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Air Quality in Fitness Centers: The Impact of Ventilation Restrictions - A Case Study

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Abstract

To stay healthy, people frequent sports facilities. This work aimed to evaluate air pollution and comfort parameters in a fitness club in the post lockdown period (due to the COVID-19 pandemic), focusing on particulate material (PM_{10}, $PM_{2.5}$) and gaseous pollutants (total volatile organic compounds -TVOCs, carbon dioxide - CO_2, and carbon monoxide – CO). Sampling was carried out for 10 consecutive days in October 2020 in one fitness center (Oporto, Portugal). The results showed that indoor PM_{10} ranged from 1.4 to 122.5 µg/m^3 and $PM_{2.5}$ was between 0.8 and 25 µg/m^3; the overall levels were in accordance with the current legislation. TVOC means were 0.39 mg/m^3 when not occupied and 0.43 mg/m^3 when exercising subjects were present, thus also fulfilling the limit 0.6 mg/m^3). Average CO_2 was 1400 mg/m^3 with temporal maxima (2660-2894 mg/m^3) exceeding the protection threshold. Finally, temperature and relative humidity exceeded the recommended comfort levels, especially during group activity classes.

Author Keywords. Indoor Air Quality (IAQ), Particulate Matter, Pollutant Gases, Comfort Parameters, Fitness Centers.

Type: Research Article

1. Introduction

In the nowadays society, for which sedentary routines have become a common standard, it is important, more than ever, to promote healthy lifestyle that should include some degree of physical activity. For improved health benefits, the World Health Organization (WHO) recommends a minimum of 150 min of moderate-intensity of aerobic physical activity per week for adults (World Health Organization 2016). In order to stay healthy, people frequent fitness centers and gyms. Compared to other indoor spaces (such as offices or homes), these represent an unique indoor microenvironment (Andrade, Dominski, and Coimbra 2017; Revel and Arnesano 2014) where, due to increased inhalations (from physical activities), occupants might be exposed to higher risks of some relevant indoor pollutants (Alves et al. 2014; Andrade, Dominski, and Coimbra 2017; Ramos et al. 2015). Considering the public health perspective, the most relevant concerns are related to air quality in spaces in which people spend their time, both indoor and outdoor (EEA 2011; Almeida, Silva, and Sarmento 2014). During the COVID-19 pandemic, gyms and fitness centers in Portugal were closed due to the general lockdown of the country. When the public lockdown of the society was released, the country was still subjected to specific public health rules, which aimed to prevent a new wave of infections. Specifically for fitness centers and clubs, restrictions in terms of indoor space ventilation and limitations of human occupancy (including during group classes) were set in force.

Overwhelming scientific evidence has shown that exposure to particulate matter (PM), namely PM_{10} (aerodynamic diameter <10 μm) and $PM_{2.5}$ (<2.5 μm), is associated with increased mortality rates, in particular with deaths from cardiovascular and respiratory diseases (Amato et al. 2014; Beelen et al. 2015; Brook et al. 2010; Holgate 2017). While the previous studies characterized the levels of air pollution in the sports facilities (Slezakova et al. 2018a; Slezakova et al. 2018b; Ramos, Wolterbeek, and Almeida 2014; Alves et al. 2013), the available data do not apply to these specific indoor conditions (under the ventilation and human occupancy restrictions). In addition, the wide range of physical activities performed in the gyms may have an impact on the current exposures. Therefore, it is important to assess indoor air quality in these spaces, as well as the impacts of the public health guidelines on levels of indoor air pollutants, such as volatile organic compounds (VOCs), carbon dioxide (CO_2), carbon monoxide (CO) and ozone (O_3) and parameters of comfort, temperature (T) and relative humidity (RH) in sports facilities.

