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Exposure to indoor air pollutants during physical activity in fitness centers

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ABSTRACT

Physical activity has become a social need among people and it has been clearly proved that exercise is a way to prevent all-cause and cardiovascular-related death, diabetes mellitus and obesity. However, athletes and the common individual can be at risk when they are practicing exercise in polluted environments. In 2012, a monitoring program was undertaken in 11 fitness centers from Lisbon where comfort parameters (temperature and humidity) and indoor air pollutants (PM_{10}, $PM_{2.5}$, CO_2, CO, CH_2O and VOC) were measured. Three gyms were selected to perform a deeper analysis consisting of longer measurement periods and more parameters, such as particle chemical composition and nanoparticle lung deposition. Measurements were performed during the occupation time, in the studios and in the bodybuilding room, in order to recognize daily patterns and to identify pollutant sources. The pollutants CO_2, VOC and CH_2O presented high concentrations exceeding the national limit values, while O_3 and CO did not present concerning levels. Pollutant continuous measurements demonstrated increased levels of particles when the spaces were occupied during classes. Results indicated that it is crucial to optimize the HVAC systems, ventilation rates and occupants behavior in order to reduce the exposure to air pollutants in fitness centers and to potentiate the benefits of sport activities.

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1. Introduction

According to the World Health Organization, physical inactivity was identified as the fourth greatest risk factor for mortality, accounting for 3.2 million deaths per year in the world [1]. Physical activity is an important factor for life quality and frequent practice of exercise, like walking or bicycling, presents great benefits for health [2]. A clean environment is also essential for human health and well-being. In Europe, the environmental aspect with most concern on human health is related to indoor and outdoor air pollution [3,4]. Considering these two aspects and in order to potentiate the benefits of physical activity, people who live in urban areas choose less polluted outdoor spots or fitness centers to avoid air pollution. In fact, athletes and the common individual can be at risk when they are practicing exercise in polluted environments due the fact that 1) the increase in the minute ventilation increases proportionally the quantity of inhaled pollutants; 2) most of the air is inhaled through the mouth, bypassing the normal nasal mechanisms for filtration of large particles and 3) the increased airflow velocity carries gaseous pollutants deeper into the respiratory tract [5].

Fitness centers present specific characteristics that can affect the indoor air quality (IAQ). Like in other indoor places, IAQ in gymnasiums is affected by building maintenance, building materials and type of ventilation, but what makes these places peculiar are the higher human occupancy and the type of activity developing inside. Fitness centers join all the conditions that promote the increase of CO_2 concentrations because occupants are the dominant source of indoor CO_2 and its production rate depends primarily on the number of people in the room and on their metabolic level [6]. Occupancy also has influence in the PM_{10} concentrations [7]. Braniš and colleagues [8] observed a direct relation between the indoor concentrations of coarse PM and the number of children present in a scholar gymnasium. Also in school gyms, Buonanno [9] concluded that the high levels of coarse PM concentrations are produced by students' activity.

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Therefore, there is an indubitable higher exposure to air pollutants in gymnasiums not only due to the characteristics of these places but also due to the changes in the respiratory parameters caused by the physical activity. However, despite the importance of healthy air in sport facilities, IAQ studies have been focused principally on schools [10–18], elderly care centers [19–21]; homes [22] and offices [23]. Comparatively, IAQ monitoring programs carried out in sport facilities are very scarce. Aside from the studies of Buonanno [9] and Braniš [8,24] performed in school gyms, only the exposure in ice rings are object of study since the 90's due to the high levels of CO, NO_2 and PM that are emitted by the ice resurface vehicles [25–27] and exposure in swimming-pools due to the high concentrations of trihalomethanes [28]. Some other works were conducted in fitness centers but their focus was energy consumption or thermal comfort [29–31].

This paper aims to conduct a comprehensive characterization of IAQ in fitness centers and to identify the principal sources that compromise IAQ. This evaluation will be useful for epidemiological studies and to develop appropriate control strategies not only to minimize the adverse health effects on exercise practitioners, but also to potentiate the benefits of the physical activity.

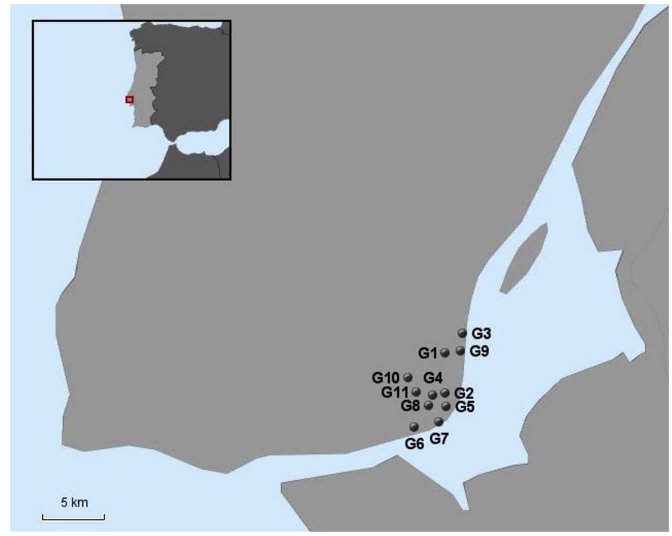

Fig. 1. Localization of the 11 fitness centers (G1-G11) in Lisbon, Portugal.

2. Methodology

2.1. IAQ assessment in 11 fitness centers

A monitoring program was undertaken in 11 fitness centers from Lisbon where comfort parameters (temperature and humidity) and indoor air pollutants (PM, CO_2, CO, CH_2O, VOC and O_3) were measured. Fig. 1 shows the localization of the selected fitness centers and Table 1 presents their specific characteristics.

Three direct reading apparatus were used: a Lighthouse Handled 3016 to measure $PM_{5\text{-}10}$, $PM_{2.5\text{-}5}$, $PM_{1\text{-}2.5}$, $PM_{0.5\text{-}1}$ and $PM_{0.3\text{-}0.5}$, temperature and relative humidity, a WolfSense to assess CO_2, CO, VOC and O_3 and a Formaldemeter htV-M to quantify the levels of CH_2O. All devices were calibrated according to the fabricators specifications.

Measurements were performed during the period of the late afternoon/night, in order to overlap with the more occupied period and with the worst case scenario. In each fitness center, measurements took place in the bodybuilding room (Bb) for 60 min, and in two studios (S1 and S2), during the time of a fitness class (varied between 45 and 60 min). Equipment was positioned at an elevation of 1.20 m from the ground and 1.50 m away from walls in order to avoid the influence on airborne particle dispersion [32,33]. The same air pollutants described previously were measured in the outdoor air. The sampling campaign was performed in October of 2012.

2.2. IAQ assessment in 3 selected fitness centers

After the previous analysis, three fitness centers were selected in order to perform a deeper IAQ assessment. In these sport facilities 1) daily continuous measurements of pollutants were performed in different spaces of the gymnasiums in order to recognize daily patterns and identify pollutant sources; 2) particles were sampled and element concentrations were measured; and 3) nanoparticle deposition in lungs were studied. The adopted methodology resulted in three campaigns of six days assessment, in each fitness center, that occurred from October to December 2012.

The selection of the fitness centers (G9, G10 and G11) was made based on the number of daily users, number of fitness classes during the day and type of ventilation. In G9, two studios and the Bb room were selected and monitored during two days in each space. In G10 and G11 only one studio was monitored (since the equipment's noise was incompatible with the classes practiced inside the other studios) resulting in four days of monitoring in the selected studio and two days in the bodybuilding room.

2.2.1. Continuous measurements of gases

The pollutants CO_2, CO, VOC and O_3 were measured continuously with the equipment WolfSense. Data was registered in the same conditions as in 2.1. In outdoor, parallel measurements of CO_2 and CO were performed with the equipment TSI 7545. Both devices were calibrated according with the fabricator specifications.

