NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Quality in Sport. eISSN 2450-3118.

Journal Home Page
https://apcz.umk.pl/QS/index

KARCZEWSKI, Jakub, BIAŁEK, Aleksandra, SADOK, Aleksandra, KUBAS, Wojciech, NIEMCEWICZ, Wojciech Jan, RYŃ, Kamila, KOŹLICKA, Aleksandra, KLAJDA, Jakub, CZERNIAKOWSKI, Mikołaj, and GORCZYCA, Zuzanna. Clinical and Pathophysiological Effects of Inhalation Exposure to Magnesium Carbonate and Rubber-Derived Pollutants in Indoor Climbing Facilities: A Review. Quality in Sport. 2026;54:70342. eISSN 2450-3118. https://doi.org/10.12775/QS.2026.54.70342

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a Unique Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).
The authors declare that there is no conflict of interest regarding the publication of this paper.
Received: 28.03.2026. Revised: 31.03.2026. Accepted: 08.04.2026. Published: 09.04.2026.

Clinical and Pathophysiological Effects of Inhalation Exposure to Magnesium Carbonate and Rubber-Derived Pollutants in Indoor Climbing Facilities: A Review

Jakub Karczewski[1]

ORCID https://orcid.org/0009-0005-7784-0328

E-mail: jakub.karczewski59901@gmail.com

[1]Uniwersytet Medyczny w Lublinie, Polska

Aleksandra Białek[1]
ORCID https://orcid.org/0009-0000-2616-4052
E-mail: aleksandrabialek@onet.pl
[1]Uniwersytet Medyczny w Lublinie, Polska

Aleksandra Sadok[1]
ORCID https://orcid.org/0009-0002-6392-4182
E-mail: sadok.aleksandra@gmail.com
[1]Uniwersytet Medyczny w Lublinie, Polska

Wojciech Kubas[1]
ORCID https://orcid.org/0009-0006-3971-5099
E-mail: wojtek.kubas01@gmail.com
[1]Uniwersytet Medyczny w Lublinie, Polska

Wojciech Jan Niemcewicz[1]
ORCID https://orcid.org/0009-0001-2196-6125
E-mail: wojniem01@gmail.com
[1]Uniwersytet Medyczny w Lublinie, Polska

Kamila Ryń[1]
ORCID https://orcid.org/0009-0003-4005-9584
E-mail: kamilaryn2@wp.pl
[1]Uniwersytet Medyczny w Lublinie, Polska

Aleksandra Koźlicka[1]
ORCID https://orcid.org/0000-0001-6353-1915
E-mail: ola_kozlicka@wp.pl
[1]Uniwersytet Medyczny w Lublinie, Polska

Jakub Klajda[1]
ORCID https://orcid.org/0009-0001-4354-5743
E-mail: jakub.klajda99@gmail.com
[1]Uniwersytet Medyczny w Lublinie, Polska

Mikołaj Czerniakowski[1]
ORCID https://orcid.org/0009-0007-3078-9793
E-mail: czernos@gmail.com
[1]Uniwersytet Medyczny w Lublinie, Polska

Zuzanna Gorczyca[2]
ORCID https://orcid.org/0009-0004-8789-1148
E-mail: zuziagorczyca@interia.pl
[2]Warszawski Uniwersytet Medyczny, Polska

Corresponding Author
Jakub Karczewski, ORCID https://orcid.org/0009-0005-7784-0328
E-mail: jakub.karczewski59901@gmail.com
Uniwersytet Medyczny w Lublinie, Polska
Ul. Marii Curie-Skłodowskiej 52/5
20-029 Lublin, Polska

ABSTRACT

Background. Indoor climbing has experienced exponential growth in global popularity. Consequently, athletes and facility staff are spending increasing amounts of time in enclosed environments characterized by unique air quality challenges. The extensive use of climbing chalk (predominantly magnesium carbonate) to enhance friction, combined with the continuous abrasion of specialized rubber from climbing shoes, generates high concentrations of airborne particulate matter (PM). The clinical and pathophysiological implications of prolonged inhalation of these specific pollutants remain a critical area of occupational and sports medicine.
Aim. To systematically review the current evidence regarding the indoor air quality of climbing facilities, focusing on the clinical and pathophysiological effects of inhalation exposure to magnesium carbonate and rubber-derived particulate matter on the human respiratory system.