1.1 Portuguese legislation: A summary

Indoor air quality (IAQ) policies were primarily based on controlling the pollution in industrial buildings within the scope of "occupational health and safety". In 2006, the European Parliament established the Directive 2002/91/CE[1], which defined the need to implement energy certification systems for buildings, including public buildings. This directive was transposed into the Portuguese legislation through three diplomas: the Decree-Law nº 78/2006[2] approved the "National Energy and Indoor Air Quality Certification System" in buildings; the Decree-Law nº 79/2006[3] approved the "Regulation on Energetic Systems for Air Conditioning"; and the Decree-Law nº 80/2006[4] approved the "Regulation on the Characteristics of Thermal Behavior" in buildings. These diplomas serve as basis for National Energy Certification System (SCE) and IAQ in buildings. The SCE's legal statutes partially

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[1]Directive 2002/91/CE. "Relativa ao desempenho energético dos edifícios". https://eur-lex.europa.eu/legal-content/PT/TXT/?uri=celex:32002L0091.

[2]Decreto-Lei n.º 78/2006. "Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios e transpõe parcialmente para a ordem jurídica nacional a Directiva n.º 2002/91/CE, do Parlamento Europeu e do Conselho, de 16 de Dezembro, relativa ao desempenho energético dos edifícios". Diário da República nº 67/2006, Série I-A de 2006-04-04, nº 78, 2411-15. https://data.dre.pt/eli/dec-lei/78/2006/04/04/p/dre/pt/html.

[3]Decreto-Lei n.º 79/2006. "Regulamento dos Sistemas Energéticos de Climatização em Edifícios". Diário da República no. 67/2006, Série I-A de 2006-04-04, no. 79, 2416-68. https://data.dre.pt/eli/dec-lei/79/2006/04/04/p/dre/pt/html.

[4]Decreto-Lei n.º 80/2006. "Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE)". Diário da República no. 67/2006, Série I-A de 2006-04-04, no. 80, 2468-513. https://data.dre.pt/eli/dec-lei/80/2006/04/04/p/dre/pt/html.

transpose the Directive 2010/31/EU[5] on the energy performance of buildings. Furthermore, taking into account the goals and challenges defined for 0, a new diploma was established in Decree-Law nº 118/2013, in which the IAQ is no longer mandatory in building energy certification. This diploma contemplates the transposition of the associated directive and reviews the national legislation. In relation to IAQ policies, it is important to maintain the minimum values of fresh air flow per space and the protection thresholds for indoor air pollutants, in order to safeguard the same levels of health and well-being of building occupants. Despite IAQ audits being eliminated, it is necessary to maintain the control of pollution sources and adopt preventive measures. In order to comply with legal requirements to reduce possible risks to public health, commercial buildings and existing services are subject to compliance with the protection thresholds and reference conditions for pollutants provided in Ordinance nº 353-A/2013[6].

In addition to the IAQ regulations, Portuguese legislation includes a diploma established by the Secretariat of State for Youth and Sports, whose objective is to regulate the construction, installation and operation of gyms (SEJD 2008). This diploma requires that natural ventilation is conducted through controllable openings with a total area corresponding to 12% of the area per occupant. In case of mechanical ventilation, it is necessary to guarantee that an air flow corresponding to at least 20 m^3/h per occupant is ensured, with an air speed below 2.0 m/s and a noise level not exceeding 20 dB. The reference values for the relative air humidity are 55 to 75% for the temperature range of 16 ºC to 21 ºC in winter and 18 ºC to 25 ºC in summer. It is important to mention that sport facilities themself no longer have to conduct mandatory air quality audits. However, they do need to ensure compliance with the rules of the current legislation. Further, the responsibility to control IAQ has been passed to the building owners. General Inspection of Agriculture, Environment, Sea and Spatial Planning (IGAMAOT) then ensures the compliance of these rules.

2. Materials and Methods

The air quality sampling was conducted for 10 days in October 2020. The fitness center was situated in Oporto Metropolitan Area and belonged to a branch of low-cost fitness clubs. The indoor space consisted of main bodybuilding area with cardio fitness zone, group exercise studios (3), locker rooms with associated functions, administrative and support spaces (reception, storage room or support for staff), and enhanced spaces (vending machine and bar service, fitness assessment spaces); the club did not have swimming pools or any outdoor facilities. Mechanical ventilation was provided through HVAC system, which typically regulates both indoor ventilation and air condition. However, due to national public health guidelines to limit the spread of SARS-CoV-2 virus in confined places at time of sampling, the system was only used to provide a ventilation (in a limited manner). The sampling was carried out

[5]Directive 2010/31/EU. "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings". https://eur-lex.europa.eu/eli/dir/2010/31/oj.

