

Air Quality in Sports Venues with Distinct Characteristics

C. A. Alves, A. I. Calvo, A. Castro, R. Fraile, M. Evtugina, and E. F. Bate-Epey

II. METHODOLOGY

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, CO and CO₂) and total volatile organic compounds (VOCs) were continuously monitored. Concentrations of NO₂, carbonyl compounds and individual VOCs were obtained. Low volume samplers were used to collect particulate matter (PM₁₀). 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. The PM₁₀ concentrations obtained during the occupancy periods ranged between 38 and 43 μg m⁻³ in the fronton and from 154 to 198 μg m⁻³ in the gymnasium.

Keywords—Air exchange rates, carbonyls, gymnasiums, indoor air quality, PM₁₀, VOCs.

I. INTRODUCTION

In spite of the importance of healthy air in indoor spaces, evaluation studies have been focused almost exclusively on schools (e.g. [1]-[8]), homes (e.g. [2], [6], [9]-[10]), and some offices (e.g. [6], [11]-[12]). 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 [13]-[17]. 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.

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A. Characterisation of Sports Facilities

Two sports facilities belonging to the University of León, 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 León 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 36m length x 20m width x 27m 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 15m wide, 27m long and has a height of 10.6m. It has no windows and a half-cylinder skylight (5m diameter and 20.3m 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, pommel 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.

B. 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), CO₂, 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). NO₂ 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 10µm (PM₁₀) was performed. At weekends, a 24-h sampling schedule was adopted. The PM₁₀ samples were collected onto pre-baked (6h at 500°C) 47mm diameter quartz filters using Echo TCR Tecora samplers, following the EN 12341 norm.

C. Analytical Methodologies

VOCs were extracted from the exposed samplers with 2mL carbon disulphide (CS₂ from Aldrich) containing 2-fluorotoluene (from Aldrich) as internal standard. The glass vials were shaken for approximately 30min. 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 2mL acetonitrile (Fisher Scientific). The glass vials were shaken for approximately 30min. The extracts were filtered through 0.45µm 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 [18]. NO₂ was analysed by Gradko (Gradko Laboratories, UK), using a 50% triethanolamine (TEA) in acetone method. Before and after sampling, the gravimetric determination of PM₁₀ filters was performed with a microbalance Mettler Toledo AG245 (readability- 0.1 mg/0.01mg).

D. Ventilation Rates

The ventilation equation (1) has been used to calculate the fresh air ventilation rate [19]. For a well-mixed space the change in CO₂ concentration with time is given by:

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

where C_t is the indoor concentration of CO₂ at time t (ppm), C_{ext} the outdoor concentration of CO₂ (ppm), C_0 the concentration of CO₂ (ppm) in the indoor air at time 0, Q the volume flow rate of air entering the space (m³·s⁻¹), q_{CO_2} the volumetric indoor emission rate of CO₂ (m³·s⁻¹), V the volume of the classroom (m³) and t is the interval since $t = 0$ (s). When the classroom is unoccupied there is no CO₂ emission from the occupants, and $q_{CO_2} = 0$. Thus, (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:

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

III. RESULTS AND DISCUSSION

A. Comfort Parameters and Air Exchange Rates

High relative humidity and thermal amplitudes between nighttime and daytime highs were registered outdoors (Table I). For summer (light clothing), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends maintaining indoor relative humidity between 25 and 60%, and 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 [20]-[22]. 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 (15min – 81ppm, 1h – 28ppm, 8h – 8.1ppm, 24h - 5.7ppm). The primary source of CO₂ in indoor spaces is respiration of the building occupants. In this study, the ASHRAE standard of 1000ppm was never surpassed, which can be considered a benchmark of good ventilation. In the fronton, the air exchange rate (AER) remained unchanged, around 1h⁻¹, from day to day. The AER values for the gymnasium ranged from 0.3 to 0.5h⁻¹. Taking into account the dimensions of both spaces, the supplied flow rates of primary air were estimated to be 4.72 and 1.00-1.67L·s⁻¹ per m² of floor area for the fronton and gymnasium, respectively. These values generally exceeded the minimum ventilation rates recommended by ASHRAE for acceptable IAQ either in sports arenas, stadiums and gymnasiums (1.5L·s⁻¹ per m²), or in health clubs and aerobics rooms (0.3L·s⁻¹ per m²).

TABLE I
CONCENTRATION 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
Max	2300	565	12.6	32.5	49.8
Min	30.0	370	<d.l.	15.9	22.0
FRONTON - OUTDOOR					
Average	n.m.	409	0.02	18.4	52.4
Max	n.m.	503	1.00	30.9	89.8
Min	n.m.	375	<d.l.	5.1	11.3
GYMNASIUM - INDOOR					
Average	53.0	468	0.01	29.0	25.8
Max	2318	787	2.10	36.6	37.3
Min	35.0	397	<d.l.	20.4	10.8
GYMNASIUM - OUTDOOR					
Average	n.m.	418	4.9	228	43.2
Max	n.m.	458	0.50	37.0	90.9
Min	n.m.	379	<d.l.	7.70	7.50

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

B. Air Pollutants

The NO₂ 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 [23] to protect public health.

