Bulletin de veille QAI
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Objectif : *Qualité de l'air intérieur*

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Google Scholar, Lens, WoS

Crizel, L.

Advancing Evidence-Based Design (EBD) with Biosensor Integration: A Pathway to Data-Enriched Architectural Solutions.

In: Routledge Handbook of Neuroscience and the Built Environment. 2025. 422-432 p.

This chapter presents an evidence-based design (EBD) approach applied to architecture and interior design, emphasizing the integration and use of biosensor technologies. The objective is to incorporate the use of biosensors as tools for collecting data on how built environments impact human physiology and psychology. This data-driven methodology aims to enhance the effectiveness and precision of EBD, validating and ensuring that design decisions are grounded in verifiable evidence, rather than solely on theoretical models or subjective preferences. It provides an overview, along with a literature review, of the use of biosensors to monitor and analyze key environmental parameters—such as spatial composition, lighting, materials, colors, and acoustic conditions, among others that could be included in the scope of analysis—and their direct effects on occupant well-being, stress levels, and productivity. By correlating these environmental factors with measurable human responses this methodology implements a responsive and adaptable EBD process.

The chapter further explores the implications of this approach in various settings, including healthcare facilities, workplaces, and educational institutions, where occupant well-being is paramount. It highlights the contribution of incorporating biosensor feedback into the design process to promote environments that meet sustainability criteria while also actively contributing to the health and satisfaction of their users. Ultimately, the chapter suggests a paradigm shift in the design model, where the EBD process, through the employment of biosensors, serves as an instructive tool in creating spaces that seek proven benefits for occupants. The goal is to promote a continuous evolution in EBD, underpinned by tangible data, to ensure environments that are both environmentally sustainable and conducive to human health and happiness.

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Rasha, Shamail, Y, Sonia, S D, Vishakha, D, Suhana, B B, Dr Manjula

AI based smart indoor air quality prediction and monitoring system.

IJARCCE, Vol. **14** n°(11), (2025)

Indoor Air Quality (IAQ) greatly affects health, comfort, and sustainability in modern spaces. This project introduces an AI-powered Indoor Air Wellness System that uses Kalman Filter and LSTM algorithms to predict and monitor air quality in real time. Sensors for CO_2, CO, NO_2, temperature, humidity, and light work with an ESP32 microcontroller to process and share data via LCD, ThingSpeak, and Telegram. A solar-powered fan system replaces traditional HVAC, promoting energy efficiency and eco-friendly air circulation. By combining AI, IoT, and renewable energy, the system offers a smart and sustainable way to maintain healthy indoor environments.

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Ali, M., Ahmad, T., Arshad, G., Alam, P., Ahmad, K., Mazhar, M. A.*, et al.*

Assessment of indoor and outdoor air quality using low-cost sensors and analysing ventilation effect.

Discover Environment, Vol. **3** n°(1), (2025)

Air pollution, driven by rapid urbanization and industrialization, poses serious health risks, particularly in densely populated cities where individuals spend most of their time indoors. This study assessed indoor and outdoor air quality in residential houses in Okhla, South Delhi—a recognized high-pollution hotspot—during spring 2023 (February–April) using calibrated low-cost sensors. A total of 24 houses were monitored and categorized as well-ventilated or poorly ventilated based on the presence of mechanical ventilation systems. Concentrations of particulate matter (PM2.5 and PM10) were measured indoors and outdoors, and indoor/outdoor (I/O) ratios were calculated to evaluate the role of ventilation. Results revealed that indoor PM10 levels in poorly ventilated houses reached approximately 320 µg/m3, far exceeding the WHO guideline of 45 µg/m3, while indoor PM2.5 levels were nearly five times above permissible limits. PM2.5 and PM10 exhibited similar temporal patterns, with I/O ratios consistently greater than one, indicating substantial indoor contributions to exposure. Poorly ventilated houses demonstrated higher ratios, underscoring the influence of inadequate ventilation in exacerbating indoor air quality. These findings highlight the urgent need for improved ventilation practices and sustainable urban planning to mitigate health risks. Beyond providing evidence of high indoor exposures in a critical urban hotspot, the study demonstrates the utility of low-cost sensors for monitoring. It contributes to policy discussions on scalable, affordable tools for managing indoor air quality in rapidly urbanizing regions.

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Khankari, K.

Basics of Air Change Rates.