2.2.2. Particle sampling and measurement

Within the indoor areas of the selected fitness centers, particles were not only measured continuously with a Lighthouse Handled 3016, but were also sampled for subsequent PM_{10} chemical characterization with the medium volume sampler, MVS6 Leckel (flow rate 3.5 m^3/h). Simultaneously, a Partisol 2000 (flow rate 1 m^3/h) was used for outdoor PM_{10} chemical characterization. Teflon filters with 47 mm were used to collect particles.

When the sampling was conducted in the studios, PM_{10} samplers (MVS6 and Partisol 2000) only worked during the occupied time, whereas in the Bb room, these devices worked continuously from the opening until the closure of the fitness centers.

The direct reading apparatus worked continuously, from the opening until the closure of the gymnasiums, and particle concentrations were registered every 60 s.

A correction factor (β) was applied to the PM indoor concentrations obtained by the Lighthouse Handled 3016. This correction factor was obtained by calculating the ratio between the concentrations obtained by the gravimetric method (considered as the reference method) and the concentrations measured by the Lighthouse 3016 [34,35]. The opening and closing of windows and the number of occupants were registered.

2.2.3. Elemental composition of PM_{10}

The filter loads were determined by gravimetry using a 0.1 μg-sensitivity balance in a clean laboratory (class 10,000) at a temperature of 20 ± 1 °C and a relative humidity of 50 ± 5% [36]. Before being weighted, filters were equilibrated for 24 h in the same room. Filters were weighted before and after sampling and the mass was

Table 1
Main characteristics of the studied gymnasiums.

Gym	Year of construction	Location	Space	Volume (m^3)	Capacity (person)[a]	Floor type	Wall type	Ventilation system
G1	2009	Urban (residential area)	S1	337	20	Linoleum	Brickwork	Mixed
			S2	448	20			
			Bb	65	40			
G2	1997	Urban (street with intense road traffic)	S1	129	20	Floating floor	Brickwork	Mechanical
			S2	266	30			
			Bb	2442	50			
G3	2003	Urban (residential area)	S1	394	25	Floating floor	Brickwork glass	Mechanical
			S2	394	25			
			Bb	990	40			
G4	1982	Urban (street with intense road traffic)	S1	146	15	Wood	Brickwork	Natural
			S2	136	15			
			Bb	87	10			
G5	2012	Urban (street with intense road traffic)	S1	219	30	Floating floor	Brickwork	Mechanical
			S2	82	15			
			Bb	641	20			
G6	2012	Urban (residential area)	S1	395	35	Linoleum	Brickwork glass	Mechanical
			S2	462	35			
			Bb	1509	50			
G7	1923	Urban (residential area)	S1	387	30	Wood/Linoleum	Brickwork	Mixed
			S2	748	40			
			Bb	866	40			
G8	2012	Urban (street with intense road traffic)	S1	148	20	Linoleum	Brickwork glass	Mechanical
			S2	306	30			
			Bb	1062	50			
G9	2010	Urban (street with intense road traffic)	S1	447	35	Floating floor	Brickwork glass	Mechanical
			S2	788	35			
			Bb	1948	60			
G10	2000	Urban (residential area)	S1	1156	40	Floating floor	Brickwork glass	Natural
			S2	1156	40			
			Bb	540	40	Linoleum		
G11	2005	Urban (inside a city park)	S1	745	35	Floating floor	Brickwork glass	Mechanical
			S2	745	35			
			Bb	1843	70			

[a] Maximum capacity. S1 – Studio 1; S2 – Studio 2; Bb – Bodybuilding room.

obtained as the average of three measurements, when observed variations were less than 1%.

The chemical characterization of indoor and outdoor PM_{10} samples was performed by Instrumental Neutron Activation Analysis using the k_0 methodology (k_0-INAA) [37–39].

For k_0-INAA, half of a filter was rolled up and put into a clean thin foil of aluminum and irradiated for 5 h at a thermal neutron flux of 1.03×10^{13} cm^2/s in the Portuguese Research Reactor. After irradiation, the sample was removed from the aluminum foil and transferred to a polyethylene container. For each irradiated sample, two gamma spectra were measured during 7 h with a hyperpure germanium detector: one spectrum 2–3 days after the irradiation and the other after 4 weeks [40,41]. The accuracy of the analytical method was evaluated with the certified reference material NIST-1633a, Coal Fly Ash, revealing results with an agreement of ±12% [42,43]. During the sampling campaign, 6 blank filters were treated the same way as regular samples. All measured species were homogeneously distributed; therefore, concentrations were corrected by subtracting the filter blank contents.

2.2.4. Nanoparticle deposition

Nanoparticles are described as having an increasing surface area with a decreasing particle size for the same amount of mass. Consequently, from the viewpoint of nanoparticle toxicity, the determination of nanoparticle surface area deposited in the human lung is very desirable [44]. Therefore, in this study, a nanoparticle surface area monitor (NSAM) (TSI, Model 3550; Shoreview, MN) was used to measure the lung-deposited surface area of particles which is expressed as square micrometers of lung surface per cubic centimeter of inhaled air ($\mu m^2/cm^3$). This deposition corresponds to the tracheobronchial or alveolar regions of the human lung, according to the International Commission on Radiological Protection deposition model developed by the American Conference of Governmental Industrial Hygienists [45].

This equipment worked continuously in the studios and in the Bb room and was installed at the same conditions as in chapter 2.1 but the data was registered every 10 s.

3. Results and discussion

3.1. Part 1: IAQ in 11 fitness centers

Table 2 presents the concentrations obtained in the monitoring program that was undertaken in 11 fitness centers from Lisbon. The average and the range values are presented together with the outdoor air measurements.

The Portuguese legislation, Portaria n.° 353-A/2013 [46], defines indoor air limit values (LV) for the pollutants PM_{10}, $PM_{2.5}$, CO_2, CO, CH_2O, and VOC, as presented in Table 3. Nevertheless, authors considered it important to include O_3 in this table due to its impact on human health, reactivity with other pollutants, producing submicron particles that contribute to total particulate exposures, and indoor sources [47]. In Fig. 2, the results obtained in this work were compared with the LV based on a color scale where a) green corresponds to levels below 75% of the LV, b) yellow relates to concentrations between 75% of the LV and the limit value and c) red corresponds to values higher than the LV.

In the fitness centers G9 and G10, all spaces were classified as green for PM_{10} concentrations, representing 18% of the studied group. In G1, G3 and G7, PM_{10} concentrations exceeded the LV of 50 $\mu g/m^3$, representing 27% of the evaluated spaces. Except for the fitness centers G4 and G10, PM_{10} levels were higher in the outdoor

Table 2
Pollutant concentrations measured in the 11 fitness centers.

