Bulletin de veille QAI
N° 09-2025

Objectif : *Qualité de l'air intérieur*

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Google Scholar, Lens, WoS

Valença, M. M., Franco, O. a. D. O., Peres, M. F. P., Andrade, J. R. D.

Addressing sick building syndrome and its connection to headache disorders.

Headache Medicine, Vol. **16** n°(2), (2025), 98-102 p.

Introduction

Sick Building Syndrome (SBS), a term introduced by the World Health Organization in 1983, refers to the occurrence of acute health and comfort issues in individuals occupying specific indoor environments without an identifiable clinical cause. Among the most commonly reported symptoms are headaches, particularly migraines and tension-type headaches, which significantly affect daily functioning and workplace productivity.

Review

This review examines the primary environmental, chemical, biological, and psychosocial factors contributing to SBS and their influence on the onset and exacerbation of headaches. Poor indoor air quality, inadequate ventilation, and elevated carbon dioxide (CO_2) levels are identified as major physical factors. CO_2 concentrations above 1000 ppm are associated with impaired cognitive function, cerebral vasodilation, and the onset of headaches. Exposure to volatile organic compounds from office materials and cleaning agents, as well as biological contaminants such as mold and dust mites and electromagnetic radiation, is also implicated. In parallel, psychosocial elements such as occupational stress, poor ergonomics, and limited access to natural light exacerbate headache symptoms. The cumulative effect of these stressors contributes not only to physical discomfort but also to decreased performance and increased presenteeism. Preventive measures include improving ventilation systems, implementing green building practices, regulating humidity levels, implementing ergonomic interventions, and promoting mental well-being in the workplace.

Conclusions

SBS is a complex occupational health issue strongly associated with headache disorders. Addressing its multifactorial causes through integrated environmental and organizational strategies is essential for enhancing employee health, reducing headache incidence, and improving productivity. Tackling SBS represents both a health imperative and a strategic investment in workplace sustainability.

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Tian, E., Chen, Q., Gao, Y., Chen, Z., Wang, Y., Mo, J.

Advancing Indoor Air Purification by Mass Transfer Enhancement: Bridging the Gap Between High-Performance Materials and Technologies.

Engineering, (2025)

Indoor air purification, as a typical gas–solid interface process, involves the transfer of airborne pollutants to purification material surfaces through mass transfer, enabling their removal. While research on indoor air purification materials has expanded remarkably, studies on enhancing mass transfer have been relatively limited. In this work, we proposed a new concept of “integration of mass transfer and material regulation,” aiming to provide a design methodology for indoor air purification. Taking solid-phase particulate matter (PM) filtration and gas-phase pollutant adsorption as examples, we summarized the novel approach that shifts from passive material usage to active control of mass transfer through multiscale (milli–micro–nano) and multifield (mass–flow–force). For PM removal, the external electric force can enhance the migration

velocity of PM towards the fiber approximately fivefold, resulting in 1−3 orders of magnitude higher comprehensive quality factor than commercial filters, considering filtration efficiency, pressure drop, and energy consumption. For gas removal, the hierarchical structure can increase the gas–solid contact area by 58%, resulting in a 37% improvement in single-pass removal efficiency and a 152% enhancement in dynamic adsorption capacity. We bridge the gap between high-performance materials and technologies by providing a design methodology for controlling surface forces and structures to improve mass transfer.

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Aryani, Y., Purwana, R., Herdiansyah, H., Suryabrata, J. A.

Advancing Indoor Environmental Quality (IEQ) in Indonesian Hospital Wards: An Integrated Importance Performance Analysis (IPA) and Objective Approach.

Energy and Built Environment, (2025)

Indoor Environmental Quality (IEQ) plays a critical role in user comfort and health, yet research in Indonesian hospitals has predominantly emphasized objective measurements, often neglecting users' subjective perceptions. In contrast, global studies assessing IEQ performance using the Importance Performance Analysis (IPA) based on subjective user evaluations. This study addressed this gap by integrating traditional and alternative IPA methods with objective field measurements to assess 17 IEQ elements, covering thermal comfort, indoor air quality, visual comfort, acoustic comfort, and interior quality, in hospital wards. The research was conducted across three hospitals in Jakarta, Indonesia, aiming to identify and prioritize key areas for improvement. A mixed-methods research approach was employed, involving 178 participants (staff, patients, and visitors) in hospital wards. Gap analysis of users' perception revealed significant performance gaps were identified in 13 out of 17 IEQ attributes. Traditional IPA identified temperature, noise level, natural light, and lighting control as high-priority concerns, alternative IPA expanded this list to 10 IEQ attributes. Both IPA matrices consistently indicated that natural elements, outside view, glare, and thermal control were low-priority. Conversely, space layout, speech privacy, and lighting intensity were found to exceed expectations. Objective measurements confirmed environmental deficiencies: indoor temperatures ranged from 23.4-27.6°C (above the 22-23°C Indonesia's standard), average CO_2 concentration reached 827 ppm (exceeding the 1 ppm national threshold), and $PM_{2.5}$ levels averaged 93 µg/m3 (above the 25 µg/m3 limit). Ventilation was inadequate, several rooms failed to meet requirements for natural light access and occupancy density. Integrating objective data with alternative IPA enhances the precision of IEQ improvement prioritization. The combined approach identified nine critical IEQ aspects for improvement: temperature, noise level, natural lighting, air quality, cleanliness, lighting control, room size, air exchange, and air velocity, while humidity was generally satisfactory. Despite varying user roles, findings suggest a shared need for improved indoor comfort. This integrated method offers a more targeted and comprehensive framework for prioritizing IEQ enhancements in hospitals and other building types. This study advances healthcare facility design by combining subjective user perceptions with objective environmental data, offering a robust framework for IEQ assessment and improvement.

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Aguiar, E. B. D., Barros, F. S.

Air Renewal Parameters Through Application.

Revista de Gestão - RGSA, Vol. **19** n°(7), (2025)

Introduction: Air quality has been increasingly studied in the scientific community, as there is great concern about the pollutants that have accumulated on planet Earth over the years. The worrying aspect of poor air quality is reflected in external and internal environmental indicators. For the external environment, gases are primarily analyzed; however, for the internal environment (rooms), the analysis is mostly based on chemical and biological parameters. This study provides an understanding of the importance of these aspects with the help of technology, specifically, an application for air exchange data in accordance with Brazilian standards and resolutions. The main result of the study indicated that the application, developed and tested in Brazilian research, proved to be of great assistance to professionals in the field, who

approved the use of the software when using it in their projects. The basic conclusion of the research is that indoor air quality is extremely important and has become increasingly widespread in recent years. Therefore, technological innovations in this area have been increasingly widespread, encouraging professionals to engage in calculations and parameters for air renewal.

Objective: To investigate the importance of indoor air quality, focusing on the application of technologies that assist in air renewal in accordance with Brazilian standards, aiming to support professionals in this field in their projects.

Theoretical Framework: The research is based on studies on atmospheric pollutants and chemical and biological parameters that affect indoor environments, highlighting the growing scientific concern with air quality.

Method: An application aimed at analyzing indoor air renewal was developed and tested, specifically to identify the flow rate required for the ideal air renewal equipment for the space. Validation occurred through practical application of the software by professionals in the field, who evaluated its usefulness.

Results and Discussion: The results demonstrated the effectiveness of the application as a technical support tool. The discussion highlighted the relevance of technological innovation in indoor air quality control, despite specific limitations.

Research Implications: The findings contribute to more effective indoor air quality monitoring practices, influencing HVAC and environmental health projects in sectors such as engineering and architecture. However, the application serves as an aid to mathematical methods involving air exchange.

Originality/Value: The research stands out for creating an application specific to the Brazilian context, promoting advances in the interface between technology and environmental health, and adding practical value to professional practice in this field.

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Raina, R., Singh, K. J., Kumar, S.

Air Sense: Internet of Things-enabled Novel Power Efficient Indoor Air Quality Monitoring System.

2025 International Conference on Microwave, Optical, and Communication Engineering (ICMOCE)

Air pollution, known to cause health issues such as respiratory and cardiovascular diseases emphasize the importance of monitoring indoor air quality with carbon dioxide (CO2) sensor. Despite various air quality monitoring systems being discussed in the literature, their power consumption is often overlooked. This paper introduces Internet of Things (IoT) enabled novel power efficient indoor air quality monitoring system that uses CO2, temperature and humidity sensors which send data to the cloud via Global System for Mobile Communication (GSM) technology. Moreover, keeping CO2 levels below 1000 PPM is vital for optimal indoor air quality as discussed in literature. The CO2 sensor operates continuously, while the temperature and humidity sensor activates when the CO2 level becomes equal or exceeds 1000 PPM. By combining temperature and humidity data with CO2 levels, a more thorough insight into air quality is achieved. This strategy will reduce the power consumption of the device as both the sensors are active when there is a critical need of monitoring. The system's battery life is approximately 9.71 days when CO2 sensor is active only, decreasing to 8.71 days when both sensors are active using a 15600mAh/4.2 V battery. Furthermore, the sensor's fetching interval is set to 15 min when CO2 values are unstable. However, when CO2 values remain stable, the fetching interval starts at 15 min and doubles with each successive stage of continued stability. This approach minimizes the device's power consumption by reducing the frequency of data collection.

