Organisation) (2008). Prevention and Control of Noncommunicable Diseases: Implementation of the Global Strategy, Report by the Secretariat, A61/8. Geneva.

WHO (World Health Organisation) (2010). WHO Guidelines for Indoor Air Quality: Selected Pollutants. World Health Organization, Regional Office for Europe, Copenhagen, Denmark.

Wood, R.A., Burchett, M.D., Alquezar, R., Tarran, J., Orwell, R.L. and Torpy, F. (2006). The Potted-Plant Microcosm Substantially Reduces Indoor Air VOC Pollution: I. Office Field-Study. *Water Air Soil Pollut.* 175: 163–180.

Yach, D., Hawkes, C., Gould, C.L. and Hofman, K.J. (2004). The Global Burden of Chronic Diseases: Overcoming

Impediments to Prevention and Control. *JAMA* 291: 2616–2622.

Zavorsky, G.S. and Lands L.C. (2005). Lung Diffusion Capacity for Nitric Oxide and Carbon Monoxide is Impaired Similarly Following Short-Term Graded Exercise. *Nitric Oxide* 12: 31–38.

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