Gym		CO (mg/m^3)	CO_2 (mg/m^3)	PM_{10} (μg/m^3)	$PM_{2.5}$ (μg/m^3)	PM_1 (μg/m^3)	VOC (mg/m^3)	CH_2O (mg/m^3)	O_3 (mg/m^3)	*T* (°C)	RH (%)
G1	S1	1.5 [1.0–1.7]	2624 [2276–2978]	77 [60–105]	19 [12–31]	8.9 [4.8–16]	–	0.2	0.01 [0–0.02]	21 [19–22]	72 [64–82]
	S2	0.6 [0.3–1.3]	1911 [1511–2682]	54 [41–88]	17 [15–23]	12 [10–15]	–	0.17	0.01 [0–0.01]	21 [21–22]	64 [61–70]
	Bb	1.3 [1.0–1.6]	2542 [2148–2992]	61 [47–74]	17 [14–20]	11 [8.4–13]	–	0.23	0.01 [0–0.01]	22 [22–23]	64 [62–67]
	Out	0.4	861	–	–	–	–	0.19	0.02	18	56
G2	S1	0.89 [0.40–1.40]	1181 [988–1373]	31 [24–39]	10 [10–11]	3.5 [3.04–3.8]	0	0.04	0	17 [17–16]	45 [47–44]
	S2	0.087 [0.00–0.30]	1665 [1564–1860]	47 [34–103]	12 [11–14]	4.4 [3.7–4.8]	0	0.08	0	18 [18–18]	51 [50–52]
	Bb	1.7 [1.6–1.8]	1430 [1363–1557]	33 [29–37]	8.9 [9.2–8.8]	2.8 [2.7–2.8]	0.45 [0.04–0.89]	0.04	0	15 [14–16]	55 [51–55]
	Out	–	–	26 [24–28]	11 [11–11]	3.6 [3.5–3.6]	–	–	–		–
G3	S1	0.31 [0.20–0.40]	1789 [987–2299]	101 [45–153]	23 [16–27]	5.2 [4.3–5.9]	1.2 [0.92–1.4]	0.04	0	18 [17–19]	53 [48–57]
	S2	0	1993 [1813–2299]	89 [63–143]	23 [31–19]	5.6 [5.1–6.9]	1.02 [0.99–1.1]	0.04	0	20 [19–20]	53 [53–53]
	Bb	0.78 [0.40–1.2]	1069 [952–1619]	65 [52–76]	20 [18–21]	4.7 [4.6–4.9]	1.15 [0.94–1.44]	0.04	0	16 [16–17]	50 [49–51]
	Out	1.9 [1.8–2.0]	524 [456–597]	49 [42–55]	11 [12–10]	3.4 [3.5–3.2]	0.87 [0.38–1.09]	0.03	0.01 [0.01–0.02]	12 [11–13]	68 [54–76]
G4	S1	2.6 [2.4–2.7]	2431 [2022–2675]	43 [29–67]	8.9 [8.5–9.7]	2.18 [2.1–2.3]	1.9 [1.7–2.3]	0.25	0	15 [14–16]	73 [67–75]
	S2	1.8 [1.7–2.0]	2042 [1122–2986]	35 [26–50]	9.2 [8.1–10]	2.5 [2.2–2.7]	1.5 [1.4–1.7]	0.21	0	18 [16–19]	56 [54–60]
	Bb	2.2 [1.9–2.4]	4418 [3880–5021]	43 [34–52]	11 [9.4–12]	3.7 [4.2–2.7]	1.7 [1.6–1.9]	0.13	0	20 [19–21]	61 [57–65]
	Out	1.2 [1.1–1.5]	896 [859–905]	51 [39–82]	11 [10–12]	3.4 [3.2–3.5]	0.65 [0.61–0.69]	0.06	0.01 [0.01–0.02]	16 [14–17]	45 [41–50]
G5	S1	1.8 [1.5–2.2]	2401 [2077–2640]	49 [47–52]	18 [18–18]	6.8 [6.7–6.9]	2.3 [2.1–2.5]	0.10	0	18 [17–18]	77 [74–81]
	S2	1.8 [1.5–2.1]	4109 [2573–5617]	42 [34–54]	6.6 [7.2–6.1]	16 [15–18]	1.8 [1.3–2.2]	1.4	0.01	19 [18–21]	19 [18–20]
	Bb	2.6 [2.4–2.8]	3139 [2945–3341]	37 [31–44]	11 [10–11]	3.4 [3.3–3.5]	2.2 [1.6–2.5]	1.5	0	17 [16–17]	86 [84–90]
	Out	0.66 [0–2.3]	809 [784–835]	37 [34–44]	18 [16–20]	5.2 [3.8–6.8]	0.93 [0.87–1]	0.05	0.02 [0.01–0.04]	13 [11–15]	60 [53–67]
G6	S1	1.3 [1.2–1.4]	1550 [1363–1720]	17 [9–45]	5.8 [4.9–7.7]	3.5 [3.2–4]	2.03 [1.9–2.1]	0.11	0.02 [0.01–0.03]	17 [18–20]	56 [54–58]
	S2	1.01 [0.60–1.2]	3484 [2336–3932]	44 [21–68]	11 [7.4–13]	4.3 [3.7–4.7]	1.7 [1.5–1.9]	0.08	0	19 [18–20]	76 [69–79]
	Bb	1.2 [1.4–1.1]	1414 [1136–1708]	26 [21–37]	7.3 [7–8.6]	4.5 [4.3–4.8]	2 [1.8–2.2]	0.09	0.01 [0–0.02]	19 [18–20]	56 [54–58]
	Out	1.7 [1–2.1]	942 [832–999]	26 [24–28]	11 [11–11]	3.8 [3.7–4.04]	1.6 [1.5–1.7]	0.08	0.03 [0.01–0.04]	12 [11–12]	52 [47–57]
G7	S1	0	1732 [381–2835]	–	–	–	0.50 [0.06–0.57]	0.01	0.19 [0.07–0.82]	17 [16–17]	51 [61–40]
	S2	0	2751 [2078–3330]	84 [21–105]	11 [4.4–13.7]	3.3 [2.2–3.7]	0.57 [0.34–0.74]	0.01	0	16 [16–16]	68 [59–76]
	Bb	0	1660 [1811–1562]	55 [42–68]	15 [12–17]	5.5 [5.9–4.9]	0.37 [0.33–0.43]	0.01	0.01 [0–0–0.2]	17 [16–18]	53 [51–58]
	Out	0.93 [0.0–2.0]	–	11 [9.4–13]	7 [6.3–7.9]	5.4 [5–5.7]	0.34 [0.31–0.37]	0.01	1.7 [0.18–2.9]	8 [6–10]	44 [38–51]
G8	S1	0.018 [0.0–0.20]	3078 [1173–5964]	50 [19–83]	9.2 [6.3–13]	3 [2.6–4.1]	0	0.01	0	18 [17–19]	80 [64–95]
	S2	0.29 [0.20–0.40]	4234 [3803–4694]	56 [43–67]	10 [9.1–11]	3.2 [2.9–3.4]	0	0.01	0	20 [20–21]	74 [70–79]
	Bb	0	1193 [1045–1381]	29 [23–33]	5.7 [5.1–6.8]	2 [1.6–2.8]	0	0.01	0	17 [16–18]	64 [61–66]
	Out	0	–	7.6 [1.7–21]	3.7 [1.7–9.1]	2.1 [1.03–6.7]	0	0.01	0	10 [10–12]	66 [65–68]
G9	S1	0	1339 [810–1774]	34 [12–49]	7.7 [3.9–14]	4 [2.2–6.5]	2.2 [2–2.5]	0.01	0.01 [0–0.01]	18 [18–19]	73 [71–74]
	S2	0.080 [0.0–0.2]	1266 [860–1735]	17 [4.9–49]	4.1 [1.9–6.9]	2.3 [1.2–3.9]	3.3 [2.9–3.8]	0.02	0.02 [0.01–0.02]	18 [17–19]	71 [67–77]
	Bb	0.10 [0.10–0.10]	2210 [669–3590]	24 [6.8–61]	5.3 [3.2–11]	2.5 [1.5–5.1]	1.9 [1.8–2.2]	0	0.01 [0.01–0.02]	19 [18–20]	70 [66–77]
	Out	0	753 [734–845]	18 [13–23]	4.0 [3.9–4.1]	2.4 [2.4–2.4]	0.65 [0.5–1.2]	0.06	0.06 [0.05–0.09]	22 [22–23]	40 [38–44]
G10	S1	0.28 [0.10–0.50]	1549 [1139–2149]	15 [2.8–25]	12 [10–16]	5.4 [4.7–6.2]	1.8 [1.2–2.3]	0.06	0.02 [0–0.05]	25 [24–25]	43 [41–46]
	S2	0.15 [0.10–0.20]	1277 [984–1482]	3.5 [1.8–8.6]	12 [25–43]	7.3 [1–13]	1.04 [0.95–1.17]	0.06	0.02 [0.01–0.03]	24 [23–25]	44 [40–49]
	Bb	0	1479 [755–2510]	14 [13–18]	14 [13–15.5]	8.1 [7.7–8.8]	1.03 [0.88–1.1]	0.03	0.02 [0.01–0.03]	24 [24–24]	52 [50–54]
	Out	2.3 [1.5–2.9]	899 [748–770]	50 [23–115]	8.8 [6.4–12]	3.8 [3.1–6.7]	2.1 [1.8–2.8]	0.09	0.05 [0.02–0.07]	23 [23–24]	35 [34–36]
G11	S1	0.51 [0.20–0.60]	1116 [673–1652]	79 [57–126]	4 [9–1]	1.5 [3.4–0.7]	1.9 [1.7–2.2]	0.10	0.02 [0.01–0.05]	21 [20–21]	73 [62–85]
	S2	0.53 [0.30–0.80]	1188 [635–1906]	48 [35–71]	1.2 [0.90–2.4]	0.9 [0.74–1.3]	1.8 [1.7–2.02]	0.10	0.02 [0–0.03]	20 [19–21]	76 [74–84]
	Bb	0.68 [0.40–1.10]	1467 [665–2552]	90 [25–71]	7.3 [6.1–8.9]	4.8 [4.1–5.7]	2.5 [2.4–2.5]	0.12	0.01 [0–0.02]	21 [20–21]	67 [66–71]
	Out	1.6 [1.2–2.0]	–	48 [19–108]	15 [12–34]	6.9 [6.4–16]	1.3 [1.2–1.4]	–	0.06 [0.02–0.09]	21 [20–22]	44 [40–47]