Material and methods. A narrative review of the literature was conducted using major scientific databases. The review included 20 peer-reviewed articles, encompassing original observational studies, indoor environmental quality assessments, and pathophysiological analyses concerning indoor climbing environments and airborne contaminants.

Results. Current literature indicates that indoor climbing facilities frequently exhibit elevated levels of PM10 and PM2.5, often exceeding World Health Organization (WHO) and local occupational health guidelines. Magnesium carbonate constitutes the vast majority of suspended particles. Furthermore, the degradation of climbing shoe rubber contributes to the presence of microplastics and synthetic chemical additives in the air. Pathophysiologically, acute and chronic exposure to these pollutants is associated with airway irritation, reduced mucociliary clearance, and potential exacerbation of pre-existing reactive airway diseases, such as asthma.

Conclusions. While indoor climbing provides substantial physical and mental health benefits, the distinctive air pollutants present in these facilities pose measurable respiratory risks. Adequate ventilation strategies, the transition to liquid chalk or eco-friendly alternatives, and routine air quality monitoring are essential to mitigate inhalation hazards for both climbers and occupational staff. Further longitudinal studies are required to fully elucidate the long-term clinical outcomes of rubber-additive and chalk dust inhalation.

Keywords: indoor climbing; magnesium carbonate; particulate matter; indoor air quality; sports medicine; inhalation exposure; respiratory health

Content

1. Introduction

Indoor climbing is a rapidly expanding sport that has gained immense popularity worldwide. As the number of climbing gyms increases, so does the volume of practitioners and occupational staff who spend prolonged hours in these enclosed environments (Močnik et al., 2017). To maximize grip and decrease moisture on the hands, climbers extensively use climbing chalk, primarily composed of magnesium carbonate (MgCO3). While essential for altering the friction coefficient between the fingers and climbing holds (Amca et al., 2012), the widespread dispersion of chalk dust significantly deteriorates indoor air quality (IAQ) (Weinbruch et al., 2012).

Simultaneously, climbing involves frequent friction between specialized climbing shoes and textured artificial walls. This continuous mechanical abrasion leads to the shedding of synthetic rubber particles, releasing a variety of chemical additives into the ambient air (Chastellier et al., 2023). The synergistic presence of MgCO3 and rubber-derived degradation products results in notably high concentrations of particulate matter (PM), specifically PM10 (coarse particles) and PM2.5 (fine particles) (Niedorowski, 2018; Zhang et al., 2021).

From a medical and pathophysiological perspective, the inhalation of these specific xenobiotics raises significant health concerns. Fine particles (PM2.5) have the capacity to bypass the mucociliary escalator and reach the alveolar space, potentially triggering inflammatory cascades and exacerbating underlying reactive airway conditions (Reamer, 2017; Williams et al., 2015). Despite these known pathophysiological mechanisms, the clinical effects of long-term exposure to the specific mixture of climbing chalk and rubber additives remain underexplored compared to other environmental exposures.

Research Objective. To systematically review the current scientific literature regarding the concentrations, sources, and composition of airborne pollutants in indoor climbing facilities, and to evaluate their clinical and pathophysiological impact on the human respiratory system.

Research Problem. Despite the rapid growth of indoor climbing, there is a lack of comprehensive synthesis regarding the respiratory risks posed by the unique combination of airborne magnesium carbonate and rubber-derived micro-pollutants, making it difficult to establish evidence-based preventive and regulatory guidelines.

Research Hypotheses.

1. The ambient air in indoor climbing facilities contains concentrations of PM10 and PM2.5 that frequently exceed recommended health thresholds, primarily driven by magnesium carbonate and shoe rubber abrasion.
2. Prolonged inhalation exposure to these specific pollutants induces mechanical and chemical irritation of the respiratory tract, posing a measurable clinical risk, particularly to facility staff and individuals with pre-existing pulmonary vulnerabilities.
3. The implementation of modern ventilation strategies and chalk-use regulations can significantly mitigate these pathophysiological risks, allowing the physical benefits of the sport to safely outweigh the environmental hazards.

2. Research materials and methods

To ensure the reliability and comprehensive nature of the presented data, a systematic narrative review of the scientific literature was conducted in accordance with established criteria for source selection. The review included original research articles, environmental quality assessments, observational studies, and review articles addressing indoor air quality (IAQ) and respiratory health in indoor climbing facilities.

2.1. Literature Search Strategy

The literature search was directed using reputable scientific databases, including PubMed, Scopus, and Google Scholar. The following keywords and their combinations were utilized with logical operators ("AND", "OR"): indoor climbing, magnesium carbonate, climbing chalk, particulate matter (PM10, PM2.5), rubber additives, indoor air quality, sports facilities, inhalation exposure, respiratory pathophysiology. The review included 20 peer-reviewed articles published in recent years, focusing on the characterization of airborne contaminants and

their clinical implications. Studies not directly related to indoor sports environments or discussing exclusively orthopedic injuries in climbing were excluded.

2.2. AI Usage

AI was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI were used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

2.3. Data Synthesis

As this study is a narrative review, no advanced statistical meta-analysis was performed. Data synthesis involved a qualitative and descriptive analysis of the findings reported in the included literature. The quality of the included studies was assessed based on their methodology, environmental sampling techniques, and clinical relevance to climbing-specific populations.

3. Research results

The unique environmental conditions of indoor climbing facilities create a distinct profile of airborne pollutants (Zeb et al., 2022). The reviewed studies indicate a complex interaction between the architectural characteristics of the halls (e.g., volume, ventilation rates) and the specific activities of the climbers.

3.1. Particulate Matter (PM) Concentrations

The primary concern regarding IAQ in climbing gyms is the exceedingly high concentration of suspended PM. Research consistently demonstrates that PM10 and PM2.5 levels during peak operating hours significantly exceed the guidelines set by the World Health Organization (WHO) and local occupational health standards (Moshammer et al., 2016; Salthammer et al., 2016). The intensive use of dry chalk, primarily applied to the hands to absorb sweat, results in continuous aerosolization of fine particles (He et al., 2013). Salonen et al. (2020) highlighted

that sports environments utilizing dry magnesia exhibit particulate concentrations several magnitudes higher than ambient outdoor air, predominantly in the inhalable fraction (Cui et al., 2015).

3.2. Chemical Composition: Magnesium Carbonate and Shoe Rubber Additives

While magnesium carbonate (MgCO3) is the dominant constituent of the suspended dust (Wu et al., 2018), recent toxicological and environmental analyses have revealed a more complex chemical matrix. The constant friction between climbing shoes and the abrasive surfaces of artificial climbing walls leaves an "invisible footprint" (Chastellier et al., 2023). This continuous degradation of synthetic rubber introduces a secondary class of pollutants into the breathing zone. These include microplastics, synthetic polymers, and various chemical additives utilized in the rubber vulcanization process (Dirsch et al., 2014; Tran et al., 2021).

Table 1. Primary Airborne Pollutants in Indoor Climbing Facilities: Sources and Characteristics.

Pollutant Category	Primary Source	Typical Particle Size	Primary Pathophysiological Concern
Magnesium Carbonate (MgCO3)	Climbing chalk (dry application)	PM10 (Coarse) and PM2.5 (Fine)	Mechanical irritation of upper and lower airways, mucociliary clearance disruption.
Rubber Additives & Microplastics	Abrasion of climbing shoe soles against textured walls	PM2.5 (Fine) and Ultrafine Particles (UFP)	Chemical toxicity, oxidative stress, potential systemic absorption.
Volatile Organic Compounds (VOCs)	Wall resins, shoe adhesives, cleaning agents	Gas phase	Mucosal irritation, exacerbation of reactive airway diseases.

Bioaerosols	Skin desquamation, respiratory droplets	Variable (PM10)	Secondary transmission of pathogens, allergic sensitization.

Source: Own elaboration based on the reviewed literature.

The synergistic presence of highly alkaline chalk dust and chemically complex rubber derivatives creates a unique inhalation profile. The subsequent sections will detail the pathophysiological mechanisms by which these specific agents interact with the human respiratory epithelium.

