Accepted Manuscript

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PII: S0304-3894(18)30526-0
DOI: https://doi.org/10.1016/j.jhazmat.2018.07.015
Reference: HAZMAT 19523

To appear in: *Journal of Hazardous Materials*

Received date: 9-2-2018
Revised date: 2-7-2018
Accepted date: 3-7-2018

Please cite this article as: Slezakova K, Peixoto C, do Carmo Pereira M, Morais S, Indoor air quality in health clubs: Impact of occupancy and type of performed activities on exposure levels, *Journal of Hazardous Materials* (2018), https://doi.org/10.1016/j.jhazmat.2018.07.015

Indoor air quality in health clubs: Impact of occupancy and type of performed activities on exposure levels

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Highlights

- Indoor air quality of four health clubs (HC) was assessed.
- In all HC TVOCs exceeded legislative limits even when empty, thus indicative of risks.
- PM_1 and PM_4 levels were twice higher in HC with natural ventilations.
- CO_2 and relative humidity were well correlated with indoor occupancy.
- Cardio activities caused ~2 higher inhalation doses, being 20% higher for females.

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Abstract

Associations between indoor air quality (IAQ) and health in sport practise environments are not well understood due to limited knowledge of magnitude of inhaled pollutants. Thus, this study assessed IAQ in four health clubs (HC1–HC4) and estimated inhaled doses during different types of activities. Gaseous (TVOCs, CO, O_3, CO_2) and particulate pollutants (PM_1, PM_4) were continuously collected during 40 days. IAQ was influenced both by human occupancy and the intensity of the performed exercises. Levels of all pollutants were higher when clubs were occupied ($p<0.05$) than for vacant periods, with higher medians in main workout areas rather than in spaces/studios for group activities. In all spaces, TVOCs highly exceeded legislative limit (600 μg/m^3), even when unoccupied, indicating possible risks for the respective occupants. CO_2 levels were well correlated with relative humidity (r_s 0.534 – 0.625) and occupancy due to human exhalation and perspiration during exercising. Clubs with natural ventilations exhibited twice higher PM, with PM_1 accounting for 93–96% of PM_4; both PM were highly correlated (r_s 0.936–0.995) and originated from the same sources. Finally, cardio classes resulted in higher inhalation doses than other types of exercising (1.7–2.6).

Keywords: Indoor air quality (IAQ); total volatile organic compounds (TVOCs); ozone (O_3); particulate matter (PM); inhalation dose.

Introduction

Environmental pollution is a major cause of disease, disability, and premature death worldwide. Annually, 9 million of deaths (i.e. 16% of all deaths worldwide) are caused by environmental pollution alone [1], which is approximately three times more that combined mortalities from severe diseases such as tuberculosis, AIDS and malaria [2]. Out of these, 6.5 million of deaths are annually caused by air pollution alone [2]. Apart from respiratory and cardiovascular diseases, air pollution has been associated with various adverse health effects (cancers of different organs, impaired neuro- and cognition development, diabetes – type 2) [3]. Air pollution might be also a risk factor for obesity [3, 4], which is relevant for nowadays sedentary society [5, 6]; in western European countries more than half of current adult population (≥ 20 years) is overweight or even obese [7]. Due to the high exposure risks even at low concentrations of pollutants [8], air pollution effects are especially relevant in indoor environments, where people spend 90% of their daily time. The prolonged duration and lesser degree of dilution and/or pollutant dispersion indoors may eventually lead to indoor exposures of several magnitudes larger than those from ambient air [9-11]. Furthermore, humans and their activities are significant factor indoors [12]. Several studies have reported or even quantified human contribution to indoor concentration of various pollutants [9, 12]. Thus, it is particularly relevant to assess levels of indoor air quality (IAQ) in places, such as fitness centres or gyms, where a significant part of pollution is assumingly caused by the occupants [9, 13], yet simultaneously, increased ventilation rates (due to physical exertion) expose body to much great amount of pollution; inadequate IAQ in these places can easily counteract the well-being benefits of physical exercise [14, 15].

During last years many studies have produced information regarding IAQ, with specific attention to indoor microenvironments (pre- and primary/elementary schools, homes, offices, hospitals and *etc.* [16–28]), as well as some specific occupational settings [29–31]. However, indoor sport environments have been studied considerably less. The main scientific focus was on particulate matter (namely PM_{10}, $PM_{2.5}$, PM_1), with data coming either from educational settings (elementary/primary schools gymnasiums, university sport facilities; [9, 12–13, 32–40]) or from sport facilities (gymnastic and sport halls; [41– 45]); health or fitness clubs have been addressed considerably less [15, 46-49]. World Health Organization (WHO) recommends 150 (at least) – 300 min (for additional benefits) of moderate-intensity physical activity per week [50], which translates approximately to 1 h/day on 5 days/week. Time and frequency spent in these places indicate the need of further assessment of IAQ and its impacts on human health in order to develop strategies to control and reduce the respective risks.

This study evaluated IAQ in indoor fitness clubs and estimated potential inhalation doses. Concentrations of gaseous (total volatile organic compounds – TVOCs, ozone – O_3, and carbon dioxide – CO_2) and particulate (PM_4 and PM_1) pollutants, and comfort parameters in indoor air of four health clubs were evaluated. Secondly, inhalation doses for the respective occupants (exercising subjects and fitness instructors) were assessed considering three different age categories of males and females, under various types of physical activity (individual training and group classes).

Materials and methods

Sampling

Indoor air quality sampling was done in four health clubs (HC1– HC4) in spring 2014 (May–June) during 40 consecutive days (weekdays, weekends). All clubs were situated in urban zones of Oporto Metropolitan Area; road traffic and local industry were the main emission sources of the respective sites [51, 52]. HC1–HC2 were smaller and simpler local gyms. HC3–HC4 were large, sophisticated health clubs (internationally recognized) that accommodated ~400 up 1000 clients/day. Detailed descriptions of all clubs and their facilities are summarized in Table 1S of the Supplementary material.

Samplers were mounted on supports (~1.4±0.2 m), and at least 1.5 m from walls to minimize the influence on pollutant dispersion [53, 54]; location of samplers was chosen in order to avoid any direct influence (opened windows/doors, mechanical ventilation systems, cleaning product emissions, and *etc.)*. Gaseous pollutants (TVOCs, CO, O_3, and CO_2) were sampled by a multi-gas sensor probe (model TG 502; GrayWolf Sensing Solutions, Shelton, USA; accuracy ±2% reading for CO and TVOCs; ±3% reading for CO_2 and O_3). PM_4 and PM_1 were monitored by TSI DustTrak DRX photometer (model 8533; TSI Inc., MN, USA; flow rate of 3.0 L/min). Temperature (T) and relative humidity (RH) were recorded by Testo mini data-logger (model 174H; Testo AG, Lenzkirch, Germany) (Figure 2S). All equipment was calibrated (at the manufacturers) prior to the sampling campaign. Additionally, readings of multi-gas sensor probe were weekly checked using calibration standards (difference <5%) and adjusted according to the manufacturer´s instructions. In order to minimize the occurrences of sudden artefact jumps in PM concentrations [55], photometer was daily zeroed (using external zeroing module).