ASHRAE Journal, Vol. **67** n°(12), (2025)

The article focuses on the concept of air changes per hour as a metric for building ventilation and its appropriate use in heating, ventilation, and air conditioning system design. It explains that the rate of air changes reflects the supply airflow relative to the space volume, influencing the buildup and decay of contaminants, but the steady-state indoor air quality depends primarily on airflow and contaminant generation rather than the air change rate alone.

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Ojrati, A., Qasemi, M., Zarei, A., Afsharnia, M., Zarei, A.

Beauty salon technicians' exposure to formaldehyde, benzene and acetaldehyde in Gonabad City.

Scientific Reports, Vol. **15** n°(1), (2025)

Beauty salons are places where the technicians/staff personnel and clients may be exposed to high levels of various types of air pollutants. In this study, levels of formaldehyde, benzene and acetaldehyde and their associated potential health risks on beauty salon technicians in Gonabad city were investigated. Indoor levels of formaldehyde, benzene and acetaldehyde were measured in 22 randomly selected beauty salons. Formaldehyde, benzene and acetaldehyde air levels found in beauty salons ranged from 1.02 to 41.4, 1.96 to 43.66, and 41.71 to 79.41µg/m3, respectively. Formaldehyde in indoor air of all the salons were within the WHO guideline of 100 µg/m3. Levels of benzene were within the NIOSH recommended exposure limit (320 µg/m3), but higher than Korean limit (30 µg/m3) in 40% of the investigated salons. For acetaldehyde, levels of acetaldehyde in 68% of the salons surpassed the WHO guideline of 50 µg/m3. Non-carcinogenic risks of formaldehyde, benzene and acetaldehyde were below the threshold limit (HQ = 1), indicating no risks, however, carcinogenic risks over the 30-year period were not acceptable (>1x10-6), indicating cancer risk in long term exposure of beauty salon technicians to these chemicals. The results confirm that formaldehyde, benzene and acetaldehyde indoor levels are a matter of health concern, which must be taken into account by health professionals, policymakers and regulatory bodies. The findings of the current study can be used as a basis for reducing technicians' exposure to toxic aldehydes in beauty salons.

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Gautam, S., Azri, C., Khan, M. B.

Bioaerosols and Indoor Air Quality: Insights, Impacts, and Innovations.

CRC Press; 2026

This book provides a detailed exploration of bioaerosols in indoor environments, focusing on their sources, transport mechanisms, health implications, and mitigation strategies. It encompasses the biology, physics, and chemistry of bioaerosols, their interaction with indoor environments, and their influence on human health. It examines the role of HVAC systems, regulatory frameworks, and emerging technologies in understanding and controlling indoor air bioaerosols. It underscores the importance of proactive bioaerosol management in diverse indoor settings.

- Provides detailed explanation of bioaerosol transport and mitigation strategies
- Promotes comprehensive interdisciplinary approach integrating science, engineering, and public health
- Reviews case studies and examples including real-world applications in healthcare, schools, and residential spaces
- Discusses up-to-date advancements in air purification technologies and HVAC systems
- Includes ancillary materials like end-of-chapter problems, solutions, lecture slides, and downloadable figures

This book is aimed at senior undergraduate, graduate students, researchers and professionals in air quality, aerosols, and bioaerosols.

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Bralewska, K., Bralewski, A., Bihałowicz, J., Wolny, P., Chiliński, B.

BTEX and Polycyclic Aromatic Hydrocarbons Concentrations and Its Origin at Two Polish Fire Stations.

Indoor Air, Vol. **2025** n°(1), (2025)

This study aimed to determine the concentrations of BTEX and polycyclic aromatic hydrocarbons (PAHs; in gaseous and particulate phases) in the indoor air (truck bays, changing room, alarm point, and gym) of two selected fire stations in Poland (FSN and FSC), to compare these concentrations with the concentrations of the same compounds in the atmospheric air, and to assess the origin of air pollution at both fire stations. The measurements were conducted during the period from May to June of 2021, with data collection occurring at each measurement point for a period of 7 days, simultaneously inside and outside the building. A total of 42 samples of BTEX and 42 samples of PAHs in the gas phase, as well as 7 samples of PAHs in the solid phase, were collected at each measurement point. The mean concentrations of the sum of BTEX and PAHs were higher inside both fire stations (ΣBTEX 13.4-60.9 μg/m3; ΣPAH 250.4–715.0 ng/m3) than in the atmospheric air (ΣBTEX 3.4-13.1 μg/m3; ΣPAH 144.4–182.8 ng/m3). The order of BTEX concentrations at individual measurement points was as follows: truck bay (FSC) > gym (FSC) > alarm point (FSC) > changing room (FSN) > truck bay (FSN), while the concentrations of PAHs can be arranged in the following order: truck bay (FSC) > changing room (FSN) > alarm point (FSC) > gym (FSC) > truck bay (FSN). The findings of the diagnostic ratios and principal component analysis indicate that the primary source of indoor air pollution at the fire stations under study was identified as fuel combustion by fire vehicles and combustion equipment, as well as stored uniforms contaminated with combustion products. This research delineates the parameters for preventive measures aimed at enhancing air quality at fire stations and underscores the imperative for additional research in this domain.