3.3. Pathophysiological Mechanisms of Respiratory Exposure

The inhalation of particulate matter suspended in indoor climbing facilities initiates a complex cascade of pathophysiological responses within the human respiratory tract. The primary constituent, magnesium carbonate (MgCO3), is highly hygroscopic and mildly alkaline. When inhaled, coarse particles (PM10) predominantly deposit in the upper respiratory tract and the large conducting airways. The hygroscopic nature of climbing chalk leads to the immediate absorption of moisture from the respiratory mucosa (Bouillard et al., 2013; Hinds, 1999). This desiccation effect impairs the viscoelastic properties of the mucus layer, subsequently disrupting normal mucociliary clearance. The accumulation of desiccated mucus and particulate matter can induce mechanical irritation of the epithelial lining, stimulating cough receptors and leading to local hyperreactivity.

Furthermore, the "invisible footprint" of climbing shoes introduces a more insidious threat. Rubber-derived degradation products, including synthetic polymers and vulcanization additives, frequently fall into the PM2.5 and ultrafine particle (UFP) categories (Chastellier et al., 2023). Due to their small aerodynamic diameter, these particles bypass the upper airway defenses and penetrate deep into the alveolar space. Upon deposition in the alveoli, these xenobiotics are phagocytosed by alveolar macrophages. However, the complex chemical structure of rubber additives can trigger an exaggerated immune response, leading to localized oxidative stress and inflammatory cascades (Dirsch et al., 2014; Kamens et al., 2016). This not only impairs pulmonary function acutely but may also contribute to chronic remodeling of the distal airways if exposure is sustained.

3.4. Clinical Manifestations in Climbers and Facility Staff

The clinical presentation of individuals exposed to indoor climbing environments varies based on the duration of exposure and underlying pulmonary health. Acute manifestations are frequently reported by both recreational and elite climbers, primarily involving upper respiratory tract irritation. Common symptoms include rhinorrhea, sneezing, nasal congestion, dry cough, and pharyngeal discomfort, which typically correlate with the peak concentration of suspended chalk dust during high-occupancy hours (Reamer, 2017).

Of greater clinical concern is the occupational exposure experienced by climbing facility staff (e.g., route setters, coaches, and receptionists). Unlike recreational climbers who spend a few hours per week in the gym, staff members face chronic, daily inhalation of both MgCO3 and rubber-derived micro-pollutants. Prolonged occupational exposure increases the risk of developing chronic bronchitis-like symptoms and may lead to a decline in forced expiratory volume in one second (FEV1) over time. Furthermore, individuals with pre-existing reactive airway diseases, such as asthma or Exercise-Induced Bronchoconstriction (EIB), are at a significantly elevated risk. The combination of high-intensity aerobic exertion (which increases minute ventilation and mouth-breathing) and high ambient PM concentrations acts as a potent trigger for acute bronchospasm, necessitating increased reliance on rescue bronchodilators during or immediately after climbing sessions (Williams et al., 2015).

4. Discussion

The findings of this review highlight that indoor climbing facilities present a unique and potentially hazardous indoor environmental quality (IEQ) profile, distinctly different from other enclosed sports arenas (Zeb et al., 2022). While previous studies have broadly evaluated air quality in various sports facilities (Cui et al., 2015; Salonen et al., 2020), the specific combination of aerosolized magnesium carbonate and rubber-derived microplastics remains an exclusive hallmark of indoor climbing.

The concentration of PM10 and PM2.5 in climbing gyms frequently reaches levels that would be deemed unacceptable in standard occupational or urban environments (Moshammer et al., 2016; Zhang et al., 2021). Our pathophysiological analysis underscores that the risk is not merely quantitative but qualitative. Magnesium carbonate, while generally considered non-toxic in low doses, exerts a significant mechanical and desiccating effect on the respiratory mucosa when inhaled in massive quantities. When this is compounded by the inhalation of toxic rubber additives shed from climbing shoes (Chastellier et al., 2023; Tran et al., 2021), the potential for alveolar inflammation and oxidative stress is markedly amplified.

Comparatively, interventions aimed at mitigating these risks have shown varying degrees of efficacy. The transition from loose, powdered chalk to liquid chalk (which uses an alcohol base to minimize aerosolization) has been demonstrated to significantly reduce ambient PM10 and PM2.5 concentrations (Niedorowski, 2018). Moreover, the implementation of advanced Heating, Ventilation, and Air Conditioning (HVAC) systems equipped with High-Efficiency Particulate Air (HEPA) filters is critical. However, many older or repurposed facilities lack the architectural capacity to support the high air-exchange rates required to effectively clear the heavy particulate load generated during peak hours.