Air quality sampling was done continuously (with 1 min logging interval); each day approximately 1400 values were recorded. In each club, sampling was consecutively conducted in various places (Figure 1): (i) main workout areas (MWA; a joint space with free weights, bodybuilding machines and cardiovascular training-related equipment), (ii) rooms/studios for group classes (SGA); technical areas (receptions, storage rooms, locker rooms, or spa centers for HC3 and HC4; Table 1S) were not considered.

All pertinent information in regards to indoors and outdoors of the clubs (cleaning schedules, club occupancy, ventilations, ambient emission sources and etc.) was collected by a team member who was continuously present on site; staff of each club provided further information regarding any untypical occurrence/situations. Information regarding ambient air quality during the respective period is summarized in Table 2S.

Inhalation dose calculations

Inhalation doses calculation was determined according to the previous methodology [37, 56, 57], but for readers convenience details are summarized in SM (Text 1S). Considered scenarios included: (i) workout training (60 min; in MW), and classes (50 min; SGA) either “mind or body” or with “dynamic cardiovascular exercising”. Gender/weight specific parameters were adapted from USEPA [58] considering four age categories and also occupational exposure (instructors; Table 3S).

Statistical analysis

Statistical analysis was performed by Microsoft Excel 2013 (Microsoft Corporation), SPSS (IBM SPSS Statistics 20), and Statistica software (v. 7, StatSoft Inc., USA). As Shapiro−Wilk’s test did not confirm normal distributions of the obtained data, nonparametric Mann−Whitney U test was used to compare the respective medians (threshold of statistical significance set at $p < 0.05$).

Results and discussion

Gaseous pollutants

Over the sampling campaign, the levels of TVOCs (Figure 2a) highly varied. Concentration ranges were especially large in HC1 and HC2, with values, respectively, between 14 μg/m^3 – 21.8

mg/m^3 (median of 1.4 mg/m^3), and 2 μg/m^3 – 20.4 mg/m^3 (median of 1.1 mg/m^3). In HC3 and HC4, *i.e*. clubs equipped with controlled ventilations (Table 1S), obtained concentration ranges were approximately 2–3 times lower: 73 μg/m^3 – 12.4 mg/m^3 at HC3, and 3 μg/m^3 – 8.0 mg/m^3 at HC4. Considering different spaces of each club (MWA *vs*. SGA), the highest TVOCs medians were observed in HC3 (MWA: 2.6–5.0 mg/m^3, SGA: 2.3–2.8 mg/m^3) whereas the lowest were in HC4 (236–386 μg/m^3 and 600–1090 μg/m^3 in MWA and SGA, respectively). Overall, TVOCs levels (both medians and ranges) were higher in MWA rather than SGA. These findings were understandable considering larger use and scope of this type of indoor space (in terms of number of exercising subjects, conducted activities, respective emissions, *etc*.). Considering harmful health effects of these compounds, WHO provides guidelines for some individual VOCs in indoor air (such as benzene, trichloro- and tetrachloroethylene; [59]), whereas the Portuguese legislation on IAQ in public buildings [60] defines a protection limit expressed as total VOCs (600 μg/m^3; 8–h; Table 4S). This limit value was highly exceeded (3–5 times) in 88% of the analysed indoor spaces (both MWA and SGA) even when considering, more restrictively, median concentrations (Figure 2a, 1Sa). It is alarming that concentrations exceeded (up to 8 times) the limit, even during off-hours (i.e. when unoccupied). From the limited available information, it should be noted that in general, the TVOCs obtained in the four characterized HC were higher than in other published works [32, 86, 103, 104]. Alves et al. [32] reported TVOCs in a range of 35–2318 ppb (means of 53–82 ppb) in university sport facility (Léon, Spain), but that setup (a court, partly opened construction) was very different from a typical health club setting; opening doors and windows results in lower TVOCS [103]. From a national perspective, TVOCs in the four HC were still higher than in other indoor environments, including primary schools in Porto (range: 2–820 μg/m^3 [86]) or in Lisbon (range 100–500 μg/m^3 [104]), and in home bedrooms (range: 0.20–1.47 μg/m^3 [103]). As VOCs are released from various personal-care products (perfumes, hair sprays, hand disinfectants; [61]), increased VOCs (monoterpenes) have been reported in confined spaces due to occupant's activity [62]. Furthermore, VOCs are directly emitted from humans themselves (exhaled breath, perspiration; [63–65]), but secondary oxidation reactions between ozone and human skin lipids (with squalene being the major precursor) can be a relevant VOCs source [66, 67]. In agreement, in HC1–HC2 TVOCs concentrations were higher (p<0.05) when occupied (Figure 3a, Figure 3S). However, in HC3–HC4, this trend was opposite, with increased (20–90%) TVOCs during unoccupied periods. These elevated concentrations most likely resulted from pollutants accumulation (Figure 3a), as ventilation systems were off during night. In addition, in HC3 (exhibited the highest levels both during occupied and off-hours), rooms layout (central swimming pool area surrounded by spaces to exercise; separated only by glass panel; Figure 1c, g; Table 1S) led to direct connection between the spaces. Use of cleaning and sanitation products, as well as maintenance processes to disinfect pool water/the respective area can generate VOCs [68] that consequently infiltrated to exercise spaces. Thirdly, the main cleanings were conducted during off-hours, which might also elevate the respective TVOCs (when unoccupied), as previously reported [32]. Finally, in regards to intra-space comparison, HC4 was the only club where TVOCs in MWA were ~3 lower than at SGA (Figure 2a). The respective MWA room volume was significantly (~11 times) larger (*vs*. HC1–HC3: MWA room volume ~2 times larger than SGA; Table 1S), which might resulted in emissions dilution in the respective room.