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Suzana, D., Jure, R., Sašo, M.

Assessment of building renovation with modular ventilated FIPVT in terms of energy efficiency and indoor environment in office buildings.

Applied Thermal Engineering, Vol. **279**, (2025)

Energy renovation will be the challenge to fulfil the goal of zero energy for building stock. Article presents the design, modelling and performance evaluation for a modular solution of a façade-integrated photovoltaic system upgraded to supply heat and cold to the attached building (FIPVT) based on the “Balcony PV” solution. Different designs and operating strategies were analysed, from the fully integrated, naturally ventilated to bi-directionally, 3D, forced ventilated FIPVT. The research was based on in-situ experiments, computational fluid dynamics (CFD) modelling and energy efficiency evaluations with the building energy modelling (BEM) tool. Experiments showed that the thermal mass of the FIPVT causes a pronounced dynamic thermal response, with the diurnal difference of the PV temperature θPV being up to ± 15 K compared to the static model, and multiparametric models of quasi-dynamic temperature difference Δθdyn were developed for time step numerical modelling. User-defined macros were integrated into the BEM tool for an all-year evaluation of the FIPVT. A case study showed that the efficiency of the solar energy utilization increased to 28.3 % for the forced ventilated FIPVT and could be further increased with a battery having an optimal capacity of 0.35 kWh per m2 of FIPVT.

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Song, M.-K., Kim, J. W., Kim, D. I., Park, Y., Yoon, W., Lee, K.

Assessment of pulmonary toxicity in mice to evaluate human health risks from indoor airborne microorganisms.

Journal of Hazardous Materials, Vol. **495**, (2025)

Indoor air quality significantly impacts human health, with airborne microorganisms being a key pollutant. Although toxicity of indoor chemicals has been well-documented, the effects of inhalable microorganisms are not well understood. This study aims to assess the pulmonary effects of dominant resident airborne microorganisms collected from various locations across the Republic of Korea. Bacteria and fungi were isolated from indoor air samples collected from 240 to 1029 sites, and two strains each were selected for animal testing. C57BL/6 mice were exposed to these microorganisms via intratracheal instillation over four weeks. All exposure groups showed increased inflammatory cells and cytokines in broncho-alveolar lavage fluid, along with histological signs of lung injury, including inflammatory cell infiltration and mucous cell hyperplasia. The benchmark dose10 was then calculated for each adverse outcome as the mouse toxicity point of departure, which was converted to human equivalents to estimate the indoor microorganism exposure threshold capable of inducing toxic responses in humans. This threshold indicates that humans may be exposed to indoor fungi at potentially harmful levels which may lead to disease-associated inflammatory lung injury. Overall, this study provides toxicological evidence that can contribute to the development of improved standards for the management of indoor air microorganisms.

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Vela, L. a. P., Bandales, J. D. A., Marcial, Y. M.

Assessment of The Developed Protective Device for Air Conditioning Units (ACUs).

International Journal of Research and Scientific Innovation (IJRSI), (2025)

This study evaluated a protective device designed for air conditioning units (ACUs) to safeguard against power interruptions, intermittent power restoration, and voltage surges. The primary objective was to determine the device’s performance in terms of sensing accuracy and operational consistency under controlled time intervals, using an experimental method. The device integrates electrical systems with sensing and electronic components, which are all governed by a microprocessor. Statistical tools, including percentage error, arithmetic mean, and a scoring method, were utilized to analyze the results. Findings revealed that the device demonstrated high accuracy in sensing current and voltage values and exhibited

strong reliability in executing its time-delay function. These outcomes indicate the device's effectiveness in protecting ACUs during unstable power conditions.

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Taghipour, A., Saengnoree, A., Sangmanee, W.

Behavioral Intentions Toward Air Purifier Adoption in Thai Municipal Offices for Sustainable Indoor Air Quality.

SSRN, (2025)

With growing air pollution in Thailand, making sure indoor air is safe in municipal offices is becoming more important for health. This research explores the reasons behind municipal executives' interest in installing indoor air purifiers, by applying the TPB and TAM models. After applying SEM to a nationwide survey of 320 municipal executives, the study uncovered that the most important factor is air purifier innovation in shaping intention to adopt the product, through both a direct impact and indirectly through improved perception of behavior control (PBC) and performance expectancy in its use (PEU). It turns out that some beliefs related to environmental air characteristics (EAC) indirectly affect behavioral intention and do not directly predict it themselves. Because of PEU and PBC, it is especially important to center design on users and empower them. The research proves that there are important indirect pathways in understanding technology acceptance and provides input for policymakers and public administrators looking to shape sustainable and health-friendly indoor environments in the public sector. New advances in digital health visualization and air quality technologies prove that including user-friendly and informative technologies can strongly influence people's actions.

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Park, J., Moon, C. S., Lee, J. M., Rahat, S. A., Kim, S. M., Pham, J. T., *et al.*

Bioinspired capillary force-driven super-adhesive filter.

Nature, Vol. **643** n°(8071), (2025), 388-394 p.

Capturing particles with low, nanonewton-scale adhesion is an ongoing challenge for conventional air filters1,2. Inspired by the natural filtration abilities of mucus-coated nasal hairs3,4, we introduce an efficient, biomimetic filter that exploits a thin liquid coating. Here we show that a stable thin liquid layer is formed on several filter media that generates enhanced particulate adhesion, driven by micronewton to sub-micronewton capillary forces5,6. Enhanced particle adhesion increases the filtration of airborne particulates while maintaining air permeability, providing longer filter lifetime and increased energy savings. Moreover, strong adhesion of the captured particles enables effective filtration under high-speed airflow as well as suppression of particle redispersion. We anticipate that these filters with thin liquid layers afford a new way to innovate particulate matter filtering systems.

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Białas, J.

Comparison of the mass concentration of size-resolved particulate matter inside a selected fire station in poland and in the atmospheric air in its immediate surroundings.

Environment Protection Engineering, Vol. **51** n°(2), (2025)

The objective of this study was to evaluate the mass concentration of size-resolved (PM1, PM2.5, PM4, PM10, PM100) particulate matter (PM) in the indoor air of a selected fire station in Poland and to compare them with the concentrations of the same PM fractions in the atmospheric air. Optical measurements of PM concentrations were conducted for 12 hours a day, simultaneously inside and outside of the fire station, for 14 days in heating and non-heating seasons. In both measurement seasons, the average PM concentrations were higher in the fire station (26–44 µg/m3) than in the ambient air (9–32 µg/m3). The proportion of fine particles in the total PM mass was found to be higher in the fire station (83–90%) than in

the atmospheric air (40–78%). The findings of conducted analyses substantiate the notion that the concentrations and mass size distribution of PM in the fire station deviates from the concentrations and mass distribution for the urban background, a phenomenon that is attributable to the unique characteristics of the fire station and the prevalence of internal sources within it.

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Dhiman, R., Prakash, A., Saroj, S., Sahoo, P., Ambekar, A., Kore, S. D.*, et al.*

Comprehensive analysis of the fine and ultrafine particulate emissions from various welding sources in an industrial environment.

Atmospheric Pollution Research, Vol. **16** n°(12), (2025)

Industrial welding activities are responsible for ultrafine and fine particulate matter (PM) emissions, with established exposure-response functions for multiple health risks and premature mortality globally. This study examines the evolution of fine and ultrafine particle (UFP) concentrations from different welding techniques and their dispersion within a central workshop facility. Measurements were carried out using calibrated low-cost PM sensors (LCS), DustTrak8433, and Scanning-Mobility-Particle-Sizer (SMPS) at different heights for three welding processes: shielded metal arc welding (SMAW), wire arc additive manufacturing (WAAM), and friction stir welding (FSW). The relationship between welding conditions and PM emissions was investigated by various welding parameters, including current, voltage, and feed rate. In SMAW, the higher current intensity increased heat, electrode breakdown, and raised emissions of coarser UFP (300–550 nm) and PM2.5 at breathing height. PM2.5 emissions increased by 158 % near the source for SMAW at 125 Amperes (A) current compared to 50 A. At 2 m, 5 m, and 9 m distances, PM2.5 levels dropped to 880 µg/m3, 570 µg/m3, and 540 µg/m3, respectively, relative to source emissions at 125 A (2880 µg/m3). Post-welding, PM2.5 concentrations stabilized after 50 A at 12 min, 75 A at 34 min,100 A at 49 min, and 125 A at 63 min. For WAAM operations, PM2.5 and UFP levels peaked at low currents-voltage (globular-transfer) and reduced at high currents-voltage (spray-transfer). FSW results show that high or low feed rates combined with low or high RPMs increase UFP emissions, while a moderate feed rate (58 mm/min) minimizes emissions at any RPM. SMAW resulted in up to 68 % higher PM2.5 intake, whereas WAAM caused up to 74 % higher UFP exposure, highlighting distinct health risks across techniques. This contribution poses possible health risks due to the elevated concentrations of UFPs with varying size distributions across different welding methods.

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Duarte, R., Moret Rodrigues, A., Pimentel, F., Gomes, M. D.