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Daragó, A., Kilanowicz, A., Jurewicz, J., Klimczak, M.

Changes in hygiene standards for lead in the context of indoor shooting range workers exposure.

Medycyna Pracy. Workers' Health and Safety, Vol. **76** n°(6), (2025), 499-508 p.

A significant increase in the number of indoor shooting ranges for many years in Poland and most European countries is connected with a raising number of people potentially exposed to lead (both employees and users). In recent years, it has been noted that lead exposure poses a significant health risk

to both those who professionally use indoor shooting ranges, such as services officers, instructors, and shooting range staff, as well as occasional users. Exposure to lead increased its blood concentrations, which is associated with the risk of serious health effects, primarily affecting the hematopoietic system and the peripheral nervous system. Indoor shooting ranges constitute a significant source of occupational lead exposure for employees and users, primarily through inhalation. Available literature indicates existing health risks associated with working at these facilities, primarily related to the chronic effects of lead poisoning. Lead, although regulated by industry, is not routinely identified as a harmful agent at shooting ranges, resulting in a lack of measurements of lead concentrations in air and blood. The aim of this study was to assess current legal regulations regarding occupational lead exposure in the workplace in relation to exposure of employees at indoor shooting ranges. This study analyzed and summarized the current regulations regarding occupational lead exposure assessment and the literature regarding potential lead exposure at indoor shooting ranges. Due to EU Directive 2024/869 lowering the occupational exposure limit (OEL) and biological limit values (BLV) for lead, it appears necessary to develop guidelines and regulations regulating the exposure of employees at indoor shooting ranges to lead, similar to that in the United States. Lack of identification and reduction of lead exposure at indoor shooting ranges may lead to an increase in occupational disease cases, which poses a significant challenge for both employers and the healthcare system. Med Pr Work Health Saf. 2025;76(6):499–508

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Zong, J., Ai, Z., Chang, Y., Liu, O., Luo, J., Ye, J.

Characteristics and health risks of PM2.5 and VOCs in multi-chair dental offices: A case study in central China.

Building and Environment, Vol. **289**, (2026)

With the growing demand for dental services, indoor air quality in dental offices is facing increasing challenges. In this field, past studies mostly focus on monitoring indoor pollutant concentrations, while the chemical composition and exposure risks remain unknown. This study conducts air sampling in Periodontal Department (PD), Endodontics Department (ED), and outdoor environment (OE, serving as a reference group) in a large stomatological hospital in Changsha (April 22-May 1, 2025) to characterize PM2.5 and volatile organic compounds (VOCs) and assess health risks. No significant inter-departmental differences are found in PM2.5 component concentrations (Wilcoxon rank-sum test), with total carbon dominant. However, polycyclic aromatic hydrocarbons, including benzo[b]fluoranthene and benzo[k]fluoranthene (possible carcinogens), and benzo[a]pyrene (a confirmed carcinogen), are enriched indoors, with levels 1.1–1.6 (1.4–1.8) times higher in PD (ED) compared to OE. In contrast, VOCs show marked inter-departmental differences. 26 and 30 VOCs are detected in PD and ED, respectively, with 9 compounds (detection rates ≥ 50 %) showing elevated concentrations in ED compared to PD. These include 4 non-carbonyl VOCs and 5 carbonyl VOCs. Accordingly, ED also presents greater health risks. In both departments, 3 compounds have hazard quotient (HQ) above non-carcinogenic risk threshold (1.0), while 4 (PD) and 5 (ED) compounds show incremental lifetime cancer risks (ILCR) exceeding 1.0 × 10−6. The highest HQ and ILCR values are observed for acetaldehyde and formaldehyde, reaching 3.1 and 1.5 × 10−5 in PD, and 5.9 and 2.7 × 10−5 in ED. These findings support targeted occupational health measures and environmental interventions in dental environments.

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Rajan, S. K., Rupnar, D. V., Sreekala, M. S., Thomas, S., Ramgir, N. S.

Classification of Gas Sensor Devices, Their Fabrication, and Evaluation Parameters.

In: MXene Based Gas Sensors. CