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POLUENTES ATMOSFÉRICOS E EXERCÍCIO EM AMBIENTES INTERNOS: REVISÃO SISTEMÁTICA BASEADA NAS DIRETRIZES GLOBAIS DE QUALIDADE DO AR DA OMS 2021

ATMOSPHERIC POLLUTANTS AND INDOOR EXERCISE: A SYSTEMATIC REVIEW BASED ON THE WHO 2021 GLOBAL AIR QUALITY GUIDELINES

CONTAMINANTES ATMOSFÉRICOS Y EJERCICIO EN AMBIENTES INTERIORES: REVISIÓN SISTEMÁTICA BASADA EN LAS DIRECTRICES MUNDIALES DE CALIDAD DEL AIRE DE LA OMS 2021

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Resumo

Os objetivos deste estudo foram: (i) identificar os principais poluentes ambientais em ambientes internos e suas respectivas fontes; (ii) comparar suas concentrações com as Diretrizes Globais de Qualidade do Ar da OMS de 2021 (AQGs); e (iii) analisar os riscos à saúde associados ao exercício físico. Este estudo seguiu os critérios PRISMA e foi registrado na plataforma PROSPERO. A busca bibliográfica foi realizada nas bases LILACS, MEDLINE, PubMed, SciELO e Scopus. Os critérios de inclusão consideraram estudos publicados entre 2018 e 2023. O risco de viés foi avaliado utilizando as ferramentas de avaliação crítica do Joanna Briggs Institute. O monitoramento dos poluentes foi conduzido em ambientes internos onde o exercício físico era realizado. Foi feita uma comparação entre as concentrações desses poluentes e as AQGs da OMS, e foram avaliadas as consequências do exercício físico nesses ambientes para a saúde. As principais conclusões foram: (i) os principais poluentes em ambientes internos foram CO, CO_2, $MP_{2,5}$, MP_{10} e SO_2, sendo que as concentrações de MP e CO_2 estiveram diretamente relacionadas ao tipo de esporte, ao número de participantes e às condições de ventilação; (ii) nove estudos relataram concentrações acima e cinco estudos relataram concentrações abaixo dos valores recomendados pelas AQGs da OMS, enquanto quatro estudos abordaram poluentes ainda não incluídos nas AQGs da OMS; e (iii) os principais riscos à saúde humana estiveram relacionados a doenças respiratórias e cardíacas.

Palavras-chave: Exercício físico; Material particulado; Poluição do ar interior; Qualidade do ar interior; Síndrome dos edifícios doentes.

Abstract

The aims of this study were: (i) to identify the key indoor environmental pollutants and their respective sources; (ii) to compare their concentrations with the WHO 2021 Global Air Quality Guidelines (AQGs); and (iii) to analyze the health risks associated with physical exercise. This study followed the PRISMA criteria and was registered in PROSPERO. The literature search was conducted in the LILACS, MEDLINE, PubMed, SciELO, and Scopus databases. The inclusion criteria considered

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Pages: 1-37

studies published from 2018 to 2023. Risk of bias was assessed using the Joanna Briggs Institute Critical Appraisal Tools. Pollutant monitoring was conducted in indoor environments where physical exercise was performed. A comparison was made between the concentrations of these pollutants and the WHO AQGs, and the health consequences of physical exercise in these environments were evaluated. The main conclusions were as follows: (i) the main indoor pollutants were CO, CO2, PM2.5, PM10, and SO2, and PM and CO2 concentrations were directly related to the type of sport, number of participants, and ventilation conditions; (ii) nine studies reported concentrations above, and five studies reported concentrations below, the values recommended by the WHO AQGs, while four studies addressed pollutants not yet included in the WHO AQGs; and (iii) the main health risks to humans were related to respiratory and cardiac diseases.

Keywords: Physical exercise; Particulate matter; Indoor air pollution; Indoor air quality; Sick building syndrome.

Resumen

Los objetivos de este estudio fueron: (i) identificar los principales contaminantes ambientales en interiores y sus respectivas fuentes; (ii) comparar sus concentraciones con las Directrices Mundiales de Calidad del Aire (AQGs) de la OMS 2021; y (iii) analizar los riesgos para la salud asociados con la práctica de ejercicio físico. Este estudio siguió los criterios PRISMA y fue registrado en PROSPERO. La búsqueda bibliográfica se realizó en las bases de datos LILACS, MEDLINE, PubMed, SciELO y Scopus. Los criterios de inclusión consideraron estudios publicados entre 2018 y 2023. El riesgo de sesgo se evaluó mediante las herramientas de evaluación crítica del Instituto Joanna Briggs. El monitoreo de los contaminantes se llevó a cabo en ambientes interiores donde se realizaba ejercicio físico. Se compararon las concentraciones de estos contaminantes con las AQGs de la OMS y se evaluaron las consecuencias para la salud de la práctica de ejercicio físico en estos ambientes. Las principales conclusiones fueron: (i) los principales contaminantes en interiores fueron CO, CO2, PM2,5, PM10 y SO2, y las concentraciones de material particulado y CO2 se relacionaron directamente con el tipo de deporte, el número de participantes y las condiciones de ventilación; (ii) nueve estudios informaron concentraciones por encima y cinco estudios concentraciones por debajo de los valores recomendados por las AQGs de la OMS, mientras que cuatro estudios abordaron contaminantes aún no incluidos en dichas directrices; y (iii) los principales riesgos para la salud humana se relacionaron con enfermedades respiratorias y cardíacas.

Palabras clave: Ejercicio físico; Material particulado; Contaminación del Aire Interior; Calidad del aire Interior; Síndrome del Edificio Enfermo.

1. INTRODUCTION

The concern for Indoor Air Quality (IAQ) stems from scientific research that intensified in the 1970s. As a result of the association between air quality and health, the World Health Organization (WHO) acknowledged that air pollution is one of the greatest ecosystem threats to human health (WHO, 2016). What determines an element as a pollutant is the volume of its concentration added to the environment, significantly capable of causing measurable damage to living and non-living beings (FREEDMAN, 1995).

Previous studies showed that the outdoor/indoor air exchange rate is the main

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Pages: 1-37

factor responsible for the increase in indoor pollutant concentrations (SCHIRMER et al., 2011). Ventilation is one of the most important procedures used in the removal of pollutants in indoor environments and/or bioaerosols (e.g., bacteria, fungi, and viruses), as well as disinfection, thus attenuating the threat of exposure, particularly in public spaces such as gyms, offices, and sports arenas (XU et al., 2020).

The global outbreak of Coronavirus Disease 2019 (COVID-19) and its airborne transmission drew attention to the importance of air quality in enclosed spaces, specifically regarding ventilation, air conditioning, and indoor and/or outdoor bioaerosols and other pollutants. This event highlighted the need to consider air quality as an important factor in preventing the spread of diseases.

In 2021, the WHO revised and established new air quality guidelines based on health through its WHO Global Air Quality Guidelines 2021. These guidelines aim to help governments and civil society reduce human exposure to air pollution and its adverse health effects. These guidelines are aligned with the United Nations Sustainable Development Goals (SDGs), which were developed to address the public health threat posed by air pollution.