Design and Performance of a Large-Diameter Earth–Air Heat Exchanger Used for Standalone Office-Room Cooling.

Applied Sciences, Vol. **15** n°(14), (2025)

Earth–air heat exchangers (EAHXs) use the soil’s thermal capacity to dampen the amplitude of outdoor air temperature oscillations. This effect can be used in hot and dry climates for room cooling with no or very little need for resources other than those used during the EAHX construction, an obvious advantage compared to the significant operational costs of refrigeration machines. Contrary to the streamlined process applied in conventional HVAC design (using refrigeration machines), EAHX design lacks straightforward and well-established rules; moreover, EAHXs struggle to achieve office room design cooling demands determined with conventional indoor thermal environment standards, hindering designers’ confidence and the wider adoption of EAHXs for standalone room cooling. This paper presents a graph-based method to assist in the design of a large-diameter EAHX. One year of post-occupancy monitoring data are used to evaluate this method and to investigate the performance of a large-diameter EAHX with up to 16,000 m3/h design airflow rate. Considering an adaptive standard for thermal comfort, peak EAHX cooling capacity of 28 kW (330 kWh/day, with just 50 kWh/day of fan electricity consumption) and office room load extraction of up to 22 kW (49 W/m2) provided evidence in support of standalone use of EAHX for room cooling. A fair

fit between actual EAHX thermal performance and results obtained with the graph-based design method support the use of this method for large-diameter EAHX design.

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Mohammed, K., Luo, W., Walker, S., Kramer, R.

Developing key performance indicators for occupant-centric buildings using occupant feedback: A scoping review and methodological framework.

Energy and Buildings, (2025)

The use of occupant feedback in smart building control and management has been shown to enhance indoor environmental quality and building energy efficiency. Despite this potential, its use in real-world building operations remains limited. To investigate its current applications and uncover barriers to adoption, we conducted the first scoping review to examine 1) how subjective feedback is collected through surveys in the domains of thermal quality and indoor air quality, and 2) how this feedback is subsequently transformed into actionable Subjective Key Performance Indicators (SKPIs) across various application contexts. Our findings revealed significant inconsistencies in survey design, survey deployment, and SKPI computation, even within similar use cases. This highlights the absence of standardized and systematic approaches to SKPI development as a critical obstacle. In response, we proposed a comprehensive four-step framework outlining key factors requiring standardization throughout the SKPI development process and discussing the state-of-the-art recommendations and debates in the literature. We then demonstrated how the framework can guide SKPIs development by considering these key factors with an example related to fault diagnosis in air handling units. Lastly, the major challenges associated with the SKPI developments and future directions are discussed, emphasizing the need for advancement of validated and robust scales, occupant sampling methods, and exploring applications in fault detection, diagnostic, and building energy flexibility. This paper highlights the untapped potential of SKPIs and establishes a methodological foundation for their development and application in smart building management and controls.

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Roman, O., Bassier, M., Ricciuti, S., Farella, E. M., Remondino, F., Viesi, D.

Digital Twins and CFD simulations for accurate sensor positioning.

Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., Vol. **XLVIII-G-2025**, (2025), 1291-1298 p.

Building renovation to improve energy efficiency is crucial for reducing CO2 emissions, aligning with the goal of achieving net-zero emissions by 2050. This task requires a holistic approach that encompasses retrofitting outdated systems, enhancing thermal insulation, and integrating renewable energy sources. Simulating different indoor environmental conditions and technological systems within Digital Twin (DT) before interventions is crucial for optimizing energy efficiency. Simulations can support the proper installation of heating and cooling devices and facilitate the deployment of advanced technologies, including smart Heating, Ventilation, and Air Conditioning (HVAC) systems, energy-efficient lighting, and automated energy management solutions. The use of Artificial Intelligence (AI) in simulations allows for the precise sizing of HVAC systems, including heat pumps and related devices, by accurately modelling demand profiles and optimizing sensor placement based on the geometries of DTs.

This study, conducted as part of the Horizon Europe InCUBE project1, explores a real-world use-case at the Centro Servizi Culturali Santa Chiara in Trento, Italy. It introduces an innovative approach that integrates 3D surveying, computational fluid dynamics (CFD), and digital twin (DT) geometries to enhance the analysis of indoor heat distribution. The proposed data-driven pipeline optimizes sensor placement within indoor spaces, ensuring precise system design, improving performance and energy efficiency, and minimizing energy waste while preventing the oversizing of technological systems.

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Zhu, Y., Liang, W.

Effect of temperature and heat transfer on formaldehyde emissions from the medium density fiberboard: An experimental investigation.

Building and Environment, Vol. **283**, (2025)

Formaldehyde emissions from building materials pose serious health risks. Temperature influences these emissions, which can vary considerably within buildings. To verify the validity of the common-used instantaneous equilibrium assumption and to investigate the effects of heat transfer on formaldehyde emissions, experiments were conducted using medium-density fiberboard (MDF) in a dynamic environmental chamber under four thermal equilibrium conditions (15 °C, 20 °C, 25 °C, and 35 °C) and four heat transfer scenarios with initial material (environment) temperature and relative humidity controlled at 25 °C 50 % (35 °C 50 %), 35 °C 50 % (25 °C 50 %), 30 °C 76 % (25 °C 50 %) and 18 °C 37 % (25 °C 50 %). The initial conditions of materials were maintained by introducing an equilibrium stage. Under thermal equilibrium conditions, formaldehyde emissions increased with temperature rose. The initial emittable concentration (C0) rose fourfold from 6.00 × 108 μg/m³ at 15 °C to 2.40 × 109 μg/m³ at 35 °C. Under heat transfer conditions, thermal gradients induced coupled heat-moisture transfer in the MDF. Heat transfer ended within 2–4 h, while moisture transfer persisted for 40–80 h which might be the main cause of emission variations, invalidating the instantaneous equilibrium assumption. Heat transfer conditions significantly altered emission profiles: environment-to-material transfer elevated formaldehyde concentrations by more than 10 % above equilibrium values, while material-to-environment transfer suppressed emissions. Regressed key emission parameters also exhibited heat transfer sensitivity, with C0 and diffusion coefficients (Dm) deviating by 10 % and 20 %. These findings challenge conventional equilibrium-based models, highlighting the necessity of incorporating transient thermal effects for accurate formaldehyde emission predictions.

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Chang, L., Permana, I., Setiawan, T., Agharid, A. P., Wang, F.

Evaluating and enhancing thermal comfort and indoor air quality in a library building through measurement and simulation.

Ain Shams Engineering Journal, Vol. **16** n°(10), (2025)

Thermal comfort and indoor air quality (IAQ) are critical for occupant well-being and productivity. This study evaluates a library's self-study reading room for adults and children's learning center, aiming to optimize temperature and airflow conditions for different age groups. Methods included questionnaire surveys, field measurements, and Computational Fluid Dynamics (CFD) modeling. Findings revealed that occupants preferred cooler temperatures than standard Predicted Mean Vote (PMV) models predicted, with optimal conditions being 26 °C and 0.2 m/s for adults and 24 °C and 0.2 m/s for children. Installing a Total Heat Exchanger (THX) system reduced CO2 levels by approximately 200 ppm. CFD simulations identified CO2 distribution issues, leading to recommendations such as removing partition walls and rearranging desks to improve airflow. The study highlights the importance of tailored ventilation strategies to enhance IAQ and occupant comfort in diverse spaces, providing insights applicable to similar building environments.

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Xie, L., Shan, K., Wang, S.

A generic framework and strategies for integrating AI into building automation systems for field-level optimization of HVAC systems.

Energy, Vol. **333**, (2025)

With the growing demand for energy-efficient and optimized building operations, AI-based control optimization for HVAC systems has garnered increasing attention. However, most existing approaches remain confined to academic research due to challenges in practical deployment and the operational reliability of AI-driven strategies. This paper, presents a generic framework and associated strategies for integrating AI-driven online control optimization into Building Automation Systems (BAS) by adopting AI-

enabling smart control stations at the BAS field level. The proposed framework comprises two core functional modules: (1) an AI operating environment that supports lightweight and, real-time execution of AI models, and (2) a comprehensive suite of AI functional boxes that ensure effective and reliable execution of AI algorithms. The framework's functionalities are validated by integrating two smart control stations with a BAS testbed. Control robustness and energy performance are evaluated through hardware-in-the-loop testing using a simulated dynamic HVAC system. The test results demonstrate that the proposed framework and AI-driven strategies can maintain robust and stable control under various critical conditions, while achieving a 7.66 % reduction in energy consumption.

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Morantes, G., Lara-Ibeas, I., Molina, C., Sherman, M. H., Babich, F., Jones, B.

Harm from indoor air contaminants in offices.

Building and Environment, Vol. **284**, (2025)

This study uses a health-centered approach to quantify and compare the chronic harm caused by indoor air contaminants using the Disability-Adjusted Life-Year (DALY). The aim is to understand the chronic harm caused by airborne contaminants in office buildings and identify the most harmful. Harm intensities (HI) are a metric of chronic harm per unit of contaminant concentration. Starting with a broad range of 342 organic and inorganic gases and particulate matter, uncertainty is evaluated in the concentrations of 90 indoor air contaminants commonly found in offices. Chronic harm is estimated from the harm intensities and the concentrations. The most harmful contaminants in offices are fine particulate matter (PM2.5), formaldehyde (HCHO), ozone (O3), and coarse particulates (PM10−2.5), accounting for over 99% of the estimated median time-weighted chronic harm of 300DALYs/105 person/year (geometric standard deviation of 3.5).