[6]Portaria n.º 353-A/2013 de 4 de dezembro. "Estabelece os valores mínimos de caudal de ar novo por espaço, bem como os limiares de proteção e as condições de referência para os poluentes do ar interior dos edifícios de comércio e serviços novos, sujeitos a grande intervenção e existentes e a respetiva metodologia de avaliação". Diário da República n.º 235/2013, 1º Suplemento, Série I de 2013-12-04, nº 353-A, 6644-(2)-6644-(9). https://data.dre.pt/eli/port/353-a/2013/12/04/p/dre/pt/html.

continuously (24 h) during all weekdays and weekends. The equipment was placed on supports, approximately at 1.4±0.2 m above the floor and at least 1.5 m from walls to minimize the influence on particle dispersion; all direct emission sources that might interfere with data acquisition were avoided. Lighthouse Handheld 3016 IAQ particle counter (Lighthouse Worldwide Solutions, Fremont, USA) was used to monitor particles in the range of 0.3 µm – 25 µm, allowing simultaneously data from 6 different particle fractions (PM_{10}, PM_5, $PM_{2.5}$, PM_1, $PM_{0.5}$, and $PM_{0.3}$); logging interval was 1 min. Comfort parameters (T, ºC; and RH, %) and 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) continuously, with 1 min logging interval. Before the sampling campaign, all equipments were calibrated at the manufacturers; during the whole sampling period, zero value of the particle monitor was daily verified.

Ambient levels of PM_{10} ($PM_{2.5}$ was not available) were retrieved from the monitoring station situated the closest to the fitness club (approximately 4 km), which belonged to monitoring network operated by Portuguese Environmental Agency (QualAr 2021). Statistical analyses of the data were conducted using SPSS (IBM SPSS Statistics 20) and Microsoft Excel 2013 (Microsoft Corporation).

3. Results and Discussion

3.1. Particulate matter

During the sampling campaign, the daily average of PM_{10} in ambient air was 12 µg/m^3, with daily means ranging between 6 and 18 µg/m^3. These obtained values indicated very good air quality index for PM_{10} throughout the whole campaign (World Health Organization 2006).

Indoor PM_{10} was between 1.4-122.5 µg/m^3 with overall median of 7.2 µg/m^3. Occupancy had a high impact on indoor PM levels (Figure 1). When without exercising subjects, PM_{10} mean was 5.1 µg/m^3, while it was 14.6 µg/m^3 (approximately three times higher) when occupied. The temporal maxima of PM_{10} was observed in bodybuilding and cardio fitness area (122.5 µg/m^3) and reached 2.5 times higher values than the limit of 50 µg/m^3 (Decreto-Lei n.º 118 2013). Still, it is necessary to point out that PM_{10} levels in bodybuilding and cardio fulfill the current legislation. The corresponding $PM_{2.5}$ concentrations were between 0.8 and 25 µg/m^3 (median 2.4 µg/m^3). On average, $PM_{2.5}$ composed 36% of PM_{10} and the observed mean for bodybuilding and cardio fitness zone was 3.4 µg/m^3. Overall, the obtained values of the analyzed gyms were in a similar range to those previously reported for Lisbon (Almeida, Ramos, and Almeida-Silva 2016; Ramos, Wolterbeek, and Almeida 2014) or Oporto (Slezakova et al. 2018a; Slezakova et al. 2018b). In studios for group activities, the overall average concentration was 16.6 µg/m^3 (temporal maximum of 60.3 µg/m^3) for PM_{10} and 7.7 µg/m^3 (temporal maximum of 25 µg/m^3) for $PM_{2.5}$.