This study is a systematic review of descriptive–analytical cross-sectional observational studies, conducted in accordance with the PRISMA recommendations and registered in the PROSPERO platform under number CRD42022354515.

In this context, the aims of this systematic review were: (i) to identify the main indoor environmental pollutants in environments used for physical exercise and their respective sources; (ii) to compare the concentrations of these indoor pollutants with the standards established by the World Health Organization (WHO) through its Global Air Quality Guidelines (AQGs) 2021; and (iii) to analyze the health risks associated with the presence of major indoor pollutants in these environments.

2. MATERIAL AND METHODS

A systematic review of descriptive-analytical cross-sectional observational studies was performed in the recent literature (from 2018 to 2023). The study followed these steps: (i) literature article search, (ii) data collection, (iii) critical study analysis, (iv) results discussion, and (v) presentation of the review (SOUZA; SILVA;

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CARVALHO, 2010).

Study searches were performed in databases including LILACS, MEDLINE, and PubMed through the Virtual Health Library (BVS) Data Portal, SciELO, and Scopus. The following descriptors were used for the initial study selection: MeSH Terms (Medical Subject Headings); Exercise, Particulate Matter, Indoor Air Pollution, Indoor Air Quality, and Sick Building Syndrome; and DeCS (Health Sciences Descriptors) from BVS; Exercise, Particulate Matter, Indoor Air Pollution, Indoor Air Quality, and Sick Building Syndrome concatenated with the Boolean operator "AND": Particulate Matter AND Exercise, Indoor Air Pollution AND Exercise, Indoor Air Quality AND Exercise, Sick Building Syndrome AND Exercise, Particulate Matter AND Physical Exercise, Indoor Air Pollution AND Physical Exercise, Indoor Air Quality AND Physical Exercise, Sick Building Syndrome AND Physical Exercise. These databases were chosen due to their significance and relevance in health sciences, sports, and the environment.

The search was conducted from September 25, 2022, to May 9, 2023. Inclusion criteria considered studies published within the last five years (2018 to 2023), which aligns with the scope of this study (SAMPAIO and MANCINI, 2007), in any language, and studies with both quantitative and qualitative approaches after an initial search with no date or year restrictions. Excluded were duplicate articles, gray literature (Open Grey, www.opengrey.eu), inconclusive studies, those with a high risk of bias, and other literature reviews.

Bias risk in the studies was evaluated according to The Joanna Briggs Institute (JBI) Critical Appraisal Tools (Checklist for Analytical Cross-Sectional Studies) for use in JBI Systematic Reviews (MOOLA et al., 2017). The JBI critical appraisal list for analytical cross-sectional studies was assessed based on the following questions: Were the sample inclusion criteria clearly defined? Were participants and study conditions described in detail? Was exposure measured validly and reliably? Were objective and standardized criteria used for measurement conditions? We are confounding factors identified? Were strategies for dealing with confounding factors stated? Were results measured validly and reliably? Was appropriate statistical analysis used? This analysis aimed to evaluate the

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Pages: 1-37

methodological quality of a study and to what extent it addressed the possibility of bias in its design (Supplementary Material Table 1).

For initial eligibility, the titles and abstracts of each record were considered to assess compatibility with the topic. The steps followed in the study are illustrated in the PRISMA flowchart (Figure 1).

All steps of study identification, screening, eligibility, and inclusion followed the PRISMA recommendations and are documented in the flow diagram presented in Figure 1. The protocol of this systematic review was prospectively registered in PROSPERO (CRD42022354515).

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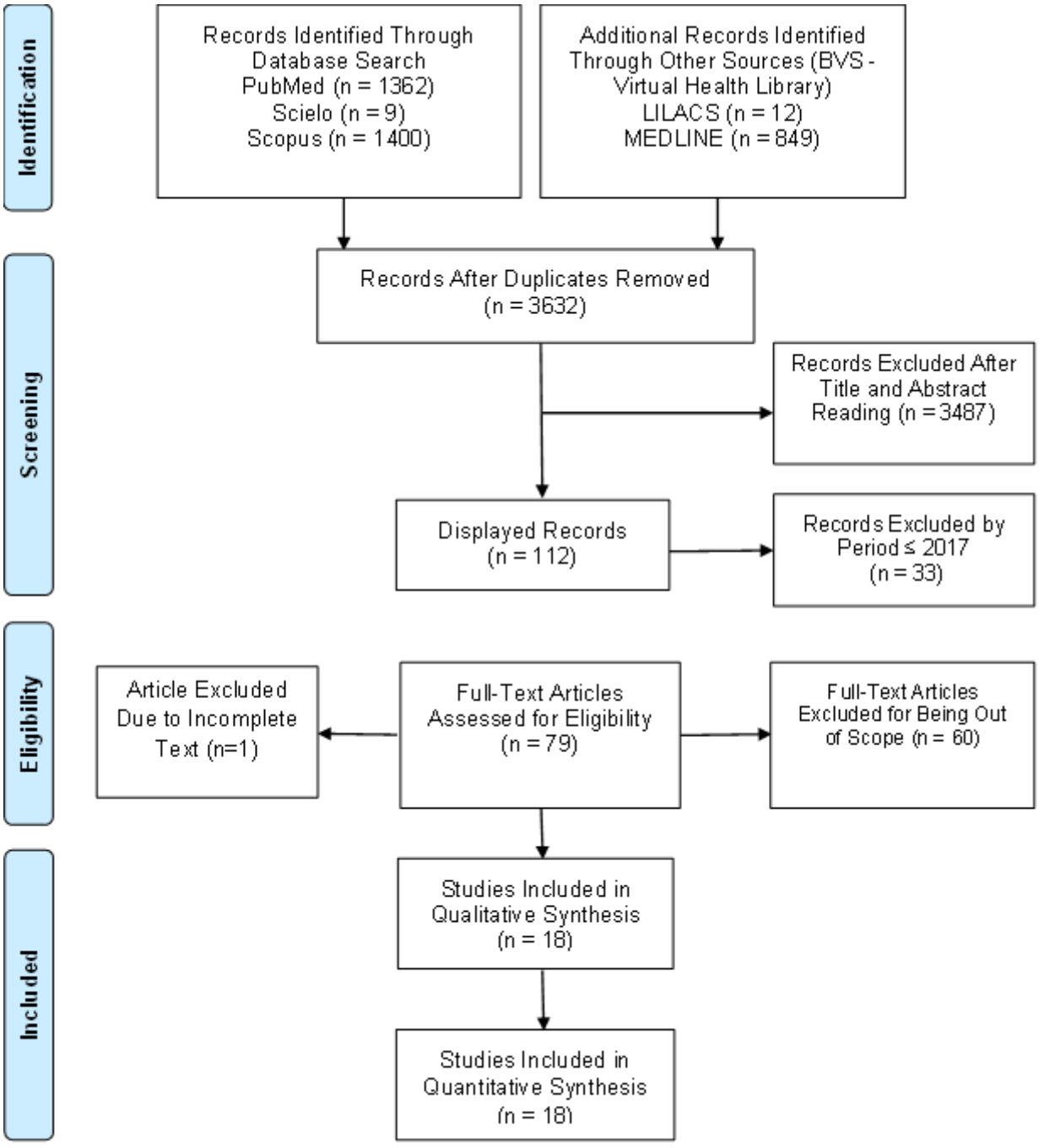
Pages: 1-37

Figure 1. Literature Search Strategy Flowchart



Source: Preferred Reporting Items for Systematic Reviews and Meta-Analysis: The PRISMA Statement (Moher et al., 2009)"*The PRISMA Statement (*Moher *et al., 2009)*.