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Folayan, A.

Health Profiles of Factory and Office Workers in Malaysia: A Survey Study.

medRxiv, (2025)

Introduction Occupational settings expose workers to varying health risks that may lead to both immediate and long-term health complications. These risks, which include chemical, biological, and physical hazards, can affect individuals differently depending on workplace conditions, exposure levels, and host factors such as immune status. This study aimed to compare the health profiles of workers in three distinct work environments: an electronics factory, an office, and a winery.Methodology A cross-sectional study was conducted using a self-administered questionnaire that collected data on demographic characteristics, workplace conditions, and self-reported health symptoms. A total of 98 workers with at least six months of experience at their respective workplaces participated. Ethical approval and written informed consent were obtained prior to data collection. Data were analysed using Microsoft Excel 2003.Results The results revealed distinct health profiles across the three occupational settings. Back and neck pain was commonly reported at all sites, affecting more than 60% of respondents. Electronics factory workers experienced a higher prevalence of cough (62.1%), frequent thirst (45.5%), and headaches (50%), likely linked to chemical exposure and poor air quality. Office workers reported the highest rates of respiratory and skin-related symptoms, including sneezing (71%), dry skin (58.8%), and memory difficulties (47%), suggesting potential indoor air quality issues. Winery workers exhibited a notably higher prevalence of shortness of breath (40%) and frequent thirst (60%), possibly due to poor ventilation and physical exertion.Conclusion This study provides valuable baseline data on occupational health differences across work settings, underscoring the need for targeted interventions, improved ergonomic designs, and further longitudinal research.Competing Interest StatementThe authors have declared no competing interest.Funding StatementThis study did not receive any funding Author DeclarationsI confirm all relevant ethical guidelines have been followed, and any necessary IRB and/or ethics committee approvals have been obtained.YesThe details of the IRB/oversight body that provided approval or exemption for the research described are given below:Ethical approval for the study was granted by the International Medical

University Ethical CommitteeI confirm that all necessary patient/participant consent has been obtained and the appropriate institutional forms have been archived, and that any patient/participant/sample identifiers included were not known to anyone (e.g., hospital staff, patients or participants themselves) outside the research group so cannot be used to identify individuals.YesI understand that all clinical trials and any other prospective interventional studies must be registered with an ICMJE-approved registry, such as ClinicalTrials.gov. I confirm that any such study reported in the manuscript has been registered and the trial registration ID is provided (note: if posting a prospective study registered retrospectively, please provide a statement in the trial ID field explaining why the study was not registered in advance).YesI have followed all appropriate research reporting guidelines, such as any relevant EQUATOR Network research reporting checklist(s) and other pertinent material, if applicable.YesAll data produced in the present study are available upon reasonable request to the authors

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Kathwate, L. H., Chandak, V. S., Mane, Y. S., Lokhande, S. D., Awale, M. B., Kanwate, A. D.

High-performance formaldehyde sensor based on Al-doped ZnO nanorods prepared by chemical bath deposition.

Ceramics International, Vol. **51** n°(19, Part B), (2025), 29146-29158 p.

Formaldehyde is a volatile organic compound and is known as a common indoor air pollutant that can cause significant effects on the human respiratory and neurological system. Therefore, it is imperative to precisely and continuously measure the formaldehyde at low operating temperatures. In the present research work, a cost-effective Chemical Bath Deposition technique has been employed for the deposition of pristine and Al-doped ZnO nanorods (NRs) on glass substrates. The various influences of Al-doping on structural, morphological, compositional, optical and gas-sensing properties have been systematically investigated and reported. The pristine and Al-doped ZnO NRs are considered as sensing material to detect formaldehyde. Among all, the 4 % Al-doped ZnO NRs sensor exhibits a high response of about 72.56 % with rapid response time (21 s) and recovery time (38 s) at 100 °C towards 50 ppm of formaldehyde. In addition, sensors respond to a low concentration of 0.1 ppm. Furthermore, the sensor showed good stability and reproducibility.

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Kabun, K., Reinhold, K.

Improving indoor air quality and mitigating health risks with sheep wool as a sustainable material.

Indoor Environments, Vol. **2** n°(3), (2025)

Sheep wool as a natural fiber is an increasingly important alternative to synthetic materials in the green economy. The study evaluates the effectiveness of sheep wool based materials in enhancing indoor air quality (IAQ) and mitigating health risks in occupational settings. Two test cabins - one with conventional synthetic materials and another with sheep wool based materials - were designed to compare the performance of these materials in terms of noise insulation, volatile organic compounds (VOC) emissions, CO2 levels and humidity regulation. A survey of the room occupants' perception of the material was also carried out. Results show that sheep wool panels provide sound insulation comparable to synthetic materials, especially at mid-range frequencies. Sheep wool's natural ability to regulate humidity contributed to a more stable indoor climate, while VOC levels remained low in both cabins, below the analytical determination limit for some parameters. The Synthetic cabin showed a slightly lower VOC level. The sheep wool cabin showed more rapid CO2 fluctuations, demanding further study. User surveys indicated a preference for the sheep wool cabin, with participants noting comfort and an overall more pleasant environment. This novel approach, which simultaneously measures IAQ indicators and examines the room users' perception of IAQ, shows that sheep wool based materials, being both sustainable and biodegradable, provide a healthier alternative to synthetic materials, supporting the goals of reducing health risks and promoting environmental sustainability.

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Mazzeo, A., Pfrang, C., Nasir, Z. A.

InAPI (v1.0): an Excel-based Indoor Air Pollution Inventory tool to visualise activity-based indoor concentrations of pollutants and their emission rates for the UK.

EGUsphere, Vol. **2025**, (2025), 1-14 p.

Indoor air quality (IAQ) has become a critical focus of research due to the substantial amount of time people spend indoors (approximately 80–90 % of their lives), where a significant proportion of air pollution exposure occurs. However, understanding how time and activity dependent sources, as well as built environment characteristics, influence pollutant emissions and distributions remains very limited. Addressing these challenges, InAPI — an Excel-based Indoor Air Pollution Inventory tool — has been developed using data synthesised from a comprehensive review of UK indoor air pollution research. For the development of the InAPI tool, we have categorised existing literature by pollutant types, indoor environments, and activities, identifying significant knowledge gaps and offering an open-access database of typical pollutant concentrations and emission rates. InAPI leverages this database, which includes estimates of emissions from multiple sources based on chemical mass balance methods, to enable users to visualise indoor pollutant levels and emission characteristics across the varied UK indoor settings. Despite the fragmented methodologies in historical IAQ research and the underrepresentation of key sources, pollutants, and environment-specific characteristics (in particular ventilation and occupant behaviour), InAPI consolidates this evidence into a practical and easy-to-use tool. This tool facilitates standardisation of IAQ measurement protocols and the creation of activity-based indoor emission inventories, bridging critical research gaps. By providing a robust platform for understanding indoor air pollutant dynamics, InAPI represents a significant step forward in advancing IAQ research in the UK and beyond given the transferability of the approach, supporting efforts to mitigate indoor air pollution and inform policy initiatives nationally and globally.

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Şimşek, H., Merdan, İ., Arslan, F. S.

Indoor Air Quality Index Measurement in Mines Based on Multi-valued Logic Techniques.

Intelligent and Fuzzy Systems. (INFUS 2025)

Recent accidents in mines highlight the need for further research and output in this sector. Mine air quality is one of the most important research topics in the mining industry in terms of worker health and safety. Various factors such as gases, required air quantity, and ventilation principles need to be considered together. The amount of gas in mines, the humidity in the air, and the amount of dust inside are among the factors that determine indoor air quality. The aim of the research is to practically evaluate indoor air quality in mines with a fuzzy logic approach, including various parameters with limit values in accordance with international standards. There are three sub- and one main fuzzy inference systems in this study. 9 different parameters affecting the problem were used in the subsystems. Three main parameters are used in the main inference system, which are air quality containing gases, climate conditions, and air criteria measuring dust amount and air velocity.

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Veiga, I., Oliveira, T., Naranjo-Zolotov, M., Martins, R., Karatzas, S.

Indoor air quality perception: Enablers and inhibitors of perceived occupant comfort.