The type of activity influenced the indoor levels. The group classes included cycling, body and mind activities (such as yoga or Pilates), high energy classes (jump or body attack) and part-specific or full-body workout classes with barbells or other material (body pump, GAP) (Figure 2). The highest concentrations were observed during the body and mind class (PM_{10}: mean of 27.0 µg/m^3, range of 16.9-44.1 µg/m^3; $PM_{2.5}$: 7.0 µg/m^3, range of 4.2-16.0 µg/m^3). While movements in these classes were less vigorous, the use of aromatherapy diffusers during the class to create a relaxing environment resulted in increased concentrations. Cycling classes resulted in means of 12.5 µg/m^3 for PM_{10} and of 8.0 µg/m^3 for $PM_{2.5}$ (range: 5.4-31.2 µg/m^3 and 3.5-25.0 µg/m^3, respectively). The mean concentrations registered during the high energy classes were 17.7 and 6.4 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively, while they were 13.0 and 7.4 µg/m^3 during the group workout classes with equipment. Though temporal maxima of

$PM_{2.5}$ in studios occasionally reached values higher than 25 µg/m³, indoor air quality guidelines were fulfilled (Decreto-Lei n.º 118 2013; World Health Organization 2006).

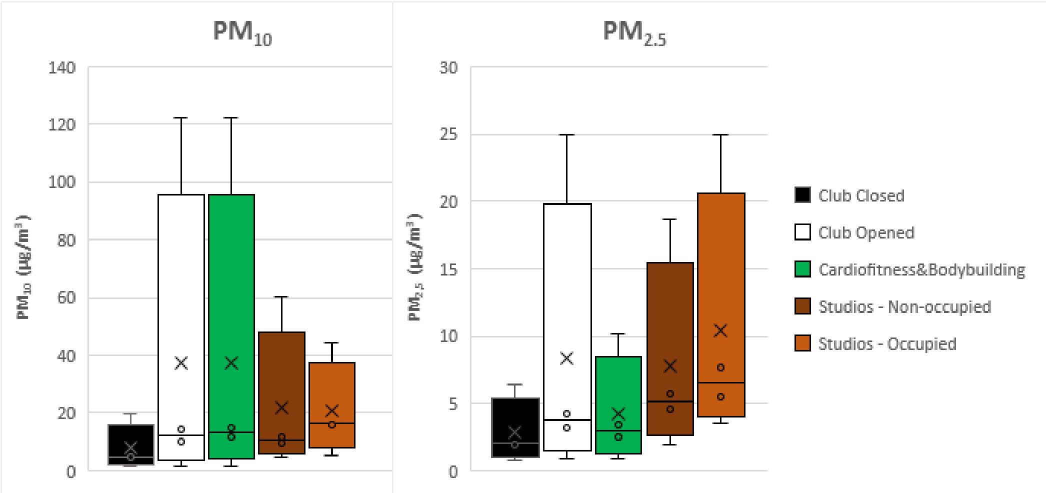

Figure 1: PM10 and PM2.5 levels at fitness center during occupied and non-occupied periods