After analyzing the study titles and abstracts, all texts were examined to extract relevant information to discuss the topic. Some key data, including author and year, objective, indoor environmental pollutants, sources of indoor environmental

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pollutants, and outcomes, were used for critical analysis and subsequent data synthesis.

This systematic literature review was conducted following the recommendations of (KHAN et al., 2003) as follows: 1) framing the questions for literature review; 2) identifying relevant research; 3) assessing study quality; 4) summarizing evidence; 5) interpreting results. Additionally, we adhered to the 24 items through checklists from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (MOHER et al., 2015) to ensure transparent and comprehensive communication of this Systematic Review.

The research question and eligibility criteria for study inclusion in a Systematic Literature Review were defined using the PVO model (Population or Problem-Variables-Outcome) following PRISMA guidelines (MOHER et al., 2015). According to the PVO model, the following were established: Population or Problem: Indoor Environments Used for Physical Exercise, Physical Activity, and Sports Practice; Variables: Indoor Air Pollution; Outcome: Risks to Human Health.

The research project was registered with PROSPERO (International Prospective Register of Systematic Reviews) under number CRD42022354515 at the Centre for Reviews and Dissemination - University of York, UK. Before the formal results, screening based on eligibility criteria was completed (BOOTH et al., 2012). According to the registration, effect measures were identified, and the results were categorized into four domains: (i) air quality monitoring following international guidelines; (ii) indoor-outdoor (I/O) ratio; (iii) air quality during physical exercise; and (iv) impact of air quality on human health.

Thus, this systematic review aligns with the categorization of four Domains (Domain 1 - Comprehensive; Domain 2 - Rigorous; Domain 3 - Transparent; Domain 4 - Objective), representing characteristics of good practice conduct to be followed in systematic reviews. Though overcome in this work, possible issues that can be identified in each domain are described at https://systematicreviewlution.com/ (UTTLEY et al., 2023).

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Pages: 1-37

These four domains (comprehensive, rigorous, transparent, and objective) were used as a reference to ensure good methodological practice in the conduct of the review and in the interpretation of the findings.

3. RESULTS AND DISCUSSION

The results presented below are discussed in light of the WHO Global Air Quality Guidelines 2021, considering the physiological mechanisms of damage and the implications for the practice of physical exercise in indoor environments.

Due to the significance of air quality for physical exercise and sports, this study aimed to investigate IAQ in environments used for physical exercise and/or sports practice through a systematic review. The search identified 3,632 articles; full-text articles assessed for eligibility were 79, of which 18 met the inclusion criteria.

To investigate this topic, we divided the results of the selected studies into 5 categories, according to the main findings of the selected studies: i) Number of studies per pollutant; ii) IAQ monitoring according to WHO Global Air Quality Guidelines (2021) guidelines; iii) IAQ during exercise; iv) Outcome of exposure to indoor and outdoor environmental pollutants during physical exercise; v) Impacts of indoor air pollution on human health according to WHO Global Air Quality Guidelines (2021).

Number of studies and analyzed pollutants

All studies used descriptive analytical cross-sectional observational and quantitative experimental methods. The research sites were indoor environments where physical exercise and/or physical activity occur. A total of 24 different pollutants were analyzed in 18 studies. The most evaluated pollutants were $PM_{2.5}$, CO_2, PM_{10}, CO, and SO_2 in 9, 9, 8, 5, and 5 studies, respectively (Table 1).

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Pages: 1-37

Table 1. Pollutants and Number of Studies by Pollutants

Pollutants	Number of studies
Bacterial Bioaerosols (anemophilic fungi, bacteria, viruses)	3
CH_4 (Methane)	1
$CHBrCl_2$ (Bromodichloromethane)	1
$CHBr_2Cl$ (Dibromochloromethane)	1
$CHCl_3$ (Trichloromethane or Chloroform)	1
CO (Carbon Monoxide)	5
CO_2 (Carbon Dioxide)	9
FeNO (Fractional Exhaled Nitric Oxide)	2
NO_2 (Nitrogen Dioxide)	3
NOx (Inorganic Compounds)	2
NO (Nitric Oxide)	1
O_3 (Ozone)	4
Ultrafine Particles (< 2.5μm) and Ultrafine Particles (below 100 nm)	2
PM (<10μm) (Particulate Matter)	1
PM_1 (Particulate Matter 1μm), (1 micron)	5
$PM_{2.5}$ (Particulate Matter 2.5μm), (2.5 microns)	9
PM_4 (Particulate Matter 4μm), (4 microns)	1
PM_7 (Particulate Matter 7μm), (7 microns)	1
PM_{10} (Particulate Matter 10μm), (10 microns)	8
HCHO (Formaldehyde)	2
SO_2 (Sulfur Dioxide)	5
TVOCs (Total Volatile Organic Compounds)	3
VOCs (Volatile Organic Compounds)	2

Source: Prepared by the authors (2026).

After years of intensive research and deliberations with experts worldwide, the WHO updated its Global Air Quality Guidelines (AQGs) from 2005 to September 2021 – WHO Air Quality Guidelines 2021 (WHO, 2021). The requalification of WHO AQGs was essential as several scientific works from the past twenty years have demonstrated the extent to which air

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Pages: 1-37

pollution affects human health and the resulting consequences can harm organs and overall human physiological functions (THURSTON et al., 2017).

The substantiation of the aforementioned assertion is evident through the studies that analyzed various pollutants, as demonstrated in Table 1. Recent studies and significant research programs reinforce that adverse effects of air pollution are not limited to high exposures; harmful effects on human health can be observed even at very low concentration levels with no observable threshold below which exposure could be considered safe (BRAUER et al., 2019; DOMINICI et al., 2019).

Studies Analyzed Environments and Indoor Pollutants

Eighteen studies investigated the association between indoor environments where physical exercise is conducted and pollutants. In all these monitored indoor environments, the presence of only one pollutant was assessed in 4 studies, whereas in 14 studies, the presence of 2 or more pollutants was investigated (Table 2).