Environment International, Vol. **202**, (2025)

Growing environmental and public health concerns have increased the need for healthy buildings, with indoor air quality (IAQ) emerging as a priority. While technological advancements in IAQ management have progressed, research often overlooks individual comfort perception and behavioral factors influencing it and disconnects IAQ improvements from behavioral insights. This study explores how personal characteristics, perceived inhibitors, and enablers shape comfort perception in indoor environments managed by Internet of

Things-based IAQ management technologies (IAQMTs). Given the EU's growing emphasis on smart, energy-efficient, and occupant-centered buildings, we examine comfort perceptions across seven European countries to inform user-centered IAQ strategies aligned with policy goals. Grounded in the dual-factor theory, we employed a survey-based approach in the European context and analyzed responses from 2800 individuals using partial least squares structural equation modeling (PLS-SEM). Our model demonstrated strong explanatory power, accounting for over 65 % of the variance in perceived IAQ and comfort in public environments. Key enablers are intuitiveness, response efficacy, and hedonic motivation, while convenience is not. Information and privacy concerns are not inhibitors. Health consciousness and environmental consciousness are important individual characteristics when it comes to perception. Perceived good IAQ was the strongest predictor of comfort in public spaces. The findings emphasize the importance of intuitive, transparent, and engaging IAQMTs that visibly demonstrate pollutant reduction and comfort enhancement. We recommend that building managers and technology developers incorporate user-centered features, such as clear interfaces, gamification elements, personalized controls, and communication strategies highlighting health and environmental benefits, to foster adoption and improve occupant comfort. Our findings support a human-centered approach, integrating behavioral insights into environmental health science, focusing beyond technical metrics and more on occupant beliefs and perceptions, supporting strategies that align with user needs and EU goals.

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Ramadhani, I. G. a. I. F., Putri, T. Z., Asmarita, Y. D., Amania, S., Mufti, N., Mizar, M. A.*, et al.*

IoT Implementation for Air Quality Monitoring System using Low Cost Sensor.

2025 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT)

This research created a gas concentration monitoring system utilizing the Internet of Things (IoT), which can measure and display eight environmental parameters in real time, such as temperature, humidity, and the concentrations of gases like O3,CO,CH4,CO2,SO2, and NO2. The system utilizes an ESP32 microcontroller to process data from sensors and transmit it to the ThingSpeak database via a Wi-Fi network. The monitoring results are displayed on a Nextion screen and an App Inventor-based application, allowing data access through smartphones. The system was tested using ambient air samples at Universitas Negeri Malang for two hours. The results indicate that the system operates stably and can accurately transmit and display data, while maintaining server connectivity even during network disruptions. The average concentrations recorded were 0.0539 ppm for CO,323.15ppm for CO2,0.35ppm for CH4, 0 ppm for SO2,0.148ppb for O3, and 0.0165 ppm for NO2, indicating good air quality. The undetected SO2 levels were due to minimal nearby sources such as traffic or industrial activity. With this success, the developed system has the potential for continuous air quality monitoring and can be integrated with other IoT platforms for further data analysis.

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Gorade, N. B., Galhe, D. S.

Iot-based indoor air quality detection and smart energy management for hvac system.

KT Journal of Mechanical Engineering, (2025)

Indoor air quality has become a growing concern due to increased indoor time and health risks linked to poor air quality. This project presents the development of an IoT-based system for monitoring indoor air quality and enabling smart energy management of HVAC systems. The system integrates various sensors, including CO_2, gas, smoke, temperature, and humidity sensors, and an ESP32 microcontroller and Blynk app interface to collect, analyze, and display real-time environmental data. In addition to monitoring air quality, the system uses an automated fan control mechanism to respond to deteriorating air conditions, enhancing both comfort and safety. A smart energy management module dynamically controls the HVAC system based on occupancy and air quality levels to reduce power consumption and improve system efficiency. The integration of IoT technology enables real-time feedback, remote access, and energy

optimization, making it a cost effective, user-friendly, and scalable solution for residential and commercial applications.

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Zhao, X., Wang, S., Li, P., Shi, X.

Long-term indoor air quality monitoring in office buildings: Data-driven and goal-oriented recommendations for sensor placement and sampling frequency.

Building and Environment, Vol. **283**, (2025)

Long-term indoor air quality (IAQ) monitoring in office buildings is essential for assessing occupants' pollutant exposure. However, a lack of clear standards regarding sensor locating and sampling intervals leads to inefficient resource use and inaccurate data collection. This study analyzed one-year in-situ measurements of PM2.5, PM10, and CO_2 collected from 16 sensors in Shanghai. Spatial similarity metrics (Pearson and Jaccard indices) were used to identify factors influencing pollutant distribution for temporal trend and high-concentration events. A feature importance evaluation framework, incorporating LASSO, random forest, and SHAP interpretation, revealed the drivers of high-concentration events. Different sampling intervals were assessed using CV(RMSE) and Peak Recall to determine optimal intervals for capturing temporal trend and high concentrations. Based on these findings, we propose two IAQ monitoring strategies: (1) A temporal trend-oriented strategy: One sensor per 150 m2, centrally located in representative spaces. PM and CO2 can be sampled at 90 and 130-minute intervals, respectively. CO2 further accounts for AC type and room sizes. (2) A high-concentration event-oriented strategy: shorter sampling intervals—every 4 min for PM2.5 and CO2, and 15 min for PM10. Additional sensors are installed in stand-alone AC spaces with varying rooms and areas distant from air outlets and windows (for PM). For CO2, additional sensors are recommended in stand-alone AC rooms and large spaces, particularly in zones far from ventilation sources, where pollutant accumulation is more likely.These findings provide practical recommendations for IAQ monitoring and offer generalizable methods for analyzing similar datasets, with direct implications for building performance standards.

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Zhang, X., Liu, P., Liu, G., Lim, S. H., Yin, H., Wan, M. P., *et al.*

Maximizing aerosol filtration via acoustics.

Journal of Hazardous Materials, Vol. **496**, (2025)

The removal of airborne particulate matter (PM10, PM2.5, and PM0.1) is of huge importance to improving air quality, which has direct impact on human health and industrial processes that require clean environments. To achieve this, fibrous air filters have been widely used to remove PM but is often associated with high energy consumption as particles quickly clog the windward pores. This increases airflow resistance and requires frequent replacements that underutilizes filter materials. Here, Acoustics-Enhanced Aerosol Filtration (AEAF) technology, leveraging sound-induced fiber vibration, redistributes particles across filter surfaces and interiors to address these issues. By consuming minimal energy for sound generation, AEAF achieves significant energy savings in air delivery systems to overcome pressure drop and further reduces solid waste from the filters. Experimental results show a 3.5-fold increase in particle capture efficiency alongside a pressure drop that is 4.7 times lower. The estimated lifespan of filters can be extended by 2.4 times, potentially saving up to 58 % of filter materials. This low-cost technology can be extensively applied to air filtration systems that incorporates fibrous filters to significantly improve air quality.

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Romero-Barriuso, Á., Ballesteros-Álvarez, J.-M., Villena-Escribano, B.-M., Rodríguez-Saiz, Á., González-Gaya, C.

Mejora de la calidad del aire interior mediante ventilación natural: Experiencias de un edificio municipal en Móstoles, España.

DYNA, Vol. **100** n°(4), (2025), 371-377 p.

This study evaluates the effectiveness of natural ventilation in enhancing indoor air quality within the Almudena Grandes Central Library, a municipal building in Mostoles, Spain. Triggered by the public health challenges highlighted during the SARS-CoV-2 pandemic, the research develops a methodological framework that integrates CO2 monitoring, occupancy modeling, and airflow calculations to assess air renewal capacities under natural ventilation conditions. The analysis reveals that cross ventilation is the only strategy capable of achieving IDA 2 air quality standards in high-occupancy areas, requiring at least five air changes per hour. Zenithal openings, such as roof ventilators, significantly enhance airflow during colder months with strong indoor-outdoor thermal differentials, even when external wind is minimal—a frequent scenario in continental Spanish climates. The study also explores buoyancy and wind-driven ventilation mechanisms and quantifies their respective contributions using empirical models. Results suggest that the library can maintain acceptable air quality for up to 310 users with sufficient cross-ventilation measures. However, single-sided ventilation proves inadequate. The proposed model supports dynamic capacity management and energy efficiency by integrating real-time environmental data. The authors highlight the potential of automating ventilation systems via domotics for continuous air quality monitoring and optimization. Limitations include the variability of outdoor conditions and the need for future validation using Computational Fluid Dynamics (CFD) and additional case studies. Overall, the findings emphasize architectural strategies as pivotal in promoting healthier, energy-efficient indoor environments in public infrastructure.

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Pasupuleti, M. K.

Model Predictive Control for Smart HVAC Systems in Green Buildings.

International Journal of Academic and Industrial Research Innovations(IJAIRI), Vol. **5** n°(6), (2025), 1-11 p.

This study investigates the application of Model Predictive Control (MPC) in optimizing smart Heating, Ventilation, and Air Conditioning (HVAC) systems for green buildings. MPC algorithms are designed to predict future indoor conditions and optimize energy usage by adjusting system outputs proactively. A simulated green building environment was used for evaluation, including real-time weather data and occupancy-based control inputs. The performance of MPC was benchmarked against traditional Proportional-Integral-Derivative (PID) control systems in terms of energy efficiency, temperature stability, and operational cost. Results indicated that MPC achieved a 28.7% reduction in energy consumption, improved thermal comfort, and lowered peak load demands. Statistical analysis and regression models confirmed significant differences in performance metrics. These findings demonstrate the viability of MPC in advancing energy-efficient HVAC operations and support its integration in next-generation smart building infrastructures.