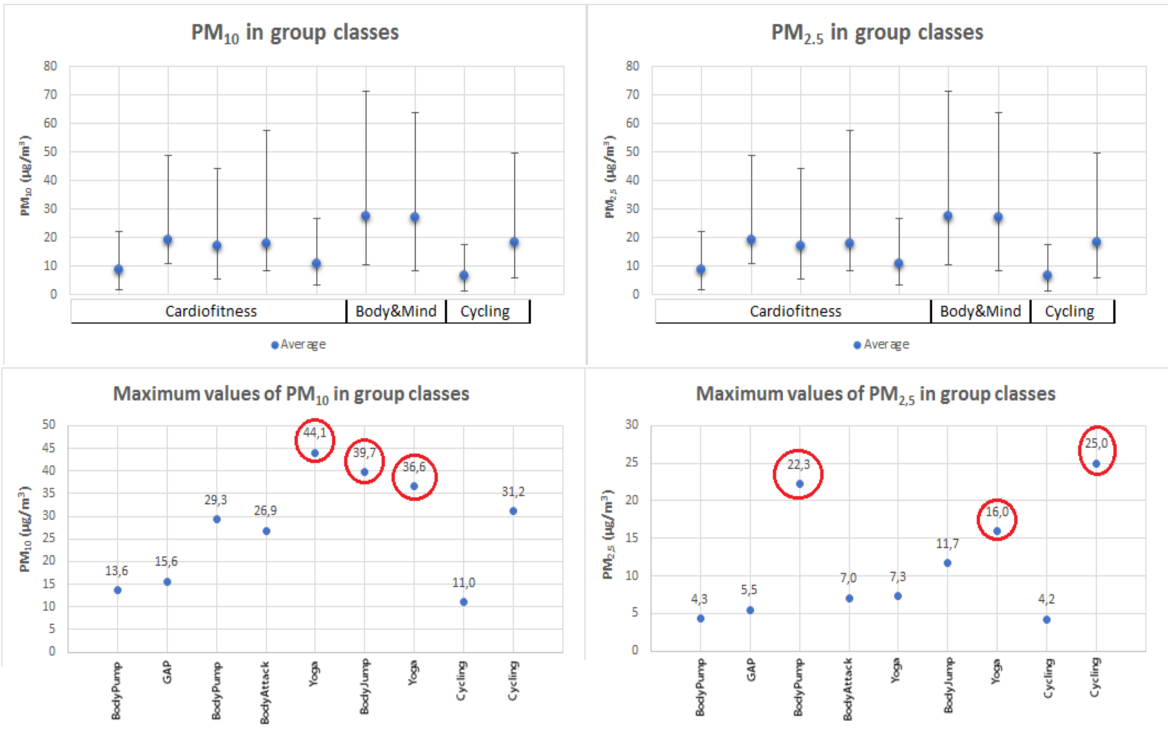

Figure 2: Maximum values of PM2.5 and PM10 in group classes

3.2. Gaseous pollutants

Unlike in the previous studies (Slezakova et al. 2018a; Ramos, Wolterbeek, and Almeida 2014; Alves et al. 2013), TVOCs levels (8 h averages) were almost always below the limit present in Portuguese legislation (0.6 mg/m³) during the sampling (an exception was registered on day 3; Figure 3a). Means (24 h) of TVOCs of 0.39 mg/m³ (median: 0.11 mg/m³) when not occupied and 0.43 mg/m³ (median: 0.38 mg/m³) during occupied period (opened club) were obtained (Figure 3b). Although the obtained average values fulfilled the legislation threshold, the maximum TVOCs levels were 5.3 times higher than the legislation limit when occupied. Note that during the period without occupants (i.e. when closed), the maximum TVOCs concentrations were still 1.4 times higher than the legislation limit of 0.6 mg/m^3. TVOCs are released from various personal care products (perfumes, hair sprays, hand sanitizers) (Corsi et al. 2007). However, they are also emitted directly from humans themselves through exhaled breathing and perspiration (Lacy Costello et al. 2014; Sun, He, and Yang 2017), which can contribute to the respective indoor levels (Gao, Xie, and Yang 2015; Wisthaler and Weschler 2010). Thus, the implemented public health restrictions, namely the limitation of the human occupancy, impacted the obtained levels. In addition, it needs to be noted that during the sampling campaign shower facilities were used to a much lesser degree due to the personal preference of the clients aiming to avoid possible infection and virus transmission.

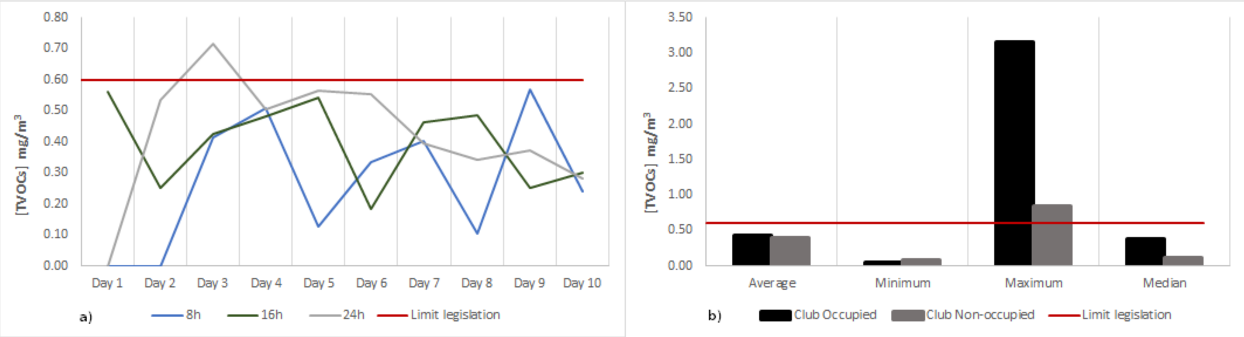

Figure 3: a) Temporal profiles (8 h) of TVOCs during the sampling period; b) TVOCs concentrations during non-occupied vs. occupied periods