Table 2. References, pollutants, and monitored environment

References	Pollutants	Monitored environment
Slezakova *et al*. (2019)	Ultrafine particles (< 2,5μm)	Gymnasiums
Kocot and Zejda (2021)	SO_2, NOx, $PM_{2,5}$, PM_{10}, FeNO	Room with Outdoor Air Exposure Conditions
Kocot *et al*. (2020)	$PM_{2,5}$, PM_{10}, SO_2, NO_2, NOx, NO, FeNO	University Sports Pavilions
Liu *et al*. (2020)	$PM_{2,5}$, O_3, NO_2, SO_2, CO	Indoor and Outdoor Residential Spaces
Zavieh *et al.* (2021)	Bacterial Bioaerosols (aeromycophytes, bacteria, viruses)	Gyms
Felgueiras *et al*. (2020)	Ultrafine Particles (below 100nm), CO, CO_2	Covered Olympic Swimming Pool
Bennett *et al.* (2018)	$PM_{2,5}$, PM_{10}	Room
Heaney *et al*. (2020)	$CHCl_3$, $CHBrCl_2$, $CHBr_2Cl$	Indoor Pool
Slezakova *et al.* (2018)	TVOCs, PM_1, PM_4, CO, CO_2, O_3	Gyms
Xie *et al*.	TVOCs, $PM_{2.5}$, PM_{10}, CO_2	

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Pages: 1-37

(2021)		Badminton Hall
Andrade *et al.* (2018)	CO_2	Gyms
Boonrattanakij *et al.* (2021)	Bacterial Bioaerosols, CO_2, PM_1, $PM_{2.5}$, PM_7, PM_{10}	Gym
Kapalo *et al.* (2019)	CO_2	University Classrooms
Finewax *et al.* (2021)	VOCs, CO_2, NH_3, CH_4, O_3, SO_2	Weight Room
Gu *et al.* (2021)	VOCs, Bacterial Bioaerosols, CO, CO_2, SO_2, NO_2, HCHO e PM (below 10µm)	Gyms
Rodeo *et al*. (2022)	PM_1, $PM_{2.5}$, PM_{10}	Laboratory Interior
Cassilhas *et al*. (2022)	PM_1, $PM_{2.5}$, PM_{10}	Laboratory Interior and Outdoor in Urban Park
Mazoteras-Brown *et al*. (2023)	CO, CO_2, HCHO, TVOCs, PM_1, $PM_{2,5}$, PM_{10}, O_3	Interior and Exterior of Training Center

Source: Prepared by the authors (2026).

In accordance with the study by Kocot et al. (2020), 76 participants engaged in physical activities in indoor environments exposed to pollutants such as $PM_{2.5}$, PM_{10}, SO_2, NO_2, NOx, NO, and FeNO with concentrations exceeding the limits permitted by the WHO Global Air Quality Guidelines (2021). During the exposure trial, there was an increase in FeNO (Fractional Exhaled Nitric Oxide), an important lung inflammation biomarker. High concentrations of FeNO indicate eosinophilic and allergic inflammation of the airways, which is why its measurement is used in diagnosing and managing diffuse airway inflammation (asthma) (HOYTE et al., 2018).

According to Shi et al. (2016), FeNO is also affected by air pollution, even in non-asthmatic individuals, which supports the findings of Kocot et al. (2020). Not only gaseous pollutants but also ultrafine particles are harmful, as observed in the study by Slezakova et al. (2019), where their levels were also above the recommendations of the WHO Global Air Quality Guidelines (2021).

In patients with Implantable Cardioverter Defibrillators (ICD), exposure to air pollution can exacerbate adverse cardiovascular effects (Liu et al., 2020). CO_2 concentrations increase as the gym's opening hours for physical activities extend, and the number of participants increases. They also rose in the spinning room and running areas in 3 gyms. They were 3 times higher in the spinning room than before

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Pages: 1-37

its use. Inhalable PM below 10μm also increased 2.5 times compared to before the spinning room was used (GU et al., 2021).

In their study at a badminton gym, Xie et al. (2021) found that physical activity is a significant source of PM. Although China has not yet established a national standard for indoor $PM_{2.5}$, the concentrations found exceeded the recommendations of the WHO Global Air Quality Guidelines (2021). Regarding PM10, there is a Chinese standard, but the concentrations of this particulate matter were elevated compared to the Chinese standard and the WHO Global Air Quality Guidelines (2021).

In studies conducted at ice skating rinks, researchers H. Guo, S.C. Lee, and L.Y. Chan found that emissions of CO and NO_2 from resurfacing machines caused air pollution issues (Yoon et al., 1996; Guo et al., 2004). Ramos et al. (2014) investigated the IAQ of 11 fitness centers in Lisbon and found that CO_2 volatile organic compounds (VOC) and CH_2O concentrations exceeded the upper limits of the Portuguese national standard. However, a correlation cannot be established since they are not specified in the WHO Global Air Quality Guidelines (2021).

Indoor Air Quality (IAQ) during Exercise

The pollutant levels examined in indoor environments where physical activities were conducted in the 18 studies were compared with the new WHO Global Air Quality Guidelines (2021) (Table 1S – Supplementary Material). In 9 studies, the levels of most pollutants exceeded the recommendations of the new WHO Global Air Quality Guidelines (Figure 2).

REMUNOM
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Vol: 13.15
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Pages: 1-37

Figure 2. References, Comparison of Pollutants with the New WHO Global Air Quality Guidelines



* Airborne fungi, bacteria, viruses, and so forth.

Concentration Below the *WHO Global Air Quality Guidelines* (2021)

Concentration Above the *WHO Global Air Quality Guidelines* (2021)

Not accounted for in the *WHO Global Air Quality Guidelines* (2021)

Source: Prepared by the authors (2026).

Riva et al. (2011) demonstrated that even a single exposure to a reduced dose of $PM_{2.5}$ caused lung tissue inflammation and oxidative stress in mice. However, in the study by Wagner and Clark (2018), an acute session of vigorous exercise in an environment with $PM_{2.5}$ pollution did not decrease exercise performance in healthy and avid individuals, nor did it harm lung function in tests or biological health markers. The exercise performance and lung function tests of healthy adults may not be sensitive enough to detect minor deleterious effects that likely occur from acute exposure to mild $PM_{2.5}$ air pollution.

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Adding physical exercise and/or physical activity leads to improved breathing, which in turn results in increased exposure to various atmospheric pollutants, causing various health damages. One of these air pollutants is ultrafine particles (UFP). High-intensity activities like running and cycling resulted in a 4 to 4.2 times increase in UFP inhalation, specifically for indoor exercise. In indoor group activity classes (Yoga, Pilates, Thai chi), lower doses of UFP were inhaled. However, when participants engaged in a mix of cardio and strength training, UFP inhalation increased by around 1.8 times. To optimize the health benefits of exercise, the environmental conditions of the places where it is performed need to be considered (SLEZAKOVA et al., 2019).

Kocot and Zejda (2021) found that physical exercise and/or physical activity in an air-polluted environment can increase the absorbed dose of atmospheric pollutants. During exercise on a cycle ergometer, elevated air pollutant concentrations were observed, with SO_2 being a statistically significant predictor of immediate (OR: 1.09, 95% CI: 1.01–1.17) and delayed airflow reduction (OR: 1.08, 95% CI: 1.01–1.16), and $PM_{2.5}$ also being a statistically relevant explanatory variable for the post-exercise decline in FEV1/FVC [FEV1 (forced expiratory volume in 1 second)/FVC (forced vital capacity)] (OR: 1.03, 95% CI: 1.00–1.06).

Particulate matter increases nitric oxide production through epigenetic changes, and the associations between $PM_{2.5}$ and Exhaled Nitric Oxide (FeNO) were stronger one day after exercise (CHEN et al., 2015).

Initially characterized as a relaxing element derived from endothelium important for arterial tone, nitric oxide (NO) is recognized as an important biomarker for respiratory diseases. Scientific studies confirmed that fractional FeNO concentration is increased in the airways of asthma patients and is well correlated with the presence and level of airway inflammation. FeNO is an important auxiliary tool in managing asthma and other inflammatory diseases (HOYTE et al., 2018).