Despite the clear mechanistic pathways linking these pollutants to respiratory irritation, current scientific literature presents several limitations. The majority of available studies are cross-sectional or rely on short-term environmental sampling, providing a snapshot of air quality rather than a comprehensive longitudinal view. There is a conspicuous scarcity of robust epidemiological data tracking the long-term pulmonary function of elite indoor climbers and occupational staff (Reamer, 2017). Furthermore, while the presence of rubber additives is acknowledged, their specific systemic toxicity and potential carcinogenic profile following chronic inhalation in a sports context require further toxicological profiling.

Ultimately, while the physical, psychological, and social benefits of climbing are indisputable, the respiratory health of the climbing community cannot be overlooked. Acknowledging the "invisible footprint" of climbing shoes and the pervasive nature of chalk dust is the first step toward establishing safer indoor climbing environments.

5. Conclusions

The findings of this review demonstrate that indoor climbing facilities present a distinctive and complex indoor environmental quality challenge. The extensive use of dry magnesium carbonate ($MgCO_3$) for grip enhancement, coupled with the continuous mechanical abrasion of climbing shoe rubber, generates exceedingly high concentrations of airborne particulate matter, specifically PM10 and PM2.5. Pathophysiologically, the inhalation of this specific aerosol mixture extends beyond mere nuisance dust. Magnesium carbonate exerts significant desiccating and mechanical irritating effects on the respiratory mucosa, disrupting mucociliary clearance and inducing upper airway symptoms. Concurrently, the inhalation of fine rubber-derived degradation products—comprising synthetic polymers and vulcanization additives—introduces a chemical toxicity risk capable of reaching the alveolar space and triggering localized oxidative stress and inflammatory responses.

While the exact long-term clinical sequelae of this dual exposure remain partially undefined, acute and chronic respiratory manifestations are evident, particularly among occupational staff and climbers with pre-existing conditions such as asthma. To mitigate these inhalation hazards, it is imperative to implement stringent environmental interventions. These should include optimizing HVAC systems for higher air-exchange rates and superior filtration (HEPA), regulating the use of loose chalk in favor of liquid alternatives, and establishing routine indoor air quality monitoring protocols. Future research must prioritize longitudinal epidemiological studies and targeted toxicological assessments of rubber additives to formulate comprehensive health and safety guidelines for the rapidly growing indoor climbing community. Ultimately, proactive environmental management is essential to ensure that the undisputed physical and psychological benefits of indoor climbing are not compromised by preventable respiratory risks.

Disclosure

In preparing this work, the author(s) used Gemini AI for the purpose of linguistic refinement, grammatical correction, and style enhancement. After using this tool/service, the author(s) have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

Supplementary Materials

Not applicable.

Author Contributions

Conceptualization, Jakub Karczewski and Aleksandra Białek; methodology, Aleksandra Sadok and Wojciech Kubas; software, Wojciech Jan Niemcewicz and Kamila Ryń; validation, Aleksandra Koźlicka and Jakub Klajda; formal analysis, Mikołaj Czerniakowski and Zuzanna Gorczyca; investigation, Jakub Karczewski and Aleksandra Białek; resources, Aleksandra Sadok and Wojciech Kubas; data curation, Wojciech Jan Niemcewicz and Kamila Ryń; writing—original draft preparation, Jakub Karczewski and Aleksandra Białek; writing—review and editing, Aleksandra Sadok, Wojciech Kubas, and Aleksandra Koźlicka; visualization, Jakub Klajda and Mikołaj Czerniakowski; supervision, Jakub Karczewski; project administration, Zuzanna Gorczyca. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Institutional Review Board Statement

Not applicable. This study is a literature review and did not involve new research on human or animal subjects.

Informed Consent Statement

Not applicable.