The average CO_2 was 1400 mg/m^3 (range 122-2894 mg/m^3). When occupied, indoor CO_2 was slightly (though not significantly; $p=0.05$) higher than when closed. The temporal maxima (2660-2894 mg/m^3) exceeded the protection threshold defined in Portuguese legislation. Whereas CO_2 does not pose a direct hazard to human health at the levels detected in clubs, exposure to moderate concentrations can cause changes in human performances and influence decision-making (Persily 1997; Satish et al. 2012). Concerning the group activities, mean CO_2 fulfilled the defined limit, on contrary to the previous studies (Slezakova et al. 2018a; Ramos, Wolterbeek, and Almeida 2014).

CO is monitored in indoor air due to its toxicity to human health; The information concerning its levels in sport facilities is very scarce. The results obtained in this study showed that observed CO levels clearly fulfilled the Portuguese legislation limit of 10 mg/m^3 (8 h average: 0.07 – 1.94 mg/m^3), being in agreement with the previous studies (Slezakova et al. 2018a; Ramos, Wolterbeek, and Almeida 2014; Alves et al. 2013).

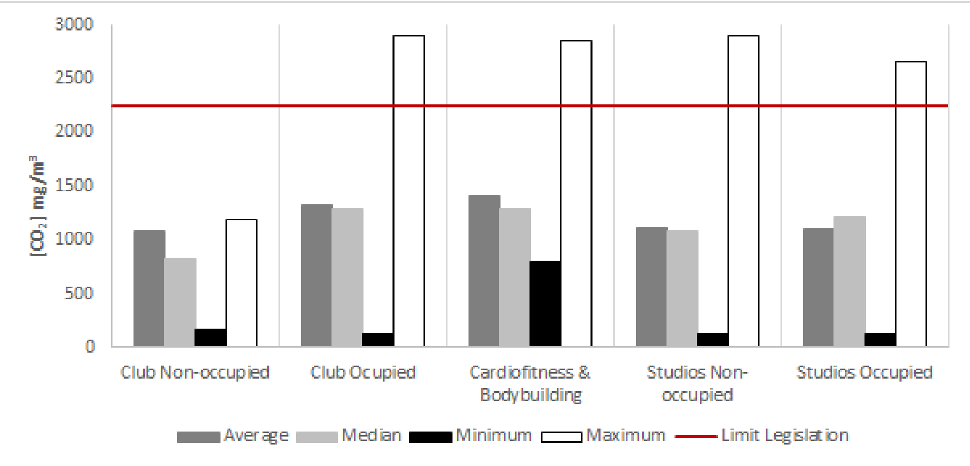

Figure 4: CO2 levels in studied indoor spaces

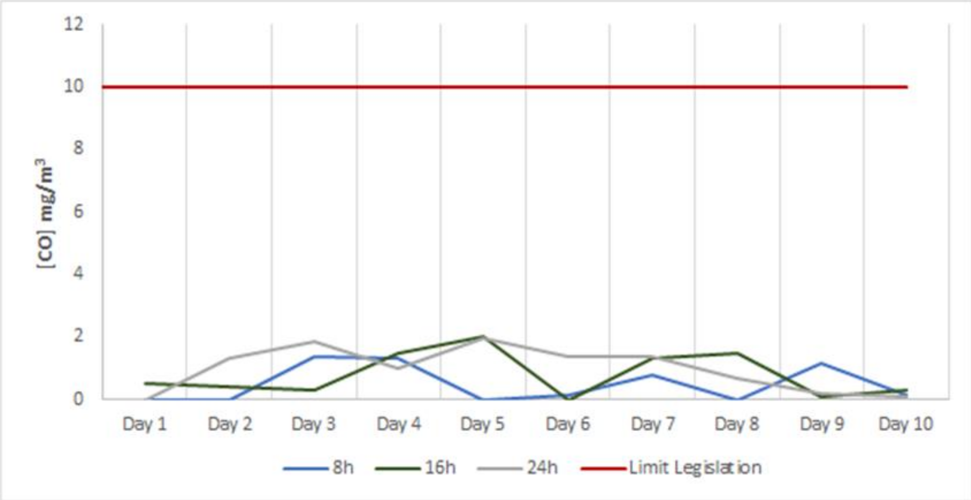

Figure 5: CO levels (8 h average)