According to Kocot et al. (2020), the increase in FeNO was related to a higher level of physical activity and/or exercise and higher external concentrations of PM_{10} and NO_2. They concluded that participants with a high level of physical activity and/or

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Pages: 1-37

exercise are more likely to experience an increase in FeNO after engaging in physical activity in a polluted environment.

Gu et al. (2021) found that CO_2 concentrations were elevated as the gym's operating hours extended in the spinning room, the three aerobic exercise rooms, and the running room area. After using the spinning room, CO_2 concentrations were three times higher than before its use.

Xie et al. (2021) highlighted the importance of proper ventilation in sports and/or exercise environments when they analyzed ventilation in a badminton hall and found it to be poor. The impact of high humidity in the same location also led to a higher perception of heat among those present.

The correlation between relative humidity and atmospheric pollutants was demonstrated by Seurat et al. (2021), who showed that the effects of actual relative humidity combined with acute exposure to various atmospheric pollutants seemed to influence skin structure and the determination of the inflammatory response outcome, depending on the pollutants' physicochemical characteristics.

These conditions are consistent with the study by Rundell et al. (2018), which observed that environmental factors influencing airway diseases include relative humidity and airborne pollutants, including chemical irritants and particulate matter.

Results of Exposure to Indoor and Outdoor Environmental Pollutants During Exercise

According to the indoor environment and the exercise or human exposure taking place in it, the results of physical exercise and/or human exposure to pollutant levels in those environments were measured (Table 2 SM).

Regularly practicing physical activities, exercises, and sports improves respiration, alleviates health conditions, and makes human life healthier. However, exposure to and absorption of various atmospheric pollutants negatively impacts human health (SLEZAKOVA et al., 2019).

Engaging in indoor physical activities, exercises, and sports increases the number of individuals exposed to atmospheric pollutants due to inefficient and poor

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Pages: 1-37

ventilation in confined spaces designated for such practices (ANDRADE and DOMINSKI, 2018).

Indoor air quality (IAQ) and its consequences for human health have been the subject of studies and discussions worldwide in various sectors, particularly among policymakers and public health professionals. The elements that constitute indoor and outdoor atmospheric air are essential determinants of human health, which can be chemical, including VOCs, ketones, aldehydes, terpenes, formaldehyde, O_3, NO_2, CO, SO_2, particulate matter (PM) of aerodynamic diameter <10µm, <2.5µm, and <0.1µm (PM_{10}, $PM_{2.5}$, $PM_{0.1}$, respectively), asbestos, radon, tobacco smoke, or contaminants (BONNEFOY et al., 2003).

Human well-being is closely related to indoor and outdoor temperatures and indoor air quality. These are important determinants of health and performance in sports activities and/or daily life, influenced by environmental factors such as surface temperature, air movement, air exchange rate, relative humidity, pressure, and CO_2 (MENDES et al., 2015; MENDES et al., 2013; ORMANDY and EZRATTY, 2012).

Xie et al. (2021) also observed this, as despite the badminton hall's indoor temperature meeting the requirements of the Chinese national standard, the high relative humidity based on the Fanger method and poor ventilation led participants to feel excessively warm.

The indoor air quality of a training center, both for sports practice and rehabilitation, must be suitable to not only achieve the beneficial effects of physical activity and/or exercise but also mitigate the possibilities of respiratory disease transmission (MAZOTERAS-BROWN et al., 2023).

Physical activity and/or exercise in a polluted atmosphere results in high airway resistance. This fact was initially reported in protocols defining this relationship with O_3 at different concentrations (ADAMS, 1987; SCHONFELD et al., 1989).

During moderate and maximal exercise in an O_3-contaminated environment, symptoms such as dyspnea, respiratory discomfort, and a feeling of chest tightness can occur, leading to the rapid suspension of physical exercise and/or physical activity (McDonnell et al., 1999; CARDONA 1990).

REMUNOM
ISSN 2178-6925
Received: 21/06/2026 - **Accepted:** 11/07/2026
Vol: 13.15
DOI: 10.66104/p5bfmq98
Pages: 1-37

In Liu et al.'s study (2020), the intervention group, which engaged in indoor exercise, saw significant associations between O_3 and CO and increased oxygen saturation, which was not observed in the control group that exercised outdoors. However, this finding was inconsistent with Li et al. (2016), who associated significant short-term exposure to major atmospheric pollutants, particularly O_3 and NO_2, with an emergent risk of COPD.

Oxygen is essential for the human body, and hemoglobins transport it to cells. Oxygen saturation measures how much hemoglobin is currently bound to oxygen compared to how much remains unbound, making it an important biomarker for human respiratory health (HAFEN and SHARMA, 2022).

The concentrations of atmospheric pollutants absorbed by the lungs during physical activities and/or exercise are subject to both the volume of air and the magnitude, intensity, and type of physical exercise and/or physical activity performed, as well as the significance of the characteristic pulmonary physiological events associated with these practices, such as bronchodilation, increased ventilation, mouth breathing, and increased diffusion capacity (DAIGLE et al., 2003).

Kocot and Zejda (2021) found that individuals experienced a decline in airflow when the ambient air pollution was high ($PM_{2.5}$: 106 µg/m3; PM_{10}: 246 µg/m3; SO_2: 47 µg/m3). According to Rundell (2003), unusual respiratory signs were also observed after an hour of physical practice and an hour of physical inactivity in an environment affected by $PM_{2.5}$ and PM_{10}. In recreational sports practice, it was found that high concentrations of UFPs in the air impair cyclists' efficiency. Increasing exercise intensity also increases the production of reactive oxygen species (RODIO et al., 2022).

A crucial condition to be observed regarding cardiovascular diseases (CVD) is air pollution, which is composed of suspended particles in the air known as PM and is seen as the tenth leading cause of death globally (STANAWAY et al., 2018). An analysis of the association between atmospheric pollution and its consequences on the cardiovascular system confirmed that for every 10 µg/m3 increase in PM with a diameter less than 10 µm (PM_{10}) and PM with a diameter less than 2.5 µm ($PM_{2.5}$),

REMUNOM
ISSN 2178-6925
Received: 21/06/2026 - **Accepted:** 11/07/2026
Vol: 13.15
DOI: 10.66104/p5bfmq98
Pages: 1-37

there was an increase in indicators of cardiovascular hospitalization and mortality (NOGUEIRA, 2009).

This fact can be explained by a multitude of pathophysiological changes that occur in the cardiovascular system, including inflammation, coagulation, and heart rhythm (VANDERLEI et al., 2009; TASK FORCE OF THE EUROPEAN SOCIETY OF CARDIOLOGY AND THE NORTH AMERICAN SOCIETY OF PACING AND ELECTROPHYSIOLOGY, 1996).

High ventilatory demands of physical activity and/or exercise intensify total exposure to deleterious stimuli, allowing particulate matter to be deposited at deeper levels within the lungs (DAIGLE et al., 2003). Healthy and non-healthy individuals, with and without respiratory diseases, can experience respiratory symptoms in environments with atmospheric pollutants or cold and dry air. These symptoms can range from recent-onset asthma due to chronic inhalation of atmospheric pollutants to acute exercise-induced bronchoconstriction reactions to chronic exposure-related development of asthma and other allergic/immunologic conditions (RUNDELL et al., 2018).