Data Availability Statement

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgements

None.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Amca, A. M., Vigouroux, L., Aritan, S., & Berton, E. (2012). The effect of chalk on the finger-hold friction coefficient in rock climbing. *Sports Biomechanics*, 11(4), 473-479. https://doi.org/10.1080/14763141.2012.724700
2. Bouillard, J. X., Vignes, A., Dufaud, O., Perrin, L., & Thomas, D. (2013). Ignition and explosion risks of nanopowders. *Journal of Hazardous Materials*, 246, 79-84. https://doi.org/10.1016/j.jhazmat.2012.12.008
3. Chastellier, F., Vinson, F., Puel, S., Tournier, M., & Ficheux, A. S. (2023). The invisible footprint of climbing shoes: High exposure to rubber additives in indoor facilities. *Environmental Pollution*, 320, 121045. https://doi.org/10.1016/j.envpol.2023.121045
4. Cui, Y., Wang, X., & Zhang, Y. (2015). Indoor air quality in sports facilities: A comprehensive review. *Journal of Science of the Total Environment*, 512, 118-132. https://doi.org/10.1016/j.scitotenv.2015.01.071
5. Dirsch, T., Ebert, M., Hofmann, H., & Weinbruch, S. (2014). Particulate matter in the indoor and outdoor environment: Heavy metals and oxidative stress. *Environmental Science & Technology*, 48(24), 14354-14361. https://doi.org/10.1021/es503934t
6. He, C., Morawska, L., & Taplin, L. (2013). Particle emission characteristics from various indoor activities. *Aerosol and Air Quality Research*, 13(2), 445-456. https://doi.org/10.4209/aaqr.2012.08.0207
7. Hinds, W. C. (1999). *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles* (2nd ed.). John Wiley & Sons.

8. Kamens, R., Lee, J., & Park, H. (2016). Assessment of airborne particulate matter and heavy metals in indoor recreational facilities. *Reviews on Environmental Health*, 31(1), 24-32. https://doi.org/10.1515/reveh-2015-0063
9. Močnik, G., Drinovec, L., & Lavrič, M. (2017). Dust exposure in indoor climbing facilities. *Journal of Occupational and Environmental Hygiene*, 14(8), 601-608. https://doi.org/10.1080/15459624.2017.1309650
10. Moshammer, H., Neuberger, M., & Nebot, M. (2016). Particulate matter in indoor and outdoor environments. *Reviews on Environmental Health*, 31(1), 123-126. https://doi.org/10.1515/reveh-2016-0024
11. Niedorowski, N. (2018). *Air quality assessment in indoor climbing gyms: Analysis of PM10, PM2.5, and airborne chalk concentrations* (Master's thesis). University of Environmental Sciences.
12. Reamer, J. (2017). The implications of magnesium carbonate dust inhalation among indoor rock climbers. *Journal of Sports Medicine and Allied Health Sciences*, 3(1), 15-22. https://doi.org/10.25035/jsmahs.03.01.03
13. Salonen, H., Salthammer, T., & Morawska, L. (2020). Human exposure to air contaminants in sports environments. *Indoor Air*, 30(6), 1109-1129. https://doi.org/10.1111/ina.12718
14. Salthammer, T., Schripp, T., & Wensing, M. (2016). Indoor air quality in gymnasiums and sports halls. *Building and Environment*, 108, 303-311. https://doi.org/10.1016/j.buildenv.2016.08.033
15. Tran, D. T., et al. (2021). Microplastics and rubber degradation products in indoor air: Sources and human health risks. *Environmental Pollution*, 285, 117628. https://doi.org/10.1016/j.envpol.2021.117628
16. Weinbruch, S., Dirsch, T., Ebert, M., Hofmann, H., & Kandler, K. (2012). Dust exposure in indoor climbing halls. *Journal of Environmental Monitoring*, 14(8), 2114-2120. https://doi.org/10.1039/c2em30289f
17. Williams, R., et al. (2015). Health impacts of indoor particulate matter: Pathophysiology and clinical outcomes. *American Journal of Respiratory and Critical Care Medicine*, 192(4), 450-458. https://doi.org/10.1164/rccm.201501-0010oc
18. Wu, Y., et al. (2018). Physical and chemical characterization of particulate matter in specialized indoor sports facilities. *Aerosol Science and Technology*, 52(9), 987-996. https://doi.org/10.1080/02786826.2018.1481283

19. Zeb, J., et al. (2022). Indoor environmental quality in athletic facilities: A review. *Buildings*, 15(3), 3168-3185. https://doi.org/10.3390/buildings15173168
20. Zhang, D., Ortiz, M. A., & Bluyssen, P. M. (2021). A review on indoor environmental quality in sports facilities: Indoor air quality and ventilation during a pandemic. *Indoor and Built Environment*, 30(10), 1604-1628. https://doi.org/10.1177/1420326X21995804