3.3. Comfort parameters

T and RH are parameters that affect the thermal comfort of the respective occupants. The RH levels recommended by different international organizations range from 30 to 60%. For RH in range of 30 and 60%, American Society of Heating (ASHRAE) recommends an indoor T range of 23.0 – 25.8 ºC (ASHRAE, n.d.). During the respective 10 days of sampling, the overall mean ambient air temperature was 15.4 °C (means of 9.9 °C and 20.8 °C for the minimum and maximum air temperature, respectively) (IPMA 2020). The indoor T between the occupied and non-occupied periods were not statistically different ($p <0.05$) with means of 22.6 ºC and 22.8 ºC, respectively. During group classes, lower temperature values (17.7 ºC) were obtained due to the sporadic use of the air conditioning system. Nevertheless, the obtained mean value did not meet the recommendations, constantly exceeding the comfort limits (maximum values up to 24-25.7 ºC). Concerning the RH, when exercising, breathing and perspiration generate a substantial amount of water vapor, which impacts the observed levels of RH (Žitnik et al. 2016). The mean RH in bodybuilding and cardio fitness area was 57%. These values were slightly higher in the group activity studio, with an average RH of 63%. Thus, it was possible to conclude that the average RH values were in accordance with the comfort guidelines through high temporal maxima (75%) that were occasionally registered indicate the necessity for comfort parameters monitoring in sports facilities.

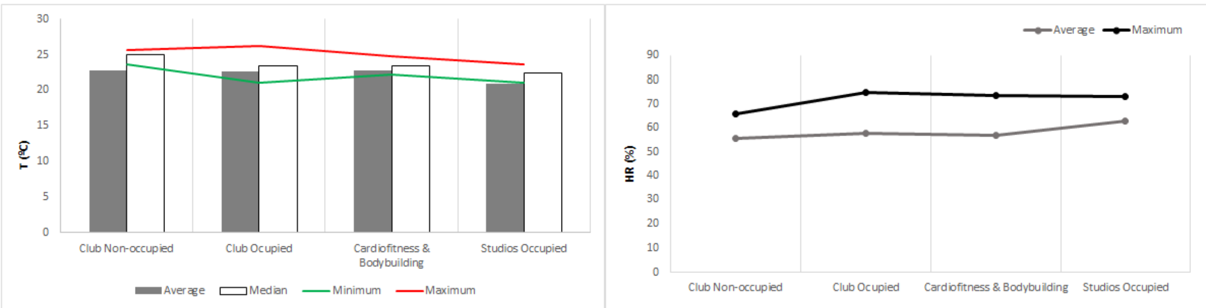

Figure 6: Temperature (ºC) and relative humidity (%) levels

4. Conclusions

This work evaluated the levels of particulate matter, gaseous pollutants and comfort parameters in the indoor air of a sports facility in the post lockdown period. Over the period of the sampling, despite the altered ventilation, PM_{10} and $PM_{2.5}$ fulfilled the limits for indoor air quality, though some temporal exceedance was observed. The highest concentration of

PM corresponded to the classes with the greatest number of practitioners, resulting from the occupant's physical activities, emissions from equipment and resuspension of particulate material due to the physical exercise performed (Alves et al. 2014; Slezakova et al. 2018a; Slezakova et al. 2018b). The restrictions in the number of occupants led to lower TVOCs and CO2 concentrations than previously reported. However, the restrictions on ventilation did not favor the levels of comfort parameters, especially in group classes (conducted with high activity intensity). Since regular exercise in environmental conditions, such as elevated T and increased RH can cause several health consequences (Sylvester et al. 2016; Racinais et al. 2012; Roelands, De Pauw, and Meeusen 2015), comfort parameters should be maintained within the recommended ranges by the proper use of air conditioning systems, isolation of the environment, reduction of sun/heat, even during restricted ventilation scenarios.

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