Shi et al. (2022) also found that exposure to atmospheric pollutants can cause allergic airway inflammation, increase FeNO levels in exercised populations, and adversely affect human health.

Indoor aerobic exercise, when performed under low PM and UFP concentrations, provides more significant benefits in glycemic management, improves cognition, and increases levels of Brain-Derived Neurotrophic Factor (BDNF) compared to the same activity performed outdoors under high concentrations of the same environmental pollutants (CASSILHAS et al., 2022).

Some VOCs are classified as highly harmful indoor air pollutants to human health, even at low concentrations (WHO, 1989; KUMAR et al., 2016). Total volatile organic compounds (VOCs) are the sum of concentrations of identified and unidentified VOCs (WHO, 2010).

Formaldehyde is a VOC, a ubiquitous indoor air pollutant. It is released from common wood-based raw materials, coatings, insulation, and floors. Short-term exposures to formaldehyde cause eye and nose irritation (GODISH, 2016; KULLE,

REMUNOM
ISSN 2178-6925
Received: 21/06/2026 - **Accepted:** 11/07/2026
Vol: 13.15
DOI: 10.66104/p5bfmq98
Pages: 1-37

1993), and long-term exposure can also cause asthma (CASSET et al., 2006; MCGWIN et al., 2010) and nasopharyngeal cancer (IARC, 2006). It has been designated as a Group 1B carcinogen by the European Union (COGLIANO et al., 2005).

Bioaerosols are airborne substances of biological origin. They are ubiquitous and include airborne pathogenic and non-pathogenic bacteria, fungal spores, and droplets (which may contain bacteria or viruses) produced during sneezing and coughing. It is worth noting that contact with indoor bioaerosols can have serious consequences for personal and public health, affecting infectious diseases, asthma, acute toxic reactions, allergies, and cancer (D'AMATO et al., 2016; DOUWES et al., 2003; SWAN et al., 2003; VON MUTIUS and VERCELLI, 2010; WURIE et al., 2016).

Various national and international organizations aiming to mitigate the harmful effects of contact with bioaerosols have suggested more up-to-date and satisfactory standards/guidelines for these pollutants. The WHO recommends a maximum value of 500 colony-forming units (CFU)/m3 of fungal bioaerosols as an allowable criterion in residences (RAO et al., 1996). The Chinese Centers for Disease Control and Prevention have set a maximum bioaerosol bacterial concentration of 2500 CFU/m3 in homes (GUO et al., 2020).

These limits focus solely on bioaerosol concentration without considering the assessment of their respective sizes. The threat to human health from bioaerosols is closely related to their size, ranging from tens of nanometers to over 100 μm, including PM_{10} and $PM_{2.5}$ classes (particulate matter with aerodynamic diameters of ≤ 10 μm and ≤ 2.5 μm, respectively), which can be involuntarily aspirated (WHO, 1999).

Microorganisms carried by the atmosphere are small enough to avoid inertial collisions in the upper airways, such as the oral and nasal cavities, but they can reach the alveolar region (CAO et al., 2014; POH et al., 2018; RICHARDSON et al., 2019). Aspiration of bioaerosols or contact with toxins can physically damage the respiratory tract (SCHIRMER et al., 2011).

Intense exposure to NO_2 is associated with reduced lung function in patients with COPD, high reactivity of lung tissue to bronchoconstrictive factors, and

REMUNOM
ISSN 2178-6925

Received: 21/06/2026 - **Accepted:** 11/07/2026
Vol: 13.15
DOI: 10.66104/p5bfmq98
Pages: 1-37

worsening of the clinical state of asthma patients. Suspended particles can have consequences for both the upper and lower respiratory tracts, causing an increase in chronic respiratory diseases and decreasing daytime activities in people with bronchitis, pneumonia, and asthma, an increase in seizures, and a reduction in the interictal phase in asthmatics (AVALIANI et al., 2014; AVALIANI et al., 2015).

Among various anthropogenic pollutants, several studies have been conducted on SO_2. Its main consequences in atmospheric pollution include a high risk of hospitalization, cardiopulmonary diseases, myocardial infarction, COPD, respiratory diseases, and death (GERAVANDI et al., 2015; KHANIABADI et al., 2017; EFFATPANAH et al., 2020).

Several scientific studies confirm the link between a high incidence of acute respiratory inflammation, upper and lower respiratory tract secretion, and photochemical and restorative pollutants, including pollutants like O_3, O_2, and acid aerosols. They consider the relationship between changes in the daily incidence of bronchial asthma and O_3 concentrations. Climatic phenomena such as smog and high urban atmospheric pollution were associated with increased cardiovascular disease mortality and high demand for emergency care. Likewise, a high neonatal mortality rate was strongly associated with increased aerosol particles with diameters less than 10 microns in the ambient air (AVALIANI et al., 2014; AVALIANI et al., 2015).

Impacts of Indoor Air Pollution on Human Health According to the WHO Global Air Quality Guidelines (2021)

Out of the 18 selected studies, all examined the relationship between pollutants present in indoor environments during physical exercise and/or human exposure and their health damages according to the new and updated WHO Global Air Quality Guidelines (2021), as demonstrated in Table 3.

REMUNOM
ISSN 2178-6925

Received: 21/06/2026 - **Accepted:** 11/07/2026
Vol: 13.15
DOI: 10.66104/p5bfmq98
Pages: 1-37

Table 3. References, pollutants, and effect on human health

References (Year)	Pollutants	Effects on Human Health
Kocot and Zejda (2021)	Ultrafines Particles (< 2,5µm)	Ultrafine Particles (UFPs) can carry other toxic pollutants such as trace metals, non-degradable and toxic elements to humans, and organic gases. They also interact with lung cells, making them more toxic and inflammatory than fine particulate matter (PM), which is associated with increased hospitalization due to obstructive lung diseases and pulmonary infections. It is the sixth-largest risk factor for premature deaths. Regarding the WHO Global Air Quality Guidelines (2021): UFPs: Not specified due to lack of scientific consensus.
	SO_2, $PM_{2,5}$ e PM_{10}	Decrease in FEV1/FVC (Forced Expiratory Volume in 1 second / Forced Vital Capacity). Regarding the WHO Global Air Quality Guidelines (2021): SO_2: Probable cause for respiratory effects, decreased lung function (when exposed for 5 to 10 minutes) in adults and children with asthma and pre-existing respiratory diseases. $PM_{2.5}$: Probable cause for respiratory effects and causality for cardiovascular and respiratory mortality. PM_{10}: Probable cause for lung cancer mortality.
Kocot *et al*. (2020)	PM_{10} e NO_2	Increase in FeNO, a marker of eosinophilic airway inflammation. Regarding the WHO Global Air Quality Guidelines (2021): PM_{10}: Probable cause for lung cancer mortality. NO_2: Probable cause for respiratory effects and Suggestive causality for respiratory mortality.