Empty spaces were caused by failures in the equipment.

Table 3
Limit values of indoor air pollutants defined by the Portuguese legislation, Portaria n.° 353-A/2013.

Pollutant	Limit value
PM_{10}	50 μg/m^3 ([a])
$PM_{2.5}$	25 μg/m^3 ([a])
CO_2	2250 mg/m^3 ([b])
CO	10 mg/m^3 ([a])
O_3	0.2 mg/m^3 ([a])
CH_2O	0.1 mg/m^3 ([a])
VOC	0.6 mg/m^3 ([a])

[a] Based on the temporal maximum.
[b] Based on the temporal average.

than in the indoor. For $PM_{2.5}$, a large part of the fitness centers (82%) presented concentrations in the green zone.

CO levels were always below the LV defined by the Portuguese legislation. CO is principally associated with infiltrations from the outdoors, garages and combustion processes that are principally related to HVAC systems and water heating [48]. Higher concentrations of this pollutant were measured in the indoors of G1, G4, G5, G8 and G9. The observed differences between fitness centers may be explained by the localization of the air intakes of the ventilation systems and by the proximity of the gyms to high traffic roads which contributes to the contamination of the indoor air.

O_3 levels measured in the fitness centers were very low. A maximum concentration of 0.02 mg/m^3 was measured in G6, G9, G10 and G11. The main O_3 sources in the buildings are the printers [49,50], which are negligible in fitness centers. Outdoors, O_3 occurs as a secondary pollutant, principally as a result from traffic. Therefore, concentrations of this pollutant were always higher outdoor when compared with the indoor environment.

Indoors, the presence of CO_2 is principally associated with occupancy [6]. In 54% of the studied fitness centers, the LV of 2250 mg/m^3 was exceeded in at least one of the spaces. CO_2 average concentration of all spaces was 2000 mg/m^3. G4 presented the highest average concentrations of CO_2 (4418 mg/m^3) while the maximum value was reached in G5 (5617 mg/m^3 in studio 2). It is not easy to properly characterize the CO_2 present indoors, since its concentration is a function of the occupation of the site, ventilation rates and metabolic activity of the occupants, with these parameters fluctuating with time [51]. CO_2 levels suggested inefficient ventilation of the studied fitness centers.

Since VOC are emitted by consumer products or structures that exist mainly in the indoor environments, such as carpeting, furniture cleaners, paints, perfumes, lacquers and solvents, the concentrations of VOC are usually found to be higher indoors than outdoors [52]. In our study, exceedances of VOC were registered in 82% of the fitness centers and in 64% of the gymnasiums all the spaces presented concentrations higher than the LV. The highest VOC average concentration was registered in G9 with 3.3 mg/m^3. CH_2O is a VOC, but given its importance due to the related health effects, it is usually assessed in an individualized form [53]. However, its indoor sources are also similar to the sources of VOC. In the

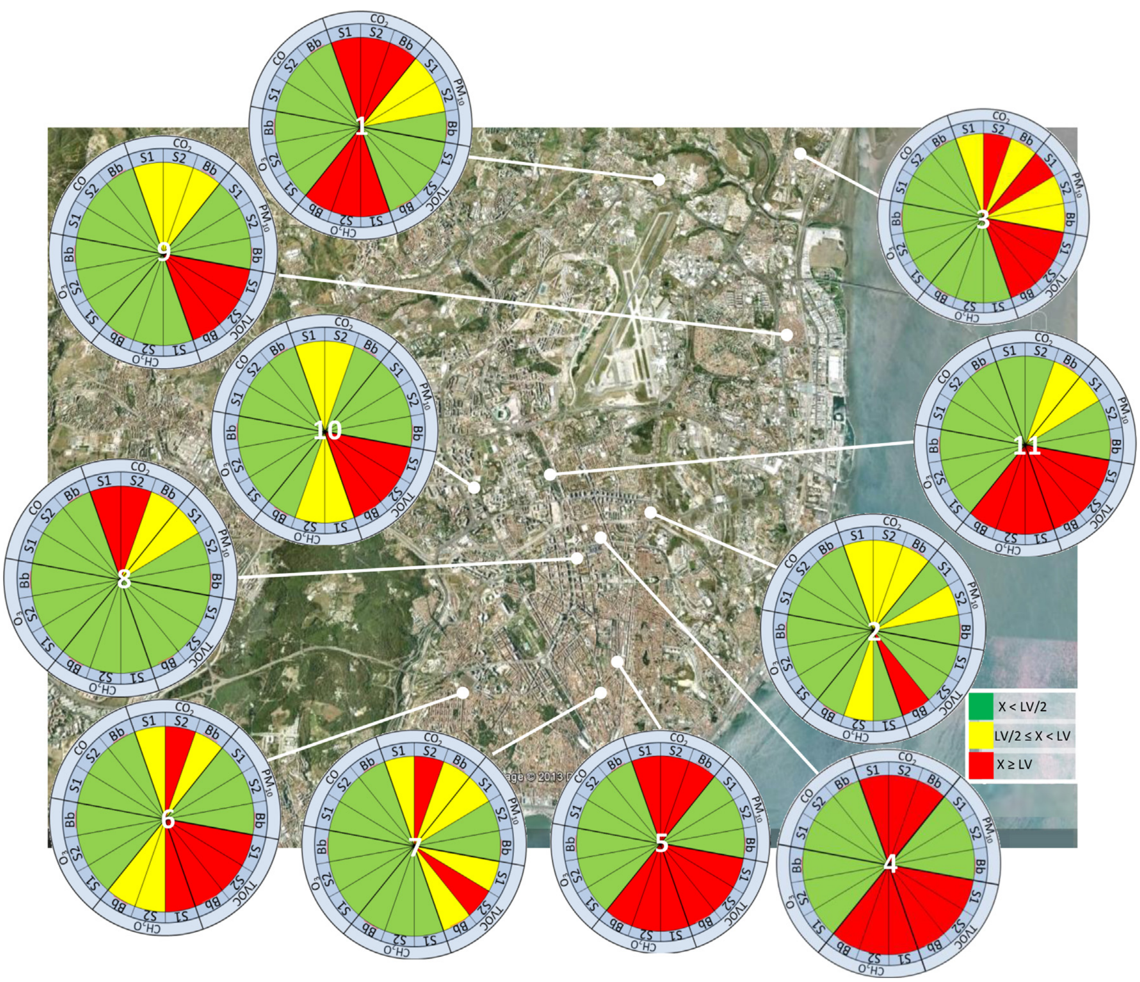

Fig. 2. Classification of the fitness centers according to the Portuguese legislation for IAQ (Portaria n.° 353-A/2013). S1 and S2 – studios; Bb – bodybuilding room.

majority of the cases, the indoor concentrations were higher than outdoors, except the cases of G7, G8, G9 and G10. The highest CH_2O concentrations were found in G4 studios (0.25 mg/m^3 in S1 and 0.21 mg/m^3 in S2) together with high concentrations of VOC that may be originated by the presence of alcohol base hand disinfectant distributed throughout this gymnasium.