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Umar, A., Syam, R. H. R., Handayani, W., Qaiser, N., Apriandanu, D. O. B., Yulizar, Y.

Modification of silver nanoparticles (AgNPs) with tollens reagent for selective colorimetric detection of formaldehyde.

Results in Chemistry, (2025)

This study uses modified silver nanoparticles (AgNPs) and Tollens' reagent to explore a novel colorimetric sensor for formaldehyde detection. AgNPs was synthesized using sodium citrate and tannic acid. Characterization of AgNPs using UV–Vis spectroscopy, XRD, and TEM were observed, confirming their size and structure. AgNPs was modified with Tollens' reagent and investigated the sensor's response to various formaldehyde concentrations. The results showed a linear relationship between the maximum absorbance wavelength and formaldehyde concentration, demonstrating the sensor's potential for quantitative detection. Crucially, the AgNPs@Tollens system exhibited remarkable selectivity towards formaldehyde over other aldehydes such as acetaldehyde and benzaldehyde, as evidenced by distinct UV–Vis absorption spectra; only formaldehyde induced a strong surface plasmon resonance (SPR) peak at

approximately 420 nm, while other aldehydes showed negligible. TEM analysis validated the rise in AgNPs size upon exposure to formaldehyde. Zeta potential measurements demonstrate a significant decrease in colloidal stability upon the addition of formaldehyde, as indicated by the shift to a less negative (−21.4 mV) zeta potential for AgNPs@Tollens with formaldehyde. This reduced electrostatic repulsion explains the increased tendency for agglomeration, which is consistent with observations from TEM analysis. The limit of detection (LOD) for formaldehyde was determined to be 11.20 μM, indicating the sensor's high sensitivity. The sensor demonstrates selectivity for formaldehyde compared to other tested interferents. This novel colorimetric sensor offers a method that is not only straightforward but also quick and economical for formaldehyde detection in various environments.

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Panda, S. A., Barala, S., Hazra, A., Gangopadhyay, S.

Modulation of 1D ZnO nanostructures for selective formaldehyde sensing: The role of surface energy, polarization, and adatom kinetics toward asymmetric growth.

Ceramics International, (2025)

The precise morphological control of highly dense, crystalline, and asymmetric one-dimensional (1D) metal oxide semiconductor nanostructures is of high practical importance for developing high-performance chemiresistive gas sensors. In this study, various 1D ZnO nanostructures, including nanobelts, nanowires, nanorods, and nanoneedles, were uniformly grown on glass substrates via the controlled thermal oxidation of thin Zn films under ambient air conditions. Comprehensive structural, chemical, optical, and electrical characterizations were conducted to investigate their properties and growth mechanism. Thermal oxidation of thin Zn films initiates only above 400 °C, whereas a transition towards asymmetric growth of 1D ZnO nanostructures starts to occur at 600 °C. Different nanoscale morphologies such as nanobelts (t = 58 nm, w = 460 nm), nanowires (d = 48 nm), nanorods (d = 280 nm), and nanoneedles (d = 85–120 nm) are obtained after thermal oxidation of [600 °C, 5h], [700 °C, 1h], [700 °C, 5h] and [800 °C, 5h], respectively. Chemiresistive gas sensing performance of these 1D nanostructures was evaluated against different volatile organic compounds (VOCs) in a static vapor mode, demonstrating exceptional sensitivity and selectivity for formaldehyde detection. The nanoneedle-based sensor exhibited superior sensitivity (36 %) with rapid response (28 s), while the nanobelt-based sensor demonstrated excellent selectivity. Notably, the nanowire-based sensor with highly porous morphology achieved an ultra-low detection limit, well below 50 ppb. The growth mechanism was explained based on surface free energy, surface polarization, and adatom diffusion kinetics. Additionally, gas sensing performance was analyzed in relation to surface-to-volume ratio, crystal defect states and crystal plane orientation. Mechanism behind controlled electron transport through the nano-junction of 1D nanostructure is also discussed. All these findings establish a growth mechanism of 1D ZnO nanostructures as promising candidates for advanced gas sensing applications.

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Hou, F., Cheng, J. C. P., Ma, J., Kwok, H. H. L., Huang, C., Wu, Z.

Occupancy-driven HVAC control optimization via LSTM and deep reinforcement learning for enhanced indoor air quality, thermal comfort and energy efficiency.

Building and Environment, Vol. **284**, (2025)

Heating, Ventilation, and Air Conditioning (HVAC) systems are critical for maintaining indoor environmental quality but constitute a major contribution to building energy consumption. It is a challenge for traditional control methods to balance indoor air quality, thermal comfort and energy efficiency under dynamic occupancy conditions. This study proposes a novel occupancy-driven HVAC control framework (OccD-LSTM-DDQN) integrating Long Short-Term Memory (LSTM) networks and Dueling Deep Q-Networks (DDQN). The framework firstly leverages the correlation between indoor CO_2 concentration fluctuations and occupancy states and develops an occupancy state estimation method through change-point analysis. Then, the proposed OccD-LSTM-DDQN control method incorporates the occupancy estimation results to

reduce HVAC operation time during unoccupied periods. Experimental results across three rooms demonstrate that the occupancy estimation methods achieved precision and recall rates of around 0.7 and 0.6, respectively. Detailed quantitative analysis identified two misclassification scenarios: high CO_2 concentrations were classified as "occupied" states, while low concentrations were classified as "unoccupied". While these inaccurate classifications reduced overall precision and recall, the proposed method ensures prompt ventilation in high-concentration scenarios while minimizing unnecessary HVAC operation during low-concentration periods. The control experimental results further demonstrate that the OccD-LSTM-DDQN control method contribute to reduce temperature violations by 9.5–14.6 %, CO_2 violations by 12.2–17.4 %, and HVAC operation time by 10.9–30.4 % across three rooms. This study also discusses a dynamic hyperparameter adjustment strategy to enhance deployment robustness. Overall, these results confirm the effectiveness of the proposed control framework in maintaining indoor temperature and CO_2 levels within desired ranges while optimizing energy efficiency.

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He, X., Wen, Y., Li, N., Zou, Q., Yang, S., Wan, M. P.*, et al.*

Optimal fresh air distribution control strategy for multi-zone variable air volume air conditioning systems.

Applied Thermal Engineering, Vol. **279**, (2025)

In Variable Air Volume (VAV) air conditioning systems, fresh air consumption significantly impacts the overall energy consumption and indoor environment quality. However, imbalanced fresh air distribution often leads to over-supply in some zones and insufficient supply in others. To address this issue, this paper proposes a hybrid ventilation optimization strategy based on imbalance rate assessment. It aims to optimize fresh air distribution across multiple zones while reducing energy consumption, ensuring indoor air quality, and maintaining thermal comfort. Under high fresh air imbalance, the critical zone with the highest fresh air ratio is dynamically identified, and its supply air volume and Proportional-Integral-Derivative (PID) controller parameters are optimized using the Non-dominated Sorting Whale Optimization Algorithm (NSWOA). The optimal non-dominated solution is chosen via the entropy-weighted Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). In other periods, the fresh air correction equation is applied across zones. The proposed strategy is validated through comparisons with existing control methods: maximum fresh air ratio control (Strategy (Ⅰ)), CO2 concentration-based demand control (Strategy (Ⅱ)), and fresh air correction equation-based control (Strategy (Ⅲ)). Results show that the proposed strategy achieves a 9.6 % energy reduction compared to Strategy (I), significantly reduces CO2 exceedance duration in the critical zone by up to 90.5 %, and lowers the average Predicted Mean Vote (PMV) by 51.5 %. Additionally, the PID tuning shortens controller's response time by approximately 57.5 %. This strategy improves ventilation efficiency without requiring additional sensors, making it suitable for practical deployment in existing multi-zone VAV systems.

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Ajifowowe, I.

Optimizing indoor environmental systems control for maximizing human comfort and energy efficiency based on reinforcement learning.

KAIST. Thèse 2025

Efficient optimization of energy distribution and indoor environmental conditions is a global priority, particularly in the context of building energy systems, which account for one-third of global energy use. Among these, Heating, Ventilation, and Air Conditioning (HVAC) systems are the largest contributors to energy consumption. Achieving sustainable energy efficiency requires the development of robust control methods capable of adapting to dynamic environmental conditions. This research explores the implementation of a Deep Q-Network-based Reinforcement Learning (DQN-RL) model to optimize HVAC and lighting systems within a dynamic indoor environment using the IRIS testbed modeled based on a typical office building with two occupants. The DQN-RL framework dynamically adjusts control actions to

balance energy efficiency with occupant comfort, focusing on three key metrics: Indoor Air Quality (IAQ), thermal comfort (PMV), and visual comfort (illuminance). The model was trained on historical datasets collected from the IRIS testbed and evaluated against a manually controlled baseline system. Findings reveal that the DQN-RL model achieved significant improvements, including a 21.4% reduction in energy consumption, a 26% improvement in thermal comfort compliance, and a 33% improvement in visual comfort compliance. Although IAQ compliance slightly underperformed compared to the manual baseline, the overall results demonstrate the model's capability to optimize energy usage while maintaining acceptable comfort levels. These results highlight the potential of reinforcement learning in enhancing energy efficiency and indoor comfort, paving the way for sustainable and adaptive building management systems.