Either at the gym or in the fronton, TVOCs reached maximum values around 2300ppm coincident with the cleaning activities, decaying to 30-40 ppm 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 II). The high VOC concentrations obtained outdoors during the monitoring period in the fronton may be associated with the 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 levels found. An I/O ratio of 7 obtained for acetone in the gymnasium indicates the presence of 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 [16]. 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=1.60), 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.

TABLE II
CONCENTRATION OF TOTAL 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
Dichloro-methane	5.30±3.11	24.1±4.03	2.24±0.21	4.39±0.50
<i>n</i> -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
<i>n</i> -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
<i>n</i> -Nonane	<d.l.	7.79±0.40	<d.l.	<d.l.
<i>n</i> -Decane	<d.l.	24.4±0.55	0.59±1.18	<d.l.

d.l. – detection limit

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 [24]. 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 [24]. In spring and summer, outdoor formaldehyde levels increase due to acceleration of photochemical activity [25], while the opposite trend is observed indoors, since the interchange rate between indoor and outdoor air is higher due to open windows [26]. 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 [27]. A large review of formaldehyde concentrations worldwide in several types of indoor environment has been summarised by [28]. 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.

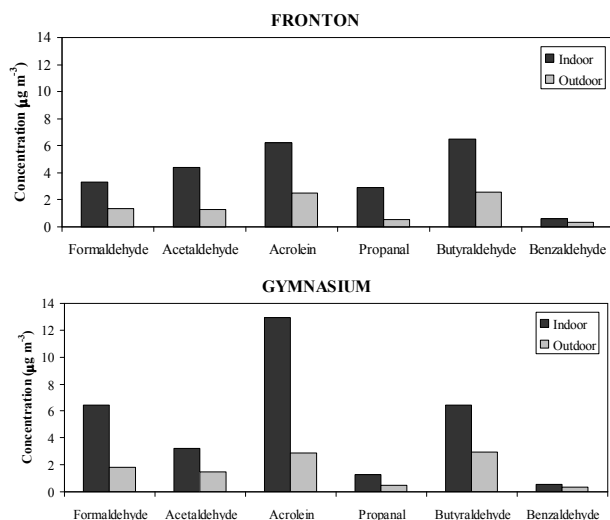


Fig. 1 Average concentrations of carbonyl compounds in both sports facilities

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 [29]. The Office of Environmental Health Hazard Assessment (California Environmental Protection Agency) has adopted an acute non-cancer reference exposure level (REL) of $0.19 \mu\text{g}\cdot\text{m}^{-3}$ and a chronic REL of $0.06 \mu\text{g}\cdot\text{m}^{-3}$ for acrolein [30], 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 $43 \mu\text{g}\cdot\text{m}^{-3}$, decreasing to average values of $13 \mu\text{g}\cdot\text{m}^{-3}$ on weekend (Fig. 2). Much higher levels, from 154 to $198 \mu\text{g}\cdot\text{m}^{-3}$, were registered in the gymnasium. A weekend average value of $17 \mu\text{g}\cdot\text{m}^{-3}$ 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. The main reason for the high particle levels in the gym 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 [31]. 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 [32]. Reference [33] 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.

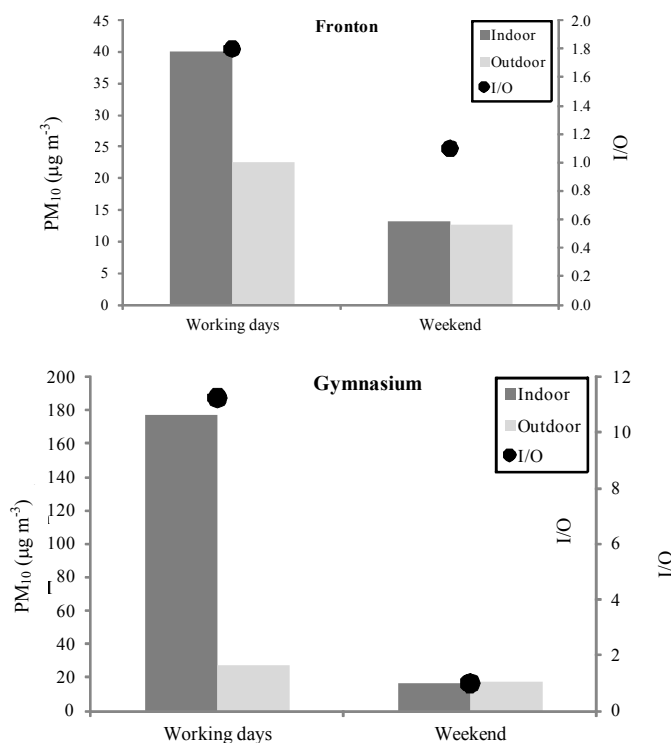


Fig. 2 PM_{10} concentrations and indoor/outdoor ratios in both sports facilities

IV. 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 magnesita alba, have to be developed. Despite the fact that a scientifically well defined limit value is not available for magnesita alba, the large number of exposed people requires a practical guiding value for the dust concentrations in indoor gyms.

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