Some fitness centers presented high values of some pollutants related to their design and construction. Table 2 shows that G5 presented high levels for CO (2.6 mg/m^3 in Bb) and furthermore elevated values for CH_2O (1.4 mg/m^3 in S2 and 1.5 mg/m^3 in Bb) and VOC (2.3 mg/m^3 in S1 and 2.2 mg/m^3 in Bb). The highest VOC and CH_2O concentrations registered in this recently open (2012) fitness center are probably associated with emissions from the new furniture, material and equipment: VOC concentrations analyzed in new apartments demonstrate a decreasing tendency in indoor VOC concentrations over the 24 month follow-up period [54]. Moreover, G5 is located on the ground floor level of a major building, so its elevated CO levels may have resulted from the inappropriate location of the air admissions of the HVAC system, which are placed near the road and close to the pavement.

3.2. Ventilation rates

Ventilation rates were calculated using the build-up method developed by Hanninen [55] which is based on the use of CO_2 as a tracer gas. CO_2 represents an advantage comparing with other tracers since it is emitted by occupants and it is inert. This method is based on the curve fit of CO_2 concentrations and requires inputs of: the indoor and outdoor CO_2 concentrations, the number of occupants and the volume of the space [56].

Air exchange rates and ventilation rates were calculated for all the fitness centers. However, these parameters were only estimated for studios because the Bb rooms did not present the required constant number of occupants necessary to run the build-up method.

Table 4 presents the air exchange rates (AER) and the ventilation rates (VR) and shows that AER varied between 1.4 h^{-1} and 4.4 h^{-1} and VR ranged between 8.9 and 51.5 lps/person. Since the Portuguese legislation [46] defines VR between 176 and 353 lps/person for fitness centers, the results indicated that no fitness center meet the Portuguese legislation criteria. According to the main national standards in Europe (but despite the lack of unanimity), the AER of 0.5 h^{-1} is defined as a threshold below which associations with poor IAQ may occur [57]. In this study, all fitness centers presented a higher AER.

3.3. Part 2: IAQ assessment in three fitness centers

Three fitness centers (G9, G10 and G11) were selected in order to perform a deeper IAQ assessment considering longer measurement periods and more parameters.

Table 4
Air exchange rates (h^{-1}) and ventilation rates (lps) in the 11 fitness centers.

Gym	Air exchange rate (h^{-1})	Ventilation rate (lps)
G1	1.6	8.9
G2	2.1	11.4
G3	3.1	43.1
G4	1.4	10.2
G5	2.3	14.0
G6	3.5	15.3
G7	–	–
G8	–	–
G9	4.4	29.3
G10	1.6	46.7
G11	2.3	51.5

3.3.1. Continuous measurements of gases

Fig. 3 presents the CO_2 concentrations measured in the three fitness centers. A similar trend was observed in all gyms which was characterized by an increase of CO_2 levels in the studios during the occupied period. However, results showed that CO_2 concentrations were influenced not only by the number of people inside the room but also by their metabolic activity during the fitness classes. Fig. 4 shows the CO_2 growth curve for the same room but in two different fitness classes: Yoga (mind class) and Body Attack (cardio class). Besides the greater number of occupants in the Yoga class (24 people in Yoga versus 20 people in Body Attack), CO_2 concentrations were significantly lower than in Body Attack class. The average CO_2 concentration was 959 mg/m^3 for Yoga and 1774 mg/m^3 for Body Attack. Additionally, the slope of the CO_2 build-up phase in the Body Attack class was higher reflecting a quick growth in the production of this pollutant. In Yoga class, this increase was not observed.

Inside the bodybuilding rooms, CO_2 concentrations also reflected the degree of occupancy. In G11, the highest CO_2 levels were associated with the cycling classes which occurred inside the bodybuilding room behind a folding screen.

Despite not causing toxicity to humans at the registered concentrations [58], CO_2 is a good indicator of IAQ and can influence the human perception of the spaces. Moreover, the performance of people is affected by the concentrations of this gas. Previous studies showed that changes in CO_2 concentrations were associated with statistically significant and meaningful reductions in decision-making performance [59].

Fig. 5 shows that CO concentrations in the three fitness centers were below the LV (10 mg/m^3) defined by the Portuguese legislation [46]. In G9, CO concentration increased in the late afternoon/night which is the period with more entrances and exits in the gymnasium. The air intake for this fitness center is located near the garage, and this fact can explain the highest contamination of indoor air by the traffic during this period. In G10, CO concentrations were higher during the morning due to the presence of trucks, which unload material for an annex building. In G11, the rises in CO levels were also traffic-related and enhanced by the surroundings, since the gymnasium building was walled by other buildings with a height greater than eight floors causing a canyon effect which lead to a lack of pollutant dispersion [60]. At the registered concentrations, CO does not present harmful health effects to humans, although this pollutant can connect with hemoglobin, replacing the O_2 which in turns reaches the tissues in smaller concentrations [61].

In fitness center G9, the VOC concentrations exceeded the limit value of 0.6 mg/m^3 most of the time (Fig. 6). Fig. 7 shows that cleaning procedures highly contributed for the increase of VOC concentrations.

3.3.2. Levels of particulate matter

Fig. 8 presents the temporal distribution of PM, measured in five ranges ($PM_{0.3\text{-}0.5}$, $PM_{0.5\text{-}1}$, $PM_{1\text{-}2.5}$, $PM_{2.5\text{-}5}$ and $PM_{5\text{-}10}$) in the selected fitness centers. In G9 and G10, the PM_{10} and $PM_{2.5}$ Portuguese LV of 50 μg/m^3 and 25 μg/m^3, respectively, were exceeded.

The maximum concentrations in G9 for PM_{10} and $PM_{2.5}$ were measured in studio 1 (109 μg/m^3 and 30 μg/m^3, respectively). In G10, the maximum PM_{10} concentrations were 157 μg/m^3 in the studio and 190 μg/m^3 in the bodybuilding room. The maximal $PM_{2.5}$ value measured in this fitness center was 37.4 μg/m^3 in studio 1.