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Shin, S., Baek, K., So, H.

Rapid Prediction of Local Mean Age of Air for Energy-Efficient Ventilation Systems Using Permutation Feature Importance.

International Journal of Energy Research, Vol. **2025** n°(1), (2025)

Prediction of local mean age of air (MAA) is a key technology that can enhance the comfort, health, and productivity of indoor residents by adjusting and optimizing the indoor environmental conditions. In this study, we developed a deep neural network (DNN)-based regression model to predict indoor air quality (IAQ) and proposed a permutation feature importance (PFI)-based explainable artificial intelligence (XAI) model to implement efficient ventilation systems in a hospital ward utilizing this regression model. The rapid prediction of the MAA in the space near each patient in the ward, depending on the location of the heating, ventilation, and air conditioning (HVAC) inlets and fluid velocity, were successfully measured through data-driven deep learning model training. Consequently, the proposed MAA prediction model achieved average R-squared values of 0.9506 and 0.9220 for MAA1 and MAA2, respectively. In addition, the DNN model demonstrated rapid predictive performance (~0.4 ms/prediction), highlighting the possibility of real-time monitoring compared to conventional methods. Furthermore, the contribution of the location and fluid velocity of the HVAC system to the MAA in the space near the patient was analyzed using PFI. These results support the rapid virtual sensing and recommendation method that has the potential to be applied in future IAQ management, human healthcare, and energy management systems.

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Biradar, S., Jagtap, V., Giram, V., Rathod, K., Mishra, N.

Real Time Air Quality Monitoring System using IoT.

2025 7th International Conference on Inventive Material Science and Applications (ICIMA)

Air pollution, because of the discharge of harmful gases which includes carbon monoxide (CO), methane (CH4), nitrogen oxide (N2O), carbon dioxide (CO2) and fluorinated gases, poses widespread environmental and health risks. continuous tracking of these pollutants is vital for mitigation efforts. This paper affords an IoT-based air fine tracking device that makes use of wi-fi sensors to discover dangerous gases and transmit actual-time statistics to a centralized server. The device employs the MQ135 sensor for accurate pollutant detection and integrates a microcontroller for statistics processing. while pollutants degrees exceed predefined thresholds, signals are brought on thru alarms, computerized control of exhaust structures, or notifications through SMS and e-mail. This actual-time monitoring method permits powerful pollution control and prompt corrective action.

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Abdul Halim, M. H., Ismail, A., Md Sakip, S. R.

Reliability and validity analysis of indoor air quality, crew stress level and self efficacy in warship environment: a pilot survey.

Malaysian Journal of Sustainable Environment, Vol. **12** n°(2), (2025), 229-242 p.

<p>Warship environments present unique challenges to personnel, including concerns about indoor air quality (IAQ). There are physical symptoms and health effects associated with poor IAQ, which affect crew stress levels. Both variables were proportionately influenced by crew self-efficacy. Previous research demonstrates a lack of holistic studies of the relationship between IAQ, self-efficacy, and crew stress levels on board warships. Hence, further studies regarding the instrument’s effectiveness in measuring all variables would be worthwhile. Thus, this study aims to evaluate the reliability and validity of the instrument to measure IAQ, crew stress level, and self-efficacy amongst warship crew by utilizing data collected from a pilot survey using the Statistical Package for the Social Sciences (SPSS). Reliability and validity of measurement variables using content validity and reliability method. The content validity assessment was carried out by three experts, including the researcher's supervisor and the Director of Malaysia Armed Forces Physiology and Counselling. Consequently, the researcher invited ten personnel with experience serving onboard KD JEBAT to participate in the face validity process. Data were collected from a sample of 52 warship personnel, and reliability analyses were conducted using Cronbach's alpha coefficient to assess the internal consistency of each dimension. Corrected item-total correlations were also examined to evaluate the relationship between individual survey items and their respective constructs. The reliability analysis revealed an internal consistency (acceptable to good levels) within variables which is IAQ, crew stress level, and self-efficacy. However, the stress-triggered dimension exhibited a lower reliability coefficient. Additionally, the corrected item-total correlations provide a significant relationship between items and corresponding constructs in support of the validity of the measurement scales. As a result, all items were accepted and valid to conduct actual survey with the value of Cronbach's alpha for dimension (a) Indoor Air Contaminant Parameter (0.747), (b) Indoor Air Physical Parameter (0.708), (c) Stress Response (0.715), (d) Stress Triggered (0.703), (e) Victorious Experience (0.780), (f) Performance Outcome (0.705). The researcher utilizes the analysis results to design the best questionnaire survey for the actual survey. Future research may enhance the understanding of this domain and contribute to the betterment of warship personnel.</p>

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Rao, C., Periyasamy, V.

Renewable-Powered HVAC and Smart Ventilation Systems for Sustainable Hospital Environments.

In. Renewable Energy Solutions for Smart Healthcare Infrastructure Sustainable Medical Facilities 2025. 284-313 p.

Renewable energy solutions for smart healthcare infrastructure aim to create sustainable medical facilities that reduce carbon footprints while ensuring uninterrupted power supply for critical operations. By integrating solar panels, wind turbines, and energy storage systems, hospitals can maintain reliable, clean energy sources even during grid failures. Smart energy management systems further optimize consumption by balancing demand and supply in real time. This approach not only lowers operational costs but also aligns with global climate goals. Sustainable healthcare facilities improve patient safety, enhance resilience during emergencies, and demonstrate environmental responsibility, setting a benchmark for future-ready, eco-friendly medical infrastructure worldwide.

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Zhang, K., Wang, S.-Y., Jin, X., Luo, Y.-X., Zhang, X.

Research on VOCs from Indoor Furniture and Influencing Factors of Their Emission.

International Journal of Medical and All Body Health Research, (2025)

Indoor furniture continuously emits various VOCs, such as aliphatic hydrocarbons, aromatic hydrocarbons, chlorinated hydrocarbons, aldehydes-ketones, and acids-esters, which affect indoor air quality and harm human health. Furniture made of different materials contains varying types and concentrations of VOCs. Dry materials (boards, leather, etc.) and wet materials (paints, adhesives, etc.) are the primary sources of VOCs in furniture. The emission of VOCs from furniture is influenced by multiple factors: the physical and

chemical properties of the furniture itself (substrates, paint films and thickness, loading rate, etc.) are the decisive factors affecting VOCs emission, while environmental factors (temperature, relative humidity, air change rate, air flow velocity, etc.) also impact VOCs emission.

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Adelodun, A. A., Hellebust, S., Wenger, J., Johnson, M. S.

Simultaneous Improvement in Building Energy Efficiency and Indoor Air Quality with Smart Demand Controlled Ventilation.

Available at SSRN 5336525, (2025)

A building's climate and air quality are important for health and productivity but they require significant energy. Improvements in energy efficiency often compromise Indoor Air Quality (IAQ). Here we present a hybrid ventilation solution that simultaneously reduces energy use and improves IAQ. We compare standard mechanical ventilation with a hybrid ventilation solution (reduced mechanical plus air cleaners), conserving total clean air delivery rate, in a field trial at two lecture theatres at University College Cork, Ireland. The air cleaners combined H13 HEPA filter and UV-C light to remove particles and kill pathogens. Sensors logged concentrations of particulate matter, carbon dioxide, and temperature. Relative to normal mechanical ventilation, the hybrid solution used 47.4% less energy, PM1 was reduced by 51.6% and PM2.5 by 72.1%. Carbon dioxide increased marginally, from 545 to 608 ppm, with hybrid ventilation. The results show that a hybrid ventilation strategy can lower energy use and improve IAQ, by reducing particulate matter concentrations, at the same time. The implications of this field trial are discussed in terms of a proposed Smart Demand Controlled Ventilation (SDCV) system in which smart sensors and data analytics would be integrated with the building management system and adaptive ventilation control.

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Anupriya V; Selvaganesh M; Shirley E; Udhaya Arthi M; Vivitha G.

Solar Boosted AI Air Cleanser for Textile Sector.

6th International Conference on Inventive Research in Computing Applications (ICIRCA) 2025

In textile industry, the quality of air becomes vital factor day by day. The dust pollutants in air causes serious respiratory risks for workers like chronic cough, bronchitis and so on. As a solution, this project is based on air quality monitoring and filtration systems with AI predictions that uses solar technology to operate efficiently. The system consists of optical dust sensors that detects dust particles which are most commonly produced in textile industries. The sensors collect real-time data, which is analysed by an AI algorithm to monitor pollution patterns in real time and predective future trends in pollution pattern. The process begins with collecting the real time sensor data. once the collected data value is above threshold limit value, then the AI optimizes the vacuum threshold, intelligently calibrating fan speed and suction power for efficient dust collection. It is powered only with solar panels to make it even more sustainable. The AI and solar technology enable this integrated solution to offer an economically viable, energy-efficient, and sustainable option for air quality management in textile sectors. Also, it both increases worker health and safety and helps to meet the standards of applying environmental regimes, overall diminishing the environmental impact of producing textiles

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Lin, C.-C., Cheng, Y.-H., Hsiao, C.-C.