CO_2 median concentration across HC was 1558 mg/m^3, with values ranging between 733–8122 mg/m^3 at HC1, 697–5299 mg/m^3 at HC2, 1046–7649 mg/m^3 at HC3, and 252–49007 mg/m^3 at HC4. In all HC, CO_2 were significantly higher (up to 2 times) when occupied; these differences were especially obvious in clubs with natural ventilations (60–120% in HC1–HC2 *vs*. 20–80% in HC3–HC4). Temporal CO_2 maxima exceeded standard of 2250 mg/m^3 set in Portuguese standard in all analysed spaces (Figure 2b) as well as the stricter recommendation of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE; 1800 mg/m^3) [69]. Furthermore, when occupied, median concentrations were higher than the limit in 75% of all analysed spaces, indicating insufficient ventilation. Similarly to TVOCs, higher levels were observed in MWA (higher number of subjects), presenting the highest median concentrations (4537 mg/m^3; ~2 higher than limit value) at MWA of HC3. In this club, medians CO_2 (MWA) exceeded limit even when unoccupied, indicating overall inadequate air quality. Whereas CO_2 is not a hazardous pollutant at the levels detected in HC [69], exposure to moderate concentrations of CO_2 can cause changes in human performances and influence decision-making [70]. CO_2 daily profiles (Figure 3b) exhibited two maxima: typically around midday (*approx.* at 12–13 h) and at early evening hours (*approx.* at 20–21 h). The lowest CO_2 levels were observed during early mornings and early afternoons (*approx.* at 8–9 and 15–16 h). Indoors, respiration of the respective occupants is the primary CO_2 source, and CO_2 profiles well corresponded with occupancies of the clubs (Figure 3b). The mean concentrations of CO_2 (that were estimated in relation l to room occupancy; Table 5S) ranged between 143 and 284 mg/m^3 per occupant in SGA and 284–735 mg/m^3 per occupant in MWA. While high variations of the obtained values were observed, it is possible to highlight that in all HC, MWA always exhibited higher (2–4 times higher) levels than in SGA, mostly likely due to higher occupancy of the respective spaces. Taking into consideration the dimensions and sizes of the spaces, CO_2 factors ranged 0.6–1.4 mg/occupant in SGA and 0.5–1.5 mg/occupant in MWA; the intra-space comparison being similar in a given club (Table 5S). However, it is important to emphasize that the indoor CO_2 concentrations are also influenced by metabolic activity of occupants [48] and physical parameters of the room (air exchange rates), which were not assessed in this work.

Overall, levels and distributions of ozone (Figure 2c; Figure 1Sc, Supplementary material) varied among HC (p<0.05), with the following ranges: 20–118 μg/m^3 at FC1, 20–1660 μg/m^3 at FC2, 20–1100 μg/m^3 at FC3, and 20–2490 μg/m^3 at FC4. Over that period, the daily concentrations of ozone (maximum 8–h mean) in ambient air ranged between 39.8–119 μg/m^3 (Table 2S), being below the indicated limit of 120 μg/m^3 [105]. These levels need to be implicated carefully, once the concurrent measurements of ozone in outdoor air were not conducted directly in the HC vicinities; data were retrieved from the national monitoring network, for each HC considering a station that was situated the closest to it and with characteristics similar to those of health club site. Similarly to TVOCs and CO_2, the highest medians were observed in spaces of HC3 (occupied periods SGA: 138 μg/m^3; MWA: 158 μg/m^3). Thus HC3 spaces (both MWA and SGA) were the most polluted ones; increased levels of gaseous pollutants (often exceeding the guidelines even during unoccupied periods) indicate the need to improve the respective IAQ. Once again, ozone showed temporal variations and exhibited significantly higher levels (p<0.05) during occupied periods. Indoor sources of ozone include equipment (photocopiers, printers, or air cleaners [71, 72]), but the major source of ozone is the ambient air and the majority of ozone indoors results from infiltrations (due to ventilation) [106]. Consequently, the use of exhaust ventilation systems may produce lower concentrations of ozone indoors than would have occurred when using natural ventilation systems (considering the same air-exchange rate) [106]. In agreement, in clubs with natural ventilations HC1–HC2, the differences of ozone levels during occupied *vs*. unoccupied were approximately twice higher (65–120%) than in clubs that were equipped with mechanical ventilation (~20–80%). Though there are no regulation for ozone indoors (Table 4S), its negative health impacts have been recognized, with recommendation to mitigate indoor ozone to ALARA levels (*i.e*. as low as reasonably achievable [73]). It is rather difficult to compare the obtained results with other studies, as information regarding indoor ozone in sport facilities is very limited (Table 6S). Some authors [48] reported fitness clubs with ozone concentrations of 0–0.17 mg/m^3, being somewhat similar to this study. Nevertheless, due to different study design (45–60 min long measurements conducted when the most occupied, i.e. late afternoon/night), the attained findings need to be implicated carefully. Additional information on ozone was reported for sport halls [44], with mean levels of 8–19 μg/m^3 (depending on the event happenings). Obviously, these concentrations differed due to their dissimilar characteristics. Furthermore, both these studies also included VOCs and CO_2 assessments. Information concerning these pollutants (though still limited for fitness/health clubs) consists of more data mainly from evaluations of sport halls [42, 43] and educatory environments (primary/elementary school gymnasiums, university centres, *etc.*) [9, 32]. Considering specifically fitness clubs [48], the reported means (CO_2: 524 – 4418 mg/m^3; TVOCs 0–3.3 mg/m^3) were in similar ranges as in presented work. In all HC, ozone was positively moderately (r_s: 0.487–0.643 at HC1–HC2, HC4) to highly (r_s: 0.835 at HC3) correlated with TVOCs, indicating associations between these pollutants. Ozone is a reactive pollutant and its indoor chemistry (*i.e.* ozone-initiated reactions) can create gaseous products, which may be even more reactive and/or heath-hazardous [74–78]; insufficient air exchange rate can then increase levels of ozone-reactive VOCs [79]. These processes may be influenced by room occupancy [77, 80] as humans are significant sinks for ozone indoor concentrations due to skin lipids that react with ozone to produce characteristic oxidation products [67].

Finally, 59–68% of the registered values for CO were below LODs (mainly in HC1, HC2, HC4). Thus, this pollutant was not further analysed. However, the obtained levels across four HC (median 0.181 mg/m^3 at HC1 – 1.26 mg/m^3 at HC3) were well below guideline limit of 10 mg/m^3, indicating that CO was not a concern in the respective environments. Nevertheless, as this pollutant is toxic to human health, its presence should be monitored.