REMUNOM
ISSN 2178-6925

Received: 21/06/2026 - **Accepted:** 11/07/2026
Vol: 13.15
DOI: 10.66104/p5bfmq98
Pages: 1-37

Liu *et al*. (2020)	$PM_{2,5}$, O_3, NO_2, SO_2 e CO	The parameters used for the qualitative/quantitative risk assessment were defined by the Canadian Air Quality Health Index (AQHI). For the Intervention Group exposed to indoor/outdoor air pollution from moderate risk to human health, $MP_{2.5}$, NO_2, and CO were considerably associated with elevated systolic blood pressure (SBP) and arterial hemoglobin oxygen saturation (SpO_2). $MP_{2.5}$ and NO_2 were significantly associated with diastolic blood pressure (DBP). $MP_{2.5}$, SO_2, and CO were significantly associated with reduced SpO_2. Pulse rate (PR) was also elevated in association with NO_2 in patients with CDI (Cardiovascular Disease). For the Control Group exposed to outdoor air pollution, there was a post-exercise increase in DBP in response to elevated AQHI of $MP_{2.5}$, NO_2, and CO and an increase in post-exercise heart rate in response to elevated levels of $MP_{2.5}$. NO_2 was also associated with increased DBP, while SO_2 was associated with an increased PR. O_3 and CO were considerably associated with increased SpO_2 in patients with CDI. In conclusion, outdoor air pollution in Toronto is associated with adverse changes in cardiovascular measures in patients with CDI. Regarding the WHO Global Air Quality Guidelines (2021): $MP_{2.5}$: Probable cause for respiratory effects and suggestive causality for cardiovascular and respiratory mortality. O_3: Probable cause for harmful respiratory effects and suggestive causality for respiratory mortality. NO_2: Probable cause for respiratory effects and suggestive causality for respiratory mortality. SO_2: Probable cause for respiratory effects, decreased lung function (when exposed for 5 to 10 minutes) in adults and children with asthma and pre-existing respiratory diseases. CO: Probable cause for short-term cardiovascular effects in epidemiological studies (US EPA, 2010).

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
DOI:
Pages: 1-25

Zavieh *et al*. (2021)	Bacterial Bioaerosols (anemophilic fungi, bacteria, viruses)	Gram-positive bacteria showed higher concentrations than Gram-negative bacteria in indoor air samples, and Pseudomonas were the most commonly detected bacteria types in gyms. Bioaerosols play a significant role in indoor air pollution as they can be pathogenic or trigger allergic reactions upon inhalation, ingestion, or skin absorption. Regarding the WHO Global Air Quality Guidelines (2021): Bacterial Bioaerosols: Not specified.
Felgueiras *et al.* (2020)	Ultrafine Particles (below 100nm), CO and CO_2	The average concentrations of Ultrafine Particles (below 100nm), CO, and CO_2 found were below the limits set by the WHO Global Air Quality Guidelines (2021).
Bennett *et al.* (2018)	$PM_{2,5}$ e PM_{10}	The average concentrations of the pollutants $PM_{2.5}$ and PM_{10} found were below the limits set by the WHO Global Air Quality Guidelines (2021).
Heaney *et a*l. (2020)	$CHCl_3$, $CHBrCl_2$ e $CHBr_2Cl$	The high concentrations of these pollutants in respiration have been associated with inflammatory/oxidative stress responses. Regarding the WHO Global Air Quality Guidelines (2021): $CHCl_3$, $CHBrCl_2$, $CHBr_2Cl$: Not specified.
Slezakova *et al*. (2018)	TVOCs (Total Volatile Organic Compounds), PM_1, PM_4, CO, CO_2, and O_3.	The studied pollutants present adverse health effects. Potentially synergistic interactions among these pollutants are indispensable when considering the relationship between human exposure to air pollutants and adverse health effects. Regarding the WHO Global Air Quality Guidelines (2021): TVOCs: Not specified. PM_1 and PM_4 cause cardiovascular and respiratory mortality and are also considered in determining the cause of respiratory/cardiovascular effects. CO: Probable cause for cardiovascular effects. CO_2: Not specified. O_3: Probable cause for harmful respiratory effects and suggestive causality for respiratory mortality.

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
DOI:
Pages: 1-25

Xie *et al.* (2021)	TVOCs, $PM_{2,5}$, PM_{10} e CO_2	Participants generally experienced heat stress, odors related to sweat, and the smell of construction materials. These symptoms, associated with high relative humidity of the ambient air, around 90%, are harmful to human health as they can lead to dehydration. Regarding the WHO Global Air Quality Guidelines (2021):TVOCs: Not specified. $PM_{2.5}$: Probable cause with respiratory effects and causality for cardiovascular and respiratory mortality. PM_{10}: Probable cause for lung cancer mortality. CO_2: Not specified.
Andrade *et al*. (2018)	CO_2	It can lead to drowsiness and reduced productivity in healthy individuals. Due to this agent's high quantum generation rate, there is also a high risk of influenza infection and tuberculosis, according to the WHO Global Air Quality Guidelines (2021): CO2: Not specified.
Boonrattanakij *et al*. (2021)	Bacterial Bioaerosols, CO_2, PM_1, $PM_{2,5}$, PM_7 e PM_{10}	With disinfection and air filtration measures, indoor environmental pollutants were neutralized, eliminating any risk to human health.
Kapalo *et al.* (2019)	CO_2	High levels of CO_2 can negatively affect the occupants' perception inside the building and cause health issues such as headaches and mucosal irritation, as noted by Krawczyk et al. (2016) and Fan et al. (2017). Elevated CO_2 levels can lead to the following adverse effects: above 20,000 ppm (parts per million) – deep breathing; 40,000 ppm – significantly increased breathing; 100,000 ppm – visual disturbances and tremors, loss of consciousness; 250,000 ppm – death (as cited by Satish et al., 2012). Regarding the WHO Global Air Quality Guidelines (2021): CO_2: Not specified.
Finewax *et a*l (2021)	VOCs (Volatile Organic Compounds), CO_2, NH_3, CH_4, O_3 e SO_2	There was no risk to human health due to effective cleaning measures and the reduction of emissions from human-derived sources and personal care products (PCPs).

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
DOI:
Pages: 1-25

Gu *et al*. (2021)	VOCs (Volatile Organic Compounds), CO, CO_2, SO_2, NO_2, HCHO e PM_{10} (abaixo de 10µm)	Indoor VOCs are one of the significant causes of childhood asthma, childhood leukemia, and acquired heart diseases in children. Exposure to formaldehyde (HCHO) is associated with central nervous system reactions, abnormal lung and liver immune function, eye, nose, and throat irritation symptoms, skin allergic reactions, and cancer. Prolonged exposure to CO and CO_2 will lead to anomalies in the human nervous and cardiovascular systems, manifesting as dizziness, headaches, and arrhythmia. There was no significant change in the inhalable particulate matter index before and after use in the running room. However, the inhalable particulate matter index in the spinning room was 2.5 times higher compared to before the use of the running room, suggesting damage to the upper and lower respiratory tract, resulting in a risk to human health. Regarding the WHO Global Air Quality Guidelines (2021): VOCs: Not specified. Bacterial Bioaerosols: Not specified. CO: Probable cause for cardiovascular effects. CO_2: Not specified. SO_2: Probable cause for respiratory effects, decreased lung function (in exposure of 5 to 10 minutes) in adults and children with asthma and other pre-existing respiratory diseases. NO_2: Probable cause for respiratory effects and suggestive causality for respiratory mortality. HCHO: Not specified. PM_{10} (particles below 10µm): Not specified due to lack of scientific consensus.
Rodeo *et al*. (2022)	PM_1, $PM_{2.5}$ e PM_{10}	The Particle Number Concentration (PNC) (expressed in particles cm–3) was 33.2 times higher under high pollutant exposure conditions compared to low exposure conditions. Similarly, the PM_{10} concentration (expressed in mg m–3) was approximately 92 times higher in the high-exposure scenario than in the low-exposure scenario. According to the WHO Global Air Quality Guidelines (2021), PM1: The probable cause of cardiovascular and respiratory mortality is also considered in determining the cause of respiratory/cardiovascular effects. $PM_{2.5}$: Probable cause with respiratory effects and suggestive causality for cardiovascular and respiratory mortality. PM_{10}: Probable cause for lung cancer mortality.