Results showed that, in the studios, the highest PM concentrations were coincident with the period of fitness classes, revealing a relation between PM concentration and the resuspension of dust caused by the practitioners of physical activity. In scholar gyms,

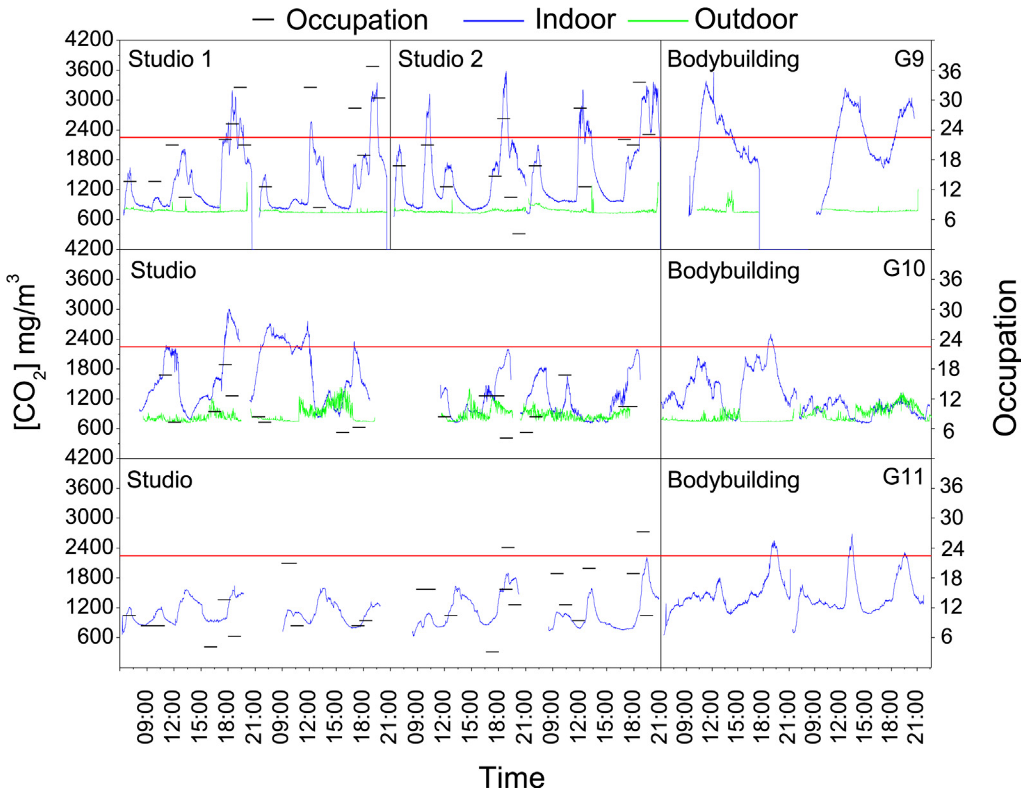

Fig. 3. Temporal variation of CO_2 concentration in the 3 fitness centers (values in mg/m^3) and human occupation inside the sites. The horizontal line corresponds to the CO_2 LV defined by the Portuguese legislation.

previous studies showed that dust resuspension influenced by students' activity is the major source of coarse particles [8,9].

The highest concentrations measured in the studios of G10 occurred principally during the cleaning operations performed during the afternoon (approximately at 14:00). Cleaning operations have already been identified as one important source for indoor particle resuspension. Corsi [62] showed that the resuspension caused by vacuum cleaning can increase PM_{10} concentrations more than 17 μg/m^3 above the average concentration. Concentrations in the G10 studio increased 8 times in the first day of sampling and 6.5 times in the third day of sampling when compared with the average PM_{10} concentrations in the space.

G10 is the only fitness center that opens the windows to ventilate the spaces and this fact was reflected in its highest levels of coarse particles. This gym is placed inside a city park where natural sources of particles, such as soil and pollens, are dominant and contribute principally for the coarse fraction. Canha presented the same conclusion between coarse fraction, natural ventilation and grove vicinity [63].

Fig. 9 presents the comparison between the indoor and outdoor PM_{10} total mass concentrations measured by gravimetry. While G9 and G11 presented significantly higher outdoor PM_{10} concentrations, in G10 the ratio between indoor and outdoor concentrations was closed to 1 or even higher than 1. These results can be explained by the fact that in G9 and G11 the coarser outdoor particles are retained in the filters, presented in the Air Treatment Units from both buildings, whereas in G10 outdoor air enters in the spaces by the windows without any filtration.

Table 5 shows the indoor and outdoor concentrations for the chemical elements As, Co, Cr, Fe, K, La, Na, Sb, Sc and Zn measured in the PM_{10} filters. The outdoor concentrations of these elements were significantly higher than the indoor, except for G10 where significant differences were not observed. This gym has natural ventilation and, consequently, higher contributions of the outdoor elements generated by traffic (As, Sb, Zn), soil (Co, Fe, La and Sc) and sea (Na) were registered [64–67]. Results showed that, besides the higher outdoor As, Co, Cr, Fe, K and Zn concentrations in G9 and G11, the air filtration by their Air Treatment Units allowed

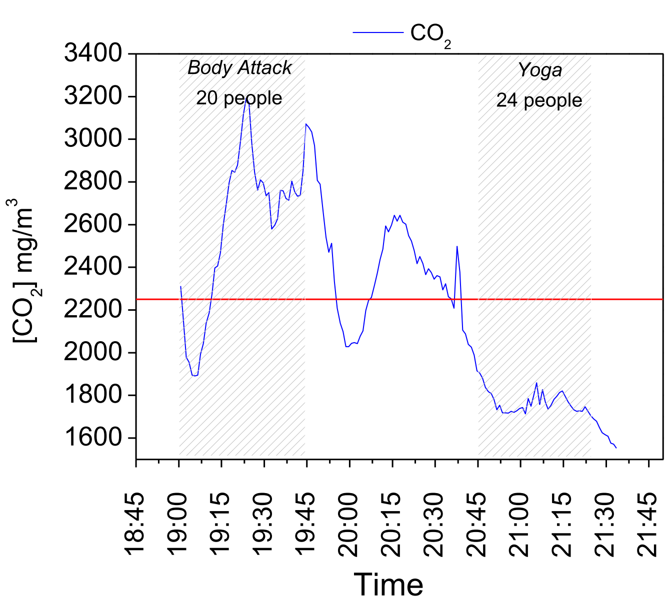

Fig. 4. Growth curve of CO_2 in fitness classes associated with different metabolic rates (values in mg/m^3). Shading represents the duration of the classes and the horizontal line corresponds to the CO_2 LV defined by the Portuguese legislation.

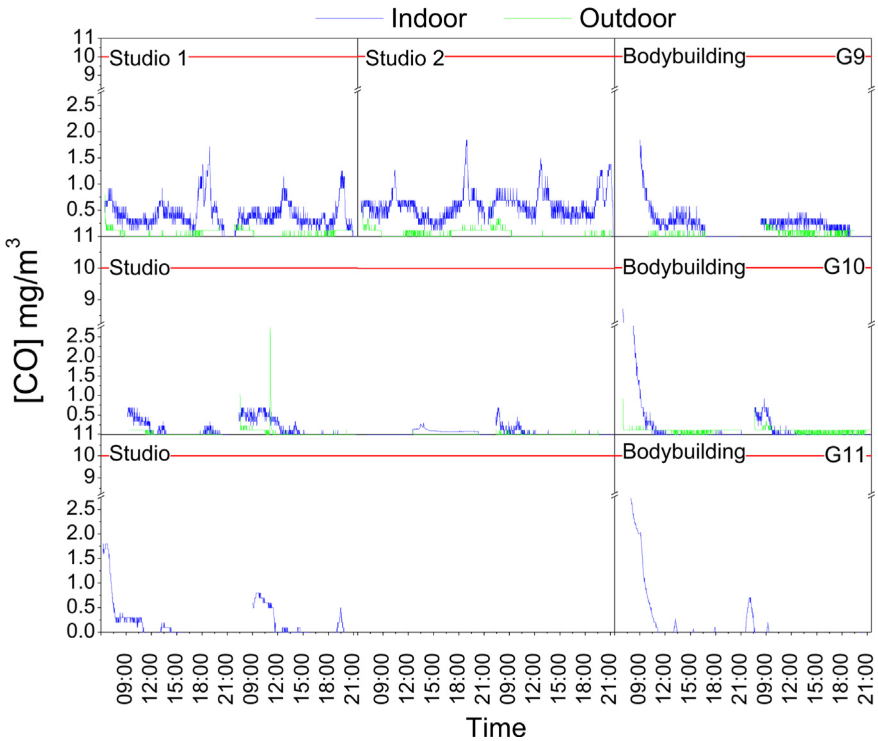

Fig. 5. Temporal variation of CO concentration in the 3 fitness centers (values in mg/m^3). The horizontal line corresponds to the CO LV defined by the Portuguese legislation.

the retention of particles and, therefore, the capture of these elements.