Particulate matter

Similarly to gaseous pollutants, PM levels highly varied. At HC1 and HC2, PM_4 ranged, respectively, 5–368 μg/m^3 (median 38 μg/m^3) and 6–829 μg/m^3 (median 21 μg/m^3). The corresponding PM_1were: 5–328 μg/m^3 (36 μg/m^3) at HC1 and 6–638 μg/m^3 (20 μg/m^3) at HC2. In the larger HC, PM varied considerably less: PM_4 of 11–78 μg/m^3 (median 20 μg/m^3) and PM_1 of 11–75 μg/m^3 (19 μg/m^3) at HC3; at HC4 the respective levels were 3–105 μg/m^3 (15 μg/m^3) for PM_4 and 3–102 μg/m^3 (14 μg/m^3) for PM_1 (Figure 4S, Supplementary material). These results showed that at HC1–HC2, the respective PM ranges were significantly higher (p<0.05) although these clubs daily accommodated fewer clients (118–265 per day *vs*. up to 410–1000 clients/day in HC3–HC4). Apart from natural ventilation, these clubs were situated directly on a street level (ground floor; Table 1S) with windows facing busy roads (414–1338 vehicles/day; Figure 5S). Thus, indoor PM might result from infiltrations of ambient emissions. Similarly, previous studies [81, 82] reported higher infiltrations of ambient particulate emissions under natural ventilation conditions (i.e. windows opening) than when using mechanical systems. During the respective period, PM levels in ambient air were on lower-end (Table 2S), ranging between 6–41 μg/m^3 and 1–9 μg/m^3 for PM_{10} and $PM_{2.5}$ (24-h means), respectively. These ranges fulfilled the regulatory guidelines (24–h PM_{10} average <50 μg/m^3 [105]). The concentrations of fine particles seemed particularly low for urban environments, however, on European scale, Portugal exhibits relatively low $PM_{2.5}$ levels [108]; the estimated average (4±2 μg/m^3) fulfilled EU annual limit of 25 μg/m^3 but also the more stringent recommendation of WHO of 10 μg/m^3 [109]. Although there is more data on PM in sport environments (compared to gaseous pollutants), the majority comes from educational sport facilities [9, 12, 13, 32–36, 38– 40]. Fitness/health clubs though have different goals than school/university gyms, and thusly represent different indoor environment (in terms of design, occupancy and conducted activities, available facilities, construction and used materials; [83]). Only few IAQ studies were conducted in fitness clubs. The main information comes from series of works [15, 48, 84] conducted in Lisbon (Portugal), with PM_1 means in a range of 0.9–18 μg/m^3 ($PM_{2.5}$:1.5–23 μg/m^3). These levels were fairly similar to those in HC3–HC4 (*i.e*. with ventilation systems) considered in the present study.

In majority of places (HC1–HC3), levels of both PM were lower ($p<0.05$) when clubs were vacant (Figure 4). The difference between PM concentrations during both periods was especially distinctive at HC2 where, when occupied, PM temporarily reached levels 13–42 times higher than when closed (means: 31 and 28 $\mu g/m^3$ for PM_4 and PM_1 when occupied *vs*. 20 $\mu g/m^3$ and 19 $\mu g/m^3$ for non-occupied; $p<0.05$). Thus, it is assumed that high indoor PM levels obtained in HC2 were greatly influenced by human occupancy. However, because of the high traffic density in streets surrounding HC2 (Figure 5S), it is likely that indoor PM patterns were influenced by the infiltrations of outdoor emissions due to use (or absence, i.e. – closed windows when unoccupied) of natural ventilations. Therefore, in future studies on assessment of air exchange rate would be important to clarify these findings. Finally, apart from human activities [13, 85], the characteristics of the built environment (*i.e.* layout, used materials, type of ventilation, indoor sources and etc.; [20, 81, 85, 86]) may strongly impact the respective indoor concentrations. The highest PM levels were observed in HC1. When occupied, PM_1 medians at both spaces of HC1 even exceeded the $PM_{2.5}$ WHO indoor air quality guideline (25 $\mu g/m^3$ for 24 h; [59]) but also the Portuguese norm (25 $\mu g/m^3$ over 8 h; [60]), thus indicating possible risks. Exercising in areas with increased PM concentrations may increase adverse health effects, as deposition of particulates doubles with increased intensity of exercise [35]. Moreover, PM deposition into respiratory tract may be up to five times higher during moderate activity than at rest [9]. Maintenance works (construction and consequent cleaning) that was repeatedly carried out in SGA of HC1 during the off-hours (*i.e.* late at night; Figure 5a), probably caused the reoccurring events of elevated PM (up to 6–7 times) and resulted in overall increased PM_4 and PM_1 medians (25 and 30% higher for PM_4 and PM_1, respectively) during unoccupied periods. HC4 was the only club where PM levels were always higher during off-hours (13 vs. 24 $\mu g/m^3$ for both PM). These results were somewhat unexpected. However, previously increased PM when the respective places were unoccupied were reported [33, 87], resulting either from secondary formations of aerosols (due to VOC emissions from cleaning products;[88]) and/or accumulation of PM indoors due to motionless air conditions that prevented mixing [87]. The intra-space comparisons also demonstrated a greater range of PM levels during occupied periods than when vacant. PM medians were statically different ($p<0.05$) between two spaces; in agreement with gaseous pollutants, higher PM_4 and PM_1 medians ($p<0.05$) were observed in MWA rather than in SGA.

PM_1/PM_4 mass ratios were relatively high and ranged 0.78–1.00 (median of 0.94) at HC1, 0.64–1.0 (0.95) at HC2, 0.84–1.0 (0.93) at HC3, and 0.83–1.0 (0.96) at HC4. Whereas in HC1 and HC2 the large contribution of coarse fraction (PM_{4-1}) was occasionally observed (36–46%) due to outdoor infiltrations, overall PM_1 composed >90% of indoor particulates, which may be relevant considering the possible health impacts of small sized PM [89, 90]. PM_4 *vs*. PM_1 daily profiles showed similar trends (Figure 5b), being highly (and positively) correlated (Spearman correlation coefficients r_s: 0.936 at HC3 – 0.995 at HC4). In SGA, maxima of PM temporal variations were typically higher than in MWA, and occurred during high intensity cardio activities (Figure 5a): HC1: 328–368 $\mu g/m^3$ during zumba; HC2: 638–829 $\mu g/m^3$ during spinning; HC3: 53–58 $\mu g/m^3$ during cardio muscular class; and HC4: 51–52 $\mu g/m^3$ during body combat. Concerning HC4, it is necessary to remark that although PM levels were higher during off-hours ($p < 0.05$), the trends of concentration profiles during that time were stable with almost no variations (particularly during midnight–7 a.m.; Figure 5b).

Comfort parameters

T and RH are among parameters that affect thermal comfort of the respective occupants. In general, RH levels recommended by different organizations range from 30–60%. For RH of 30 and 60%, ASHRAE recommends indoor T ranges 23.0–26.6 °C and 23.0–25.8 °C, respectively [91]. However, specifically for gyms, RH 55–75% and T range 18–25 °C (summer) are advised [92]. Typically, higher levels of RH were observed in all spaces when occupied (Figure 6a). When exercising, breathing and perspiration generate substantial amount of water vapour, which impacts measured RH [13]. Furthermore, RH levels were moderately and positively correlated with CO_2 (r_s 0.534 at HC3 – 0.625 at HC1) pointing towards human activities contribution and exhalation during exercising. Whereas indoor conditions of HC1 and HC4 were within the recommended range (55–68%; Figure 6a); in MA of C2 and C3, RH were somewhat lower (44–48%), which can cause some discomfort (drying nose, throat, mucous membranes and skin) [93, 94].