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
DOI:
Pages: 1-25

Cassilhas *et al*. (2022)	PM_1, $PM_{2.5}$ e PM_{10}	Exposure to higher levels of PM in the outdoor environment may partially explain the lack of improvement in BDNF levels; however, the group that exercised in the indoor environment experienced more significant benefits in glycemic management, cognitive improvement, increased BDNF levels, decreased risk of damage to cardiac and skeletal muscle fibers, and consequently, reduced inflammation. Regarding the WHO Global Air Quality Guidelines (2021), PM_1: Probable cause for cardiovascular and respiratory mortality is also considered in determining the cause of respiratory/cardiovascular effects. $PM_{2.5}$: Probable cause with respiratory effects and suggestive causality for cardiovascular and respiratory mortality. PM_{10}: Probable cause for lung cancer mortality.
Mazoteras-Brown *et al*. (2023)	CO, CO_2, HCHO, TVOCs, PM_1, $PM_{2,5}$, PM_{10} e O_3	There was a clear difference in indoor and outdoor CO levels, with much higher levels inside the gym. Outside the gym, there is more variation in CO levels between morning and afternoon, while the numbers remain relatively consistent inside. Different parameters indicated that CO_2 concentrations were higher indoors than outdoors in both measurement periods. HCHO levels were nearly insignificant and did not vary significantly, except for a slight increase in the afternoon outdoors. O_3 levels were not relevant. TVOC, PM_1, $PM_{2.5}$, and PM_{10} showed less variation, although higher outdoors in the morning, regarding the WHO Global Air Quality Guidelines (2021): CO: Probable cause for cardiovascular effects. CO_2: Not specified. HCHO: Not specified. TVOCs: Not specified. PM_1: Probable cause for cardiovascular and respiratory mortality, also considered in determining the cause of respiratory/cardiovascular effects. $PM_{2.5}$: Probable cause with respiratory effects and suggestive causality for cardiovascular and respiratory mortality. PM_{10}: Probable cause for lung cancer mortality. O_3: Probable cause for harmful respiratory effects and suggestive causality for respiratory mortality.

Source: Prepared by the authors (2026).

We suggest procedures and measures to mitigate and/or eliminate indoor air pollutants. With the growing popularity of gyms and indoor training venues where

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
DOI:
Pages: 1-25

athletes compete or train indoors, the indoor air quality of sports facilities must meet the WHO AQGs 2021 standards, as it is crucial for the athletes' health.

Therefore, it is important to have a system that monitors indoor air-related gases through various all-in-one gas sensors to collect temperature, humidity, CO_2, $PM_{2.5}$, TVOCs, and formaldehyde concentration in the air. This system could treat indoor air in exercise locations, ensuring athletes are training or competing in the best indoor air environment.

Ventilation accessing exercise areas (e.g., gymnasiums) is a key factor in Indoor Air Quality (IAQ), mitigating/excluding indoor pollutants (mainly CO_2 and significant aerosol emissions) and infectious pathogens (e.g., Influenza A, B, and C, Severe Acute Respiratory Syndrome Coronavirus-2 [SARS-CoV-2]). The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends ventilation of 15 cubic feet per minute (7.1 liters per second) for this purpose.

Ultraviolet (UV) radiation is an interesting technology. It is already used for air disinfection in indoor environments within the healthcare sector, schools, universities, and offices, targeting microorganisms like bacteria, viruses, fungi, etc. ASHRAE and the United States Environmental Protection Agency (USEPA) recognize the importance of air cleaning solutions, including filtration and UV-based systems, to prevent the spread of indoor infectious diseases.

A technology that includes self-cleaning, air purification, easy-to-clean surfaces, antibacterial surfaces, anti-fog surfaces, ecologically friendly treatment for woods and thermal insulation, anti-glare surfaces, and more is necessary. Nanotechnology can address these urgent demands, as it has been integrated into architecture and finishing, enhancing buildings' economic and environmental performance. Nano-finishing has shown superiority over traditional finishing materials in terms of economics and the environment, offering a longer lifespan, reduced carbon dioxide emissions, and lowered maintenance effort and energy consumption, leading to operational cost reduction.

REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
DOI:
Pages: 1-25

Lastly, it is recommended that additional primary research be conducted on the discussed topic so that the WHO AQGs 2021 can be further improved regarding new contaminants and levels.

Study Limitations

The study's limitations include heterogeneity and publication bias due to the limited sample adequacy in some studies.

1. CONCLUSION

During the analyzed period, this study identified the primary compromising air pollutants affecting IAQ and the well-being of individuals engaged in activities and/or exercises: CO, CO_2, $PM_{2.5}$, PM_{10}, SO_2, VOCs, and bioaerosols. The primary causes of exceeding the limits set by the WHO 2021 Guideline were outdoor pollutants, inadequate and/or inefficient ventilation, and confined spaces due to the number of exercisers. Based on the WHO Global Air Quality Guidelines (2021), 50% of the analyzed studies observed violations of the established limits. Particulate matter was the most frequently violated contaminant. Depending on the particle size, there are probable causes of respiratory effects and causality for cardiovascular and respiratory mortality, including lung cancer.

The findings of this systematic review indicate that adequate ventilation policies, continuous monitoring of indoor air quality in gyms and sports facilities, and the incorporation of the WHO AQGs 2021 limits into indoor air quality regulation are essential measures to reconcile the health benefits of physical exercise with the protection of respiratory and cardiovascular health.

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REMUNOM
ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
DOI:
Pages: 1-25

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The authors have no financial or non-financial interests to disclose.

Ethics approval

Not applicable.

Consent

Not applicable.

Clinical trial number

Not applicable.

Consent to publish declaration

Not applicable.

Consent to participate declaration

Not applicable.

Data Availablity

All data is available in the manuscript and Supplementary Material section. More information is also available in PROSPERO (International Prospective Register of Systematic Reviews) under CRD42022354515.

Authors' contribution statements

Wellington Rui Andrade de Assis Junior: Writing (original draft preparation, review, and editing); Camilo Dias Seabra Pereira: Writing (original draft preparation, review, and editing), supervision. All authors have read and agreed to the submitted version of the manuscript.

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ISSN 2178-6925

Received: 13/01/2026 - **Accepted:** 13/02/2026
Vol:
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