The study on material/air equilibrium partition coefficients and internal diffusion coefficients of volatile organic compounds within recycling green building materials.

Construction and Building Materials, Vol. **490**, (2025)

Expanding upon earlier work on VOC emissions from recycled green building materials (RGBMs), this study delves deeper into the internal equilibrium and diffusion mechanisms of the materials, offering more

detailed parameters for risk modeling. This study quantitatively evaluates the material/air equilibrium partition coefficients and internal diffusion coefficients of four representative volatile organic compounds (VOCs)—ethylbenzene, decane, n-butanol, and hexanal—in four certified RGBMs: calcium silicate board (CSB), fiber cement board (FCB), gypsum board (GB), and waterproof gypsum board (WGB). Experiments were conducted in an air-conditioned laboratory maintained at 25 ± 0.5 °C and 65 ± 5 % RH, using a dual-volume stainless steel chamber that allowed VOC diffusion solely through the test materials. Among the tested VOCs, decane exhibited the highest partition coefficients, while n-butanol demonstrated the fastest internal diffusion rates. A significant inverse relationship was observed between vapor pressure and partition coefficients, as well as between molecular weight and diffusion coefficients. Materials with greater specific surface areas and pore volumes—particularly CSB and FCB—showed enhanced VOC sorption and diffusion capacities. Sorption of polar VOCs was moderately affected by relative humidity, whereas diffusion was less sensitive. These findings provide foundational insights into how VOCs interact with RGBMs, advancing understanding beyond traditional emission studies. These findings establish a foundational dataset for emission modeling, material screening, and IAQ risk assessment in sustainable buildings.

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Dubois, C.

Travail de fin d'études/Projet de fin d'études: Ventiler mieux, consommer moins-Optimisation de la ventilation d'un bâtiment tertiaire à l'aide de simulations numériques pour équilibrer confort thermique, consommation énergétique et qualité de l'air.

Université de Liège, Liège, Belgique. Thèse 2025

Face aux enjeux de sobriété énergétique et de durabilité, la question de la ventilation dans les bâtiments tertiaires prend une place de plus en plus importante. Elle est liée aux exigences croissantes en matière de qualité de l'air, de confort et de réduction des consommations. Aujourd'hui, les systèmes double flux sont largement utilisés, mais ils restent énergivores et techniquement complexes. Ce travail explore l'opportunité de solutions plus sobres, dans une logique low-tech, à travers une étude de cas concrète : un bâtiment de bureaux en construction à Seneffe, conçu par le bureau d'architecture Hélium3.

L'objectif principal de ce mémoire est d'optimiser la ventilation d'un bâtiment tertiaire à l'aide de simulations numériques, en cherchant un équilibre entre confort thermique, consommation énergétique et qualité de l'air intérieur. Trois modèles ont été développés sous TRNSYS et TRNFlow : un système 100 % mécanique, une ventilation naturelle reposant sur les effets thermiques et de pression, et une solution hybride combinant dispositifs naturels et appoint mécanique piloté.

Les résultats montrent que la ventilation hybride constitue un bon compromis entre performance, confort et sobriété. Une analyse de généralisation met en évidence l'importance des paramètres architecturaux (orientation, géométrie, inertie) et du contexte (urbain ou rural). Enfin, ce travail questionne la rigidité des normes actuelles, souvent déconnectées de la réalité des projets, et propose une réflexion vers une approche plus souple, intégrée dès la conception.

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Aghaei, A., Pedrielli, G., Wu, T., O'neill, Z., Becerik-Gerber, B., Hoque, S.*, et al.*

Understanding the role of artificial intelligence in improving human well-being within the built environment.

Building Simulation, (2025)

The indoor environment has become the primary habitat. According to the U.S. Environmental Protection Agency, the average American spends 93% of their life indoors, with 87% spent inside buildings and 6% in automobiles. There is a pressing need to design and renovate the built environment to better serve human occupants. This requires a multidisciplinary approach, and, in recent years, due to the advances in devices, computational speed achievable on small surface chips, and Internet of Things (IoT) platforms, artificial

intelligence (AI) has come to play a crucial role in making effective use of these technologies by enhancing the modeling and control of buildings in a way that shifts the focus from the building to the occupant. The goal of this paper is to explore state-of-the-art AI research in the domain of healthy buildings. We do so by formulating seven questions focusing on three themes. First, we explore how new data sources and data platforms have enabled AI to be adopted for the paradigm of healthy buildings, including the use of IoT technologies and the associated opportunities and challenges arising from a wide range of data sources. Second, we investigate AI-informed approaches for healthy building design and control, encompassing physical building models as well as human behavioral models representing occupants. Finally, we reflect on the building certification process, and examine examples from academic research labs and real-world constructions to understand the current state and existing use cases. The study establishes a foundation to understand the role of AI in healthy buildings and it provides insights for future research directions.

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Manikonda, P., Reddy, J. R. N.

Using Sensor Networks for Environmental Monitoring in Healthcare Settings.

In: Responsible Innovation in Smart Healthcare: AI, IoT, and Ethical Sustainability Practices. IGI Global Scientific Publishing; 2026. 161-190 p.

Health care quality and patient outcomes are strongly correlated to environmental conditions. The focus of this chapter is how sensor networks in the context of IoT can provide real time environmental monitoring in healthcare environments. Some of the application listed cover the indoor air quality tracking, temperature and humidity control, and detection of hazardous substances. It also shows the significance of low power sensors, data accuracy, and integration system for good working performance. It proposes deployment strategies, and evaluates the effect of sensor data on enhancing the hospital safety, operational efficiency, and patient care while upholding sustainable goals.

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Ghaffari Jabbari, S., Fermoso Domínguez, J., Rodríguez Sufuentes, S., Nyberg, S. O., Sandnes Vehus, T., Kofoed Nielsen, H.

VOC emissions from commercial wood panels using PTR-MS for indoor air quality evaluation.

Frontiers in Built Environment, **Volume 11**, (2025)

IntroductionWood panels, commonly used in cold climates like the Nordic countries for their aesthetic surface and availability, emit volatile organic compounds (VOCs) that can impact indoor air quality and may contribute to health risks, especially with repeated or prolonged exposure. While research has primarily focused on untreated fresh wood, little attention has been given to the VOC emissions from commercial wood panels. This study aims to investigate the VOC emission pattern, intensity, and profile of nine commercially untreated and treated wood panels commonly used in indoor environments, focusing on how wood type and surface treatments influence emission characteristics.MethodsThe study utilizes Proton Transfer Reaction Time-of-Flight Mass Spectrometry combined with passive sampling, offering a more comprehensive analysis of volatile organic compounds, including both volatile and very volatile compounds, which traditional gas chromatography cannot capture. Advanced statistical methods, such as Bayesian posterior, principal component analysis, and hierarchical clustering analysis, were employed to identify key emission contributors and classify emission patterns.ResultsThe findings reveal that emission intensity and profiles are influenced by wood type and surface treatments. Pine and oak emitted higher proportions of VOCs, while spruce primarily emitted VVOCs. Glazing, staining, and painting significantly affect emission intensity, with glazing reducing pine total emissions by 81% and increasing them in spruce by 65%. Staining pine reduced VOC emissions by 74% but increased VVOC emissions by 63%, shifting the emission profile. Despite high emission intensity from untreated pine, painting reduced TVOC emissions by 93%, aligning its profile with lower-emission woods like aspen and spruce, making it more suitable for indoor use.DiscussionThe right treatment can transform high-emission woods into materials resembling low-emission species, offering a practical means to mitigate indoor VOC loads.

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Racic, N., Terzic, I., Karlovic, N., Bosnjakovic, A., Terzic, T., Jakovljevic, I.*, et al.*

Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs) in Indoor Environments: A Review and Analysis of Measured Concentrations in Europe.

INDOOR AIR, Vol. **2025** n°(1), (2025)

Indoor air quality is a significant aspect of public health, yet it remains less studied than outdoor air pollution. Understudied indoor pollutants include volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs). This review focuses on these two groups of compounds known for their health effects, including respiratory issues, neurological disorders, and carcinogenicity. We systematically compiled and analyzed data from studies reporting measured concentrations of VOCs and PAHs in European indoor environments-homes, schools, and offices-published in the past two decades. Concentration levels vary substantially across studies, influenced by regional differences, climate, building type, ventilation systems, and indoor activities. Identified sources include tobacco smoke, cooking, heating (e.g., biomass burning), and off-gassing from construction and furnishing materials. Our analysis reveals clear geographic patterns: lower concentrations of VOCs and PAHs are consistently reported in Northern and Western European countries, likely due to stricter air quality regulations, cleaner outdoor air, greater use of electric heating, and more advanced ventilation systems. Conversely, higher concentrations are more commonly observed in Southern and Eastern Europe, where biomass heating and poorer ventilation remain more prevalent. Seasonal variation also has a significant role, with higher indoor levels typically measured during colder months due to increased heating and reduced air exchange. This highlights the need for improved indoor air quality management practices and regulatory standards to minimize the health risks associated with VOCs and PAHs. This review of 46 scientific publications is aimed at informing future studies and guiding future field measurements and risk assessments in epidemiological studies.

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