In general, during occupied periods (Figure 6b) T was within the recommended guidelines [95]. Higher exceedance (maxima value of 33°C) was observed in MA of C2, which occurred during the later-afternoon period. As human body adds to room heat, accumulation of larger number of room occupants can increase air temperature [13]. However, considering the position and orientation of the rooms in HC2, T increase was most likely caused by sun shining; the room walls almost entirely consisted of glass panels (Table 1S) and entering heat power might warm up room air by few degrees [13]. As regular exercising in environmental conditions such as elevated T and increased RH can cause various health consequences [94, 96, 97], comfort parameters should be maintained within the recommended ranges (by proper use of air conditioning systems, room insulating, sun/heat reductions, and *etc*.).

Inhalation dose assessment

Total age- and gender-specific inhalation doses for different levels of physical activities are presented in Figure 7, whereas doses estimated for each pollutant (gaseous, PM_4 and PM_1) are summarized in Table 7S. In agreement with the previous results, the highest magnitude of inhaled total doses (all ages and both genders) were in HC3 (1.6–3.5 times), which was the club with the poorest IAQ (Figure 2 and 4). Type of the conducted activities is relevant for the inhaled dose. More intense exercising (cardio classes) were associated with the highest doses (due to increased breathing); inhaled doses of cardio classes were approximately 1.7–1.9 (males) and 1.9–2.6 (females) times higher than for mind and body activities. Exercise duration is also important. As individual training lasts longer (*approx*. 20% in this study), cardio *vs*. individual training doses comparison was much lower (1.0–1.17 for females, 1–1.12 for males). Furthermore, under this scenario, individual training included 20 min of warm-up session (high intensity breathing) and 40 min of body building (moderate inhalation), which also influenced the estimated doses. A comparison between both genders shows that women exhibited higher magnitude of inhaled doses (*approx.* 10–23% more than males), most likely due to larger limitation of expiratory flow in females and, simultaneously, increased efforts to breath when intensely exercising [15]. However, gender specific parameters were retrieved from existent records [58] with higher variations of ventilatory patterns between different age categories of females than males [58]. Results summarized in Table 7S showed that CO_2 accounted for majority (~ 98%) of the estimated inhaled doses. Nevertheless, CO_2 is also a pollutant directly produced by human respiration [98]. Overall inhalation intakes of particulates (~ 0.3–1.3 μg/kg) well corresponded to data (0.2–2.1 μg/kg) published by other authors [48, 99]. Size of particles governs the deposition and removal rate within respiratory system. Type of respiration (i.e. nasal *vs*. oral) is also relevant as particle penetration into the lower respiratory tract is dependent on breathing route [100]. Secondly, elevated air flow velocity of breathing during exercising may cause transport of pollutants into the deepest part of the respiratory system, increasing the risk to human health [14]. Ozone inhaled doses were in similar ranges to PM (0.7–3.1 μg/kg) whereas inhalation dose of TVOCs ranged between 11–90 μg/kg. For gaseous compounds, their solubility affects the inhaled uptake [101]. Apart from that, it is necessary to point out that pollutants studied within this work pose adverse health effects. Potentially synergic interactions between these pollutants seem to be indispensable factor when considering relationship between human exposure to air pollutants and adverse health effects. Despite the existing limitations for epidemiologic studies, synergism effects between ozone and other pollutants have been demonstrated in animal studies, and in limited capacity in human studies as well[102].

Inhalation doses of staff and instructors (male and female combined) who oversee the main workout area were also estimated. Obviously, large occupational duration (8–h) led to increased inhalation intakes (3–9 times higher than those who exercised). However, exposures to harmful pollutants in work places [110] represent just one microenvironment frequented on a daily basis. Therefore, other relevant microenvironments should be considered.

Conclusions

This study provides information on air quality in indoor environments for sport practise. Across four health clubs, concentrations of gaseous (TVOCs, O_3, CO_2) and particulate pollutants (PM_4 and PM_1) exhibited large temporal spatial variations. TVOCs highly exceeded limit of 600 μg/m^3 designated by Portuguese legislation in all health clubs [60], even when these were unoccupied, thus indicating magnitude of potential risks for the respective occupants. The highest levels of all gaseous pollutants were observed in HC3, where CO_2 levels exceeding the given standard of 1800 μg/m^3 (even when the club was empty) indicate insufficient ventilation. In all analyzed clubs, CO_2 was well correlated with relative humidity (r_s 0.534 – 0.625) and its daily profiles well agreed with occupancies, thus suggesting contribution of human activities (due exhalation during exercising). Overall, levels of gaseous and particulate pollutants were higher when clubs were occupied (p<0.05) than for vacant periods, with larger medians observed in main workout areas rather than in spaces/studios for group exercise. Regarding PM, higher (~2 times) concentrations were observed at clubs with natural ventilations. PM_1 accounted approximately for 93–96% of PM_4; both PM were highly correlated (r_s 0.936–0.995) pointing towards originating from the same emission sources.

Indoor chemistry of individual pollutants is complex. Additionally, during physical exercise, IAQ is influenced by human occupancy and intensity of exercise. Inhalation dose of subjects in more demanding classes (cardio) resulted in 1.7–1.9 (males) and 1.9–2.6 (females) higher than in other types of exercising. Furthermore, female subjects inhaled during exercising about 10–23% higher doses than male ones, thus demonstrating the need to consider the differences between both genders in exposure studies. As knowledge regarding the associations between IAQ and health in indoor environments used for physical exercise is not well characterized yet, further assessments of potential exposure impacts and magnitude of inhaled pollutants are needed.

Acknowledgments

This work was supported by European Union (FEDER funds through COMPETE) and National Funds (*Fundação para a Ciência e Tecnologia*) through projects UID/QUI/50006/2013 and UID/EQU/00511/2013-LEPABE, by FCT/MEC with national funds and co-funded by FEDER in the scope of the P2020 Partnership Agreement. Additional financial support was provided by *FCT* through fellowship SFRH/BPD/105100/2014.

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Figure Captions

Figure 1. Visualizations of indoor spaces at health clubs (HC1–HC4): (a–d) main workout areas; (e–h) rooms/studios for group classes.