The crustal enrichment factor method has been used as an attempt to evaluate the strength of the crustal and non-crustal origin of the elements. Enrichment factors, using Fe as a crustal reference element (EF_{Fe}), were calculated based on equation (1) and using soil composition [68]:

$$EF_{Fe} = \frac{\left(\frac{[x]}{[Fe]}\right)_{PM}}{\left(\frac{[x]}{[Fe]}\right)_{soil}} \quad (1)$$

Elements with EF_{Fe} values that approach unity can be considered predominantly from soil, whereas if the evaluated element has

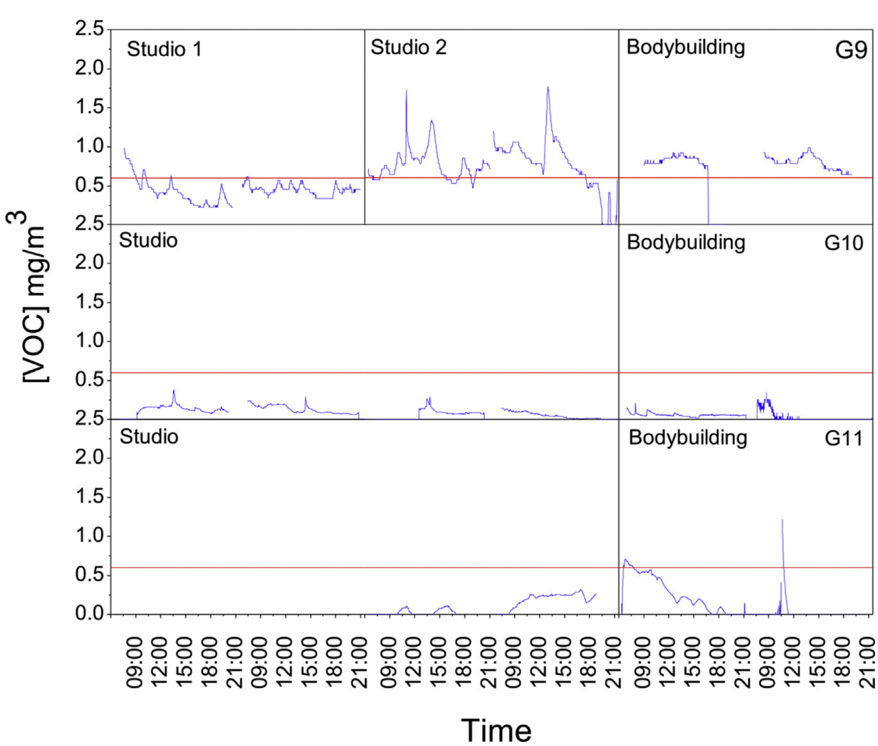

Fig. 6. Temporal variation of VOC concentration in the 3 fitness centers (values in mg/m^3). The horizontal line corresponds to the VOC LV defined by the Portuguese legislation.

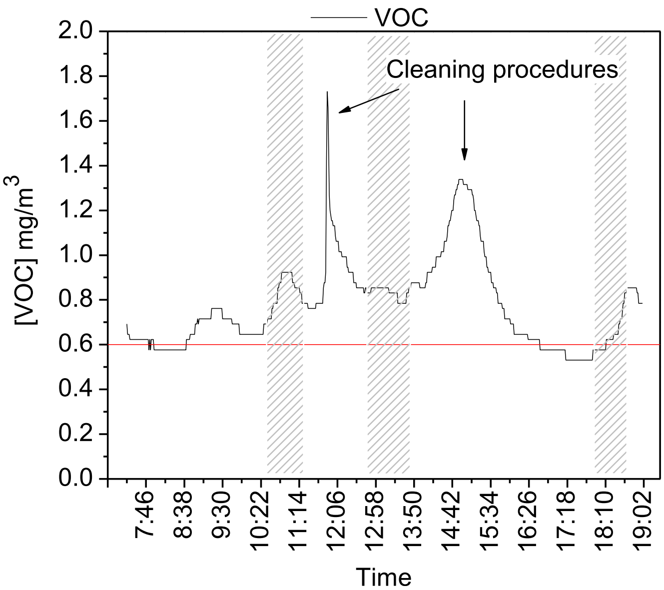

Fig. 7. Temporal variation of VOC concentration for a selected period in G9 (values in mg/m^3). Shading represents the duration of the classes and the horizontal line corresponds to the VOC LV defined by the Portuguese legislation.

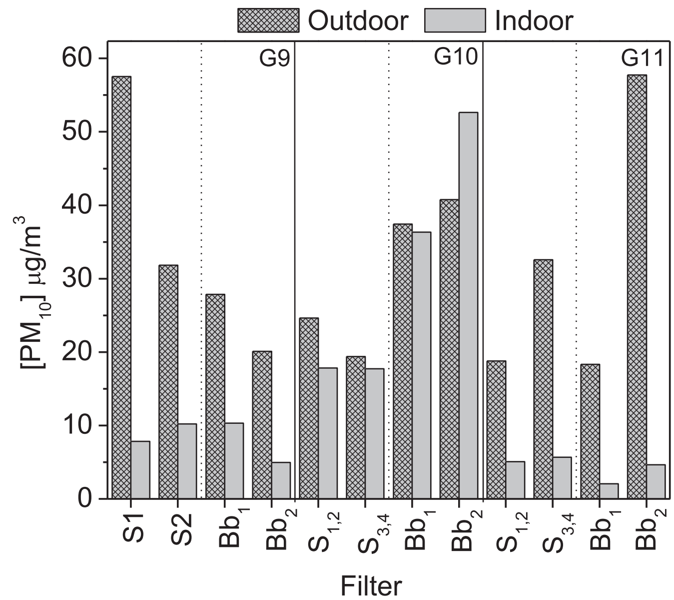

Fig. 9. PM_{10} concentrations measured indoor and outdoor of the fitness centers (values in µg/m^3). (S1 – Studio 1; S2 – Studio 2; $S_{1,2}$ – First and second day of sampling; $S_{3,4}$ – third and fourth day of sampling; Bb_1 – First day of sampling in the bodybuilding; Bb_2 – Second day of sampling in the bodybuilding).

EF values higher than 10, its provenance is asserted mainly to local, regional and/or long transportation phenomena from other natural and/or anthropogenic sources [69]. The EF_{Fe}, presented in Fig. 10, indicate that, both in indoor and outdoor, the elements Sc, La, Co, K, Fe and Cr were associated with soil emissions ($EF_{Fe} < 10$) while As, Sb and Zn were related to anthropogenic emissions ($EF_{Fe} > 10$).