Figure 2. Levels of gaseous pollutants (■ median; □ 25–75%, and ⟂ range) at health clubs (HC1–HC4) during occupied and non–occupied periods: (a) TVOCs; (b) CO_2; and (c) O_3. Horizontal dashed lines represent limit values set by Portuguese legislation (Decreto-Lei 118/2013). Distributions and medians of each pollutant were significantly different (p<0.05) across four clubs, across different places, and between both occupied and non-occupied periods. Note: for better visualization vertical axes y are shown in logarithmic scales; MWA identifies main workout areas; SGA are spaces for group activities.

Figure 3. Temporal variations of gaseous pollutants: (a) examples of continuous evolution (4 weekdays) of levels of total volatile organic compounds levels (main workout areas) of HC1 and HC3 (grey scale indicates unoccupied periods; (b) mean daily variations of CO_2 at four clubs (HC1–HC4) and the respective occupancies (note: occupancy profile of HC4 is not presented due to the proprietor restrictions.

Figure 4. Levels of particulate pollution (■ median; □ 25–75%, and ⟂ range) at health clubs (HC1–HC4) during occupied and non–occupied periods: (a) PM_4; and (b) PM_1. Horizontal dashed lines represent 8-h limit value for PM_{10} (50 μg/m^3) and $PM_{2.5}$ (25 μg/m^3) set by Portuguese legislation (Decreto-Lei 118/2013). PM data (distributions and medians) of both fractions were significantly different (p<0.05) across four clubs, across different places, and between both occupied and non-occupied periods. Note: for better visualization vertical axes y are shown in logarithmic scales; MWA identifies main workout areas; SGA are spaces for group activities.

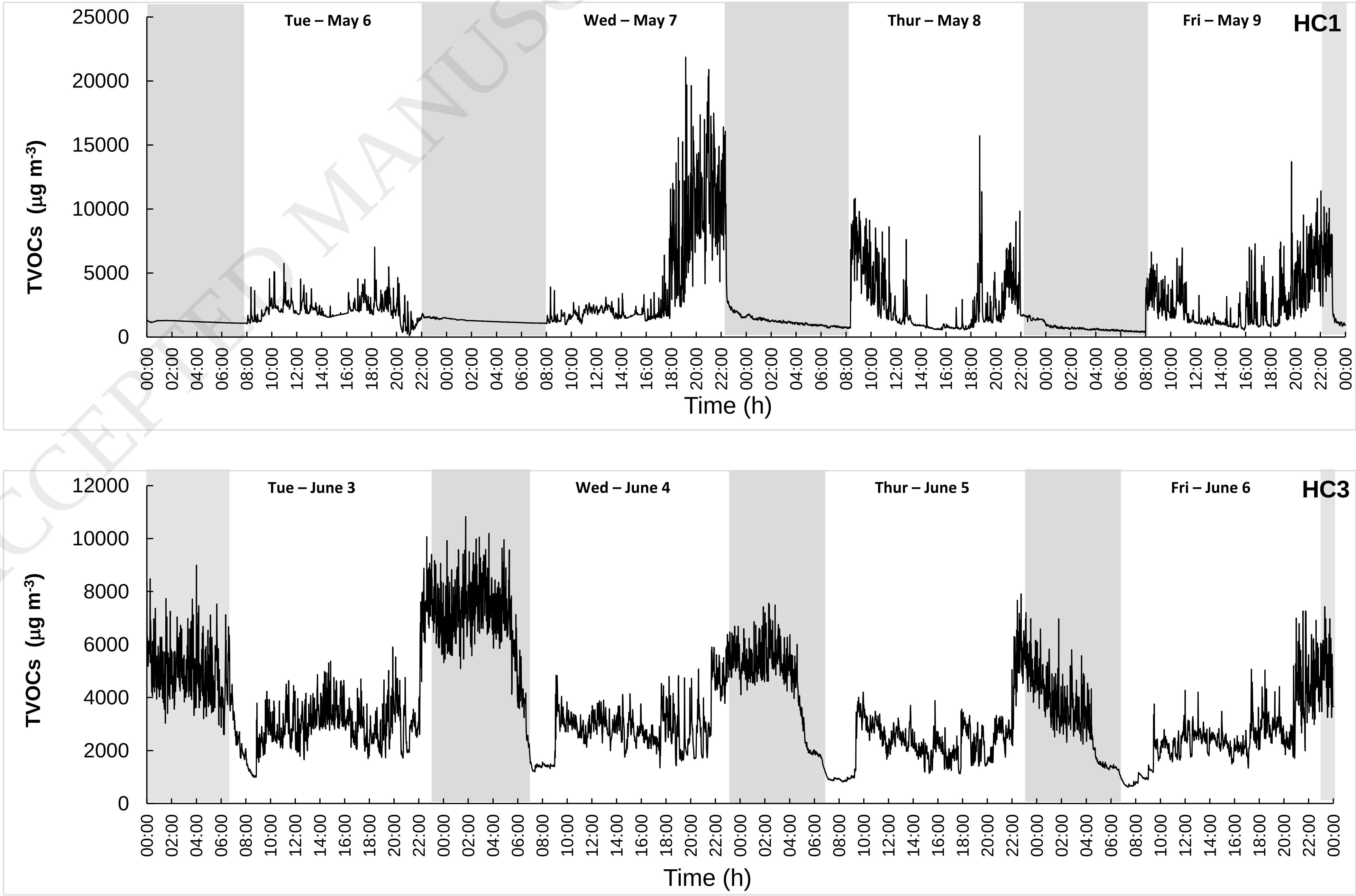
Figure 5. Example of temporal variations of PM in rooms/studios for group activities (SGA): (a) representation of PM_1 profiles collected during the same weekdays at HC1, with both profiles being relatively similar except for the concentration increase due to the maintenance works (blue line: 22:30-23:15); (b) PM_1 and PM_4 concentration profiles at HC4. Between midnight and ~7 a.m. profiles of both PM are very flat with almost no variation (noticeable drop of PM levels occurs at 6:50 when clubs opened and mechanical ventilation system were in use).

Figure 6. Comfort parameters (■ median; □ 25–75%, and range) at health clubs (HC1–HC4) during occupied and non–occupied periods: (a) relative humidity (RH); (b) temperature (T). Horizontal dashed lines represent indicated ranges for indoor spaces for sport practising (SEJD, 2008). Distributions and medians of parameter were significantly different (p<0.05) across four clubs. Note: MWA identifies main workout areas; SGA are spaces for group activities.

Figure 7. Total gender- and age-specific inhaled doses (μg/kg) during different levels of physical activities.

Figure 3

a)



Tue – May 6
Wed – May 7
Thur – May 8
Fri – May 9
HC1
TVOCs (µg m-3)
25000
20000
15000
10000
5000
0
00:00 02:00 04:00 06:00 08:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time (h)
Tue – June 3
Wed – June 4
Thur – June 5
Fri – June 6
HC3
TVOCs (µg m-3)
12000
10000
8000
6000
4000
2000
0
Time (h)

b)

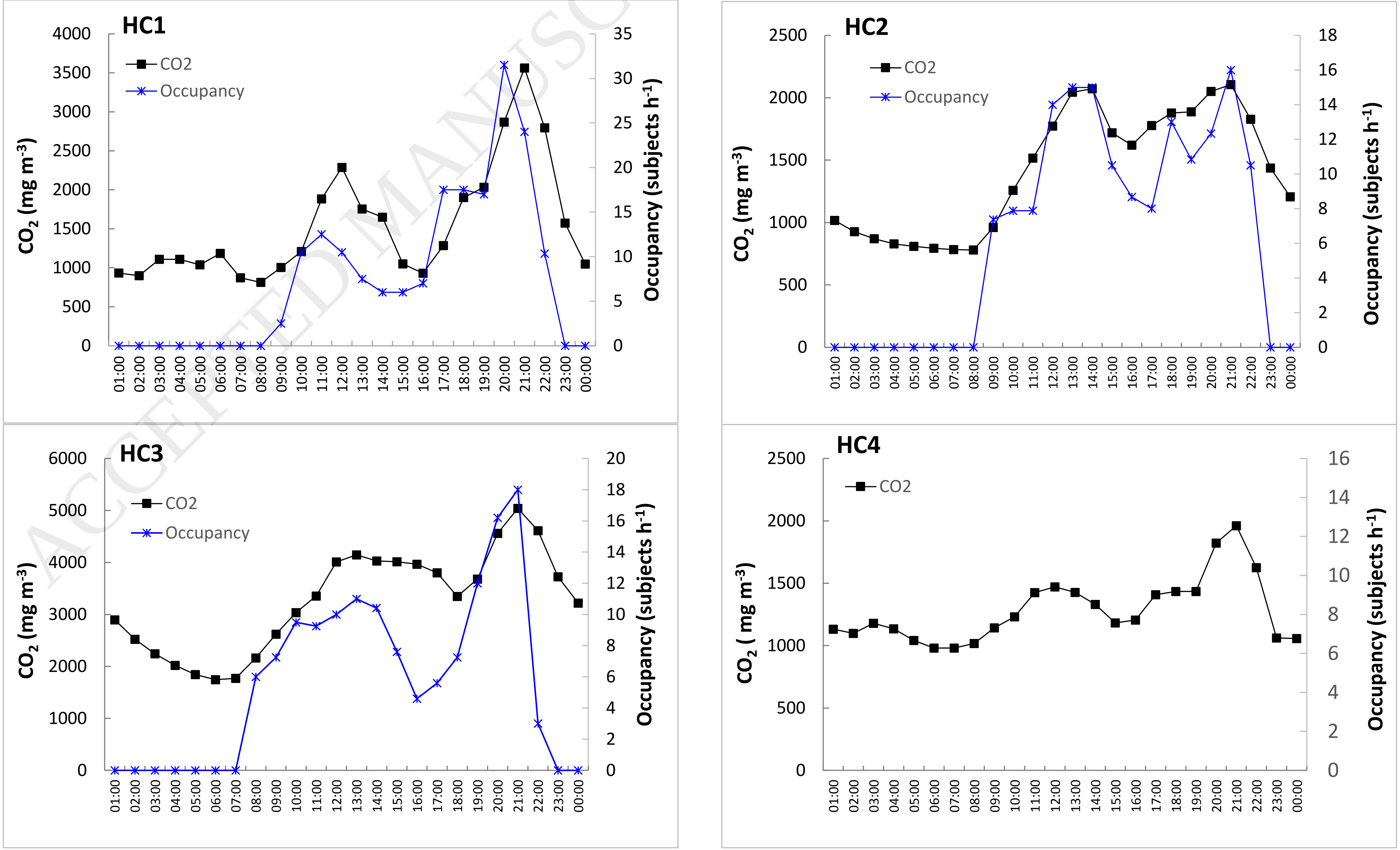
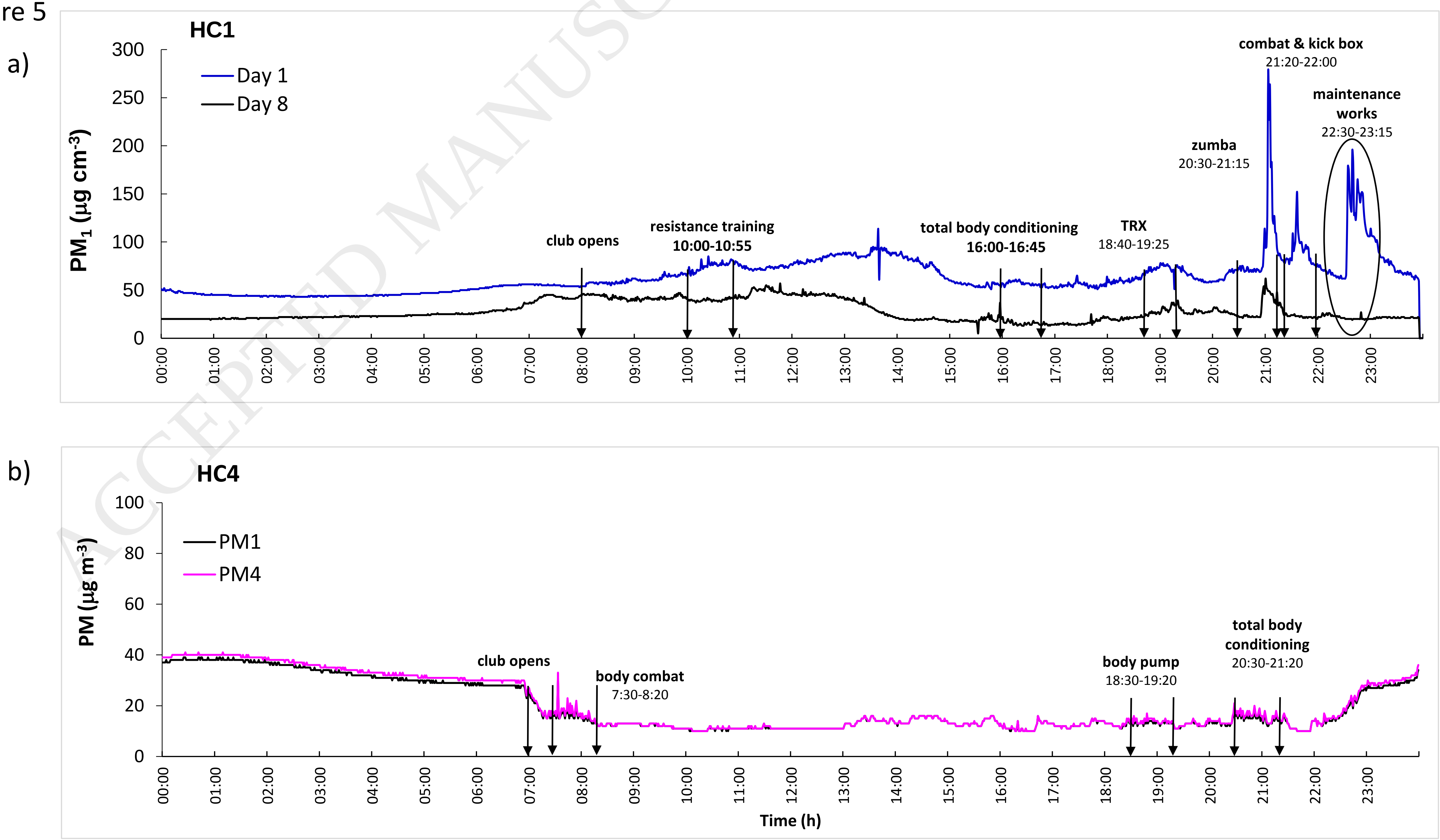
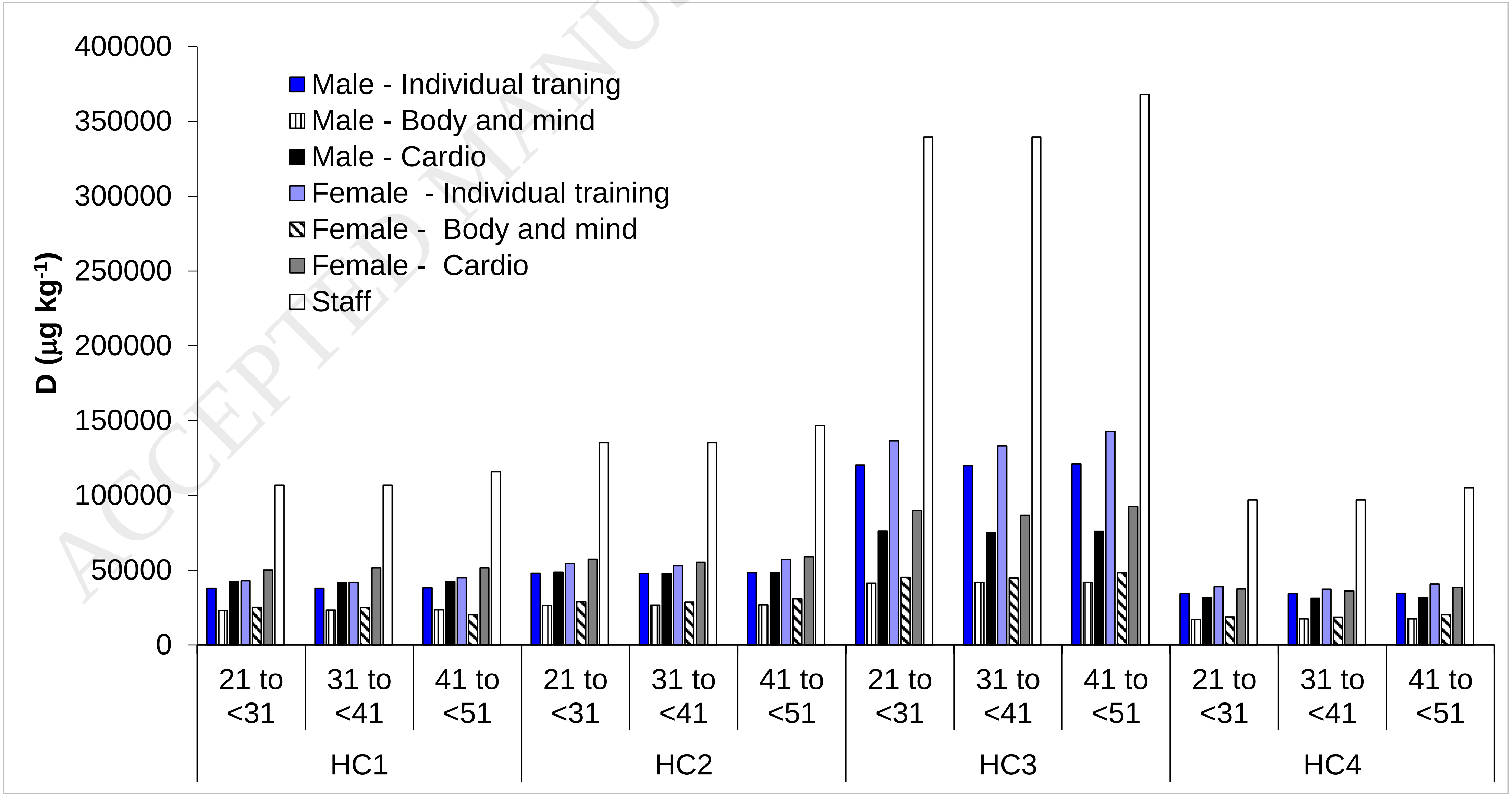