3.3.3. Nanoparticle lung deposition

The estimated total deposited alveolar area and the total deposited surface area were calculated for a lung surface area of 80 m^2, which is the defined area for an adult. Table 6 shows that the minimum value for the deposited alveolar area was reached in G11

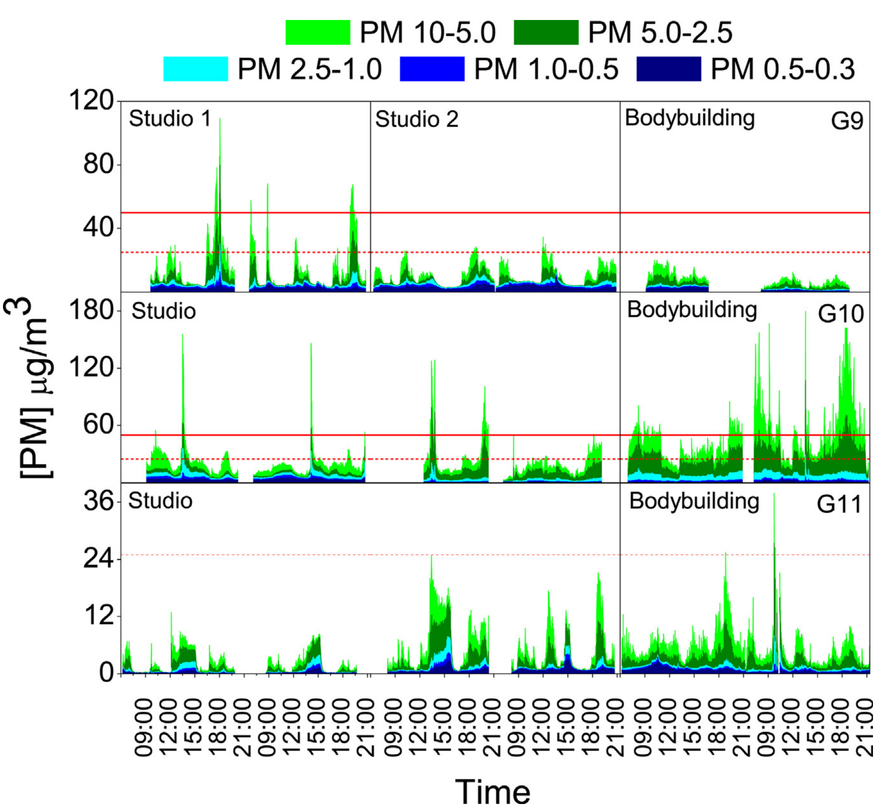

Fig. 8. Temporal variation of PM concentration in the 3 fitness centers (values in µg/m^3). The horizontal lines correspond to the PM_{10} LV defined by the Portuguese legislation (150 µg/m^3) and to the WHO guidelines to PM_{10} (100 µg/m^3) and $PM_{2.5}$ (50 µg/m^3).

Table 5
Indoor and outdoor average element concentrations in the fitness centers G9, G10 and G11 (values in ng/m^3).

	G9		G10		G11		Total	
	I	O	I	O	I	O	I	O
As	0.068 ± 0.032	0.59 ± 0.59	0.25 ± 0.032	0.29 ± 0.041	0.055 ± 0.055	0.41 ± 0.31	0.10 ± 0.088	0.48 ± 0.42
Co	0.06 ± 0.01	0.30 ± 0.22	0.11 ± 0.029	0.14 ± 0.045	0.057 ± 0.049	0.14 ± 0.040	0.076 ± 0.037	0.21 ± 0.16
Cr	1.40 ± 0.86	5.4 ± 3.9	2.47 ± 0.56	3.0 ± 2.1	0.57 ± 0.43	5.5 ± 2.5	1.60 ± 0.98	4.8 ± 2.8
Fe	161 ± 117	1250 ± 1593	375 ± 162	530 ± 350	56 ± 53	771 ± 570	215 ± 190	850 ± 954
K	55 ± 34	480 ± 290	190 ± 22	150 ± 38	51 ± 19	242 ± 257	103 ± 73	291 ± 250
La	0.071 ± 0.0077	0.16 ± 0.14	0.10 ± 0.045	0.16 ± 0.063	0.011 ± 0.010	0.12 ± 0.09	0.064 ± 0.050	0.10 ± 0.09
Na	202 ± 94	640 ± 375	1350 ± 930	1650 ± 760	74 ± 70	691 ± 167	542 ± 770	1020 ± 682
Sb	0.62 ± 0.47	2.61 ± 2.33	0.74 ± 0.16	2.9 ± 1.4	0.19 ± 0.12	2.2 ± 1.7	0.46 ± 0.36	2.5 ± 1.8
Sc	0.0087 ± 0.071	0.014 ± 0.013	0.015 ± 0.0072	0.023 ± 0.0085	<dl	0.0073 ± 0.0099	0.01 ± 0.008	0.02 ± 0.01
Zn	9.7 ± 2.7	74 ± 54	19 ± 11	27 ± 19	5.8 ± 4.7	29 ± 20	12.0 ± 9.0	46 ± 42

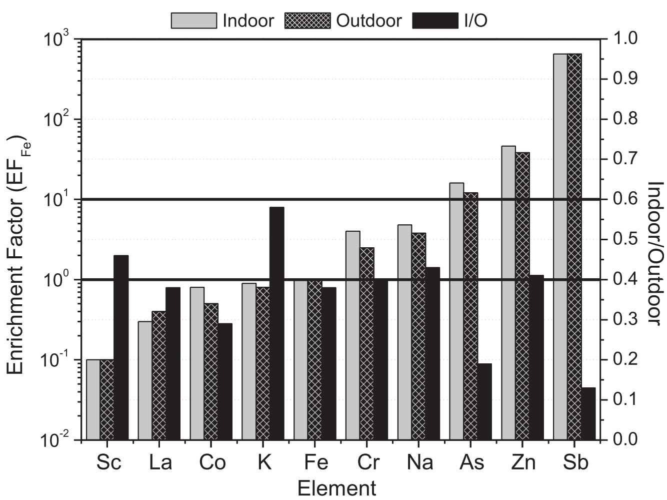

Fig. 10. Enrichment factor using Fe as a reference element and Mason and Moore (1982) soil composition and ratio indoor/outdoor.

with 13 μm^2/cm^3 and the maximum was registered in G10 with 39 μm^2/cm^3. As these measurements were performed for the first time in fitness centers, levels were compared with studies performed in other indoor environments. In schools, Buonanno [70] registered higher alveolar area levels deposits which ranged between 35 μm^2/cm^3 and 150 μm^2/cm^3. In elderly care centers, Almeida-Silva [44] found values between 10 μm^2/cm^3 and 46 μm^2/cm^3 and in houses, Gomes [71] recorded an average value of 29 ± 1.0 μm^2/cm^3 and Ntziachristos [72] registered an average value of 45 ± 26 μm^2/cm^3.

4. Conclusions

This paper conducted a comprehensive characterization of a vast array of indoor pollutants in 11 fitness centers and identified sources that compromise IAQ.

The high CO_2 levels registered within this study and the calculated ventilation rates indicated that, in general, the fitness centers have inefficient ventilation, considering the type of activity that is preconized indoors. This fact influences the human perception of the space and gives the feeling of discomfort during the practice of sports. Taking into account that VOC spikes were observed during cleaning activities and that cleaning products are recognized as risk factors for respiratory health, low emitting agents and “green” practices should be adopted. The levels of particles were highly influenced by the intense indoor activities and by the type of ventilation. Results showed that the location of the air intakes and the efficiency of the air filtration are essential for the maintenance of a good IAQ.

Taking into account the unique characteristics of the fitness centers - intense indoor activities, large number of people who are more susceptible to air pollutants during exercise, insufficient ventilation and relatively small room sizes – there is a need to better assess the exposure and inhaled doses by gyms practitioners in order to minimize adverse health effects and to potentiate the benefits of the physical activity.

Table 6
Average deposited area and total deposited surface area in the fitness centers G9, G10 and G11.

Fitness center	Average deposited area (μm^2/cm^3)	Total deposited surface area (μm^2)
G9	28.61 ± 25.40	1.93 × 10^7
G10	39.17 ± 15.95	2.37 × 10^7
G11	13.47 ± 6.12	7.99 × 10^8

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