HC1
CO2
Occupancy
CO_2 (mg m^{-3})
Occupancy (subjects h^{-1})
HC2
CO2
Occupancy
CO_2 (mg m^{-3})
Occupancy (subjects h^{-1})
HC3
CO2
Occupancy
CO_2 (mg m^{-3})
Occupancy (subjects h^{-1})
HC4
CO2
CO_2 (mg m^{-3})
Occupancy (subjects h^{-1})

Figure 5



a)
HC1
Day 1
Day 8
PM1 (µg cm-3)
300
250
200
150
100
50
0
club opens
resistance training
10:00-10:55
total body conditioning
16:00-16:45
TRX
18:40-19:25
zumba
20:30-21:15
combat & kick box
21:20-22:00
maintenance
works
22:30-23:15
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
b)
HC4
PM1
PM4
PM (µg m-3)
100
80
60
40
20
0
club opens
body combat
7:30-8:20
body pump
18:30-19:20
total body
conditioning
20:30-21:20
Time (h)

Figure 7


400000
350000
300000
250000
200000
150000
100000
50000
0
D (µg kg-1)
Male - Individual traning
Male - Body and mind
Male - Cardio
Female - Individual training
Female - Body and mind
Female - Cardio
Staff
21 to <31
31 to <41
41 to <51
21 to <31
31 to <41
41 to <51
21 to <31
31 to <41
41 to <51
21 to <31
31 to <41
41 to <51
HC1
HC2
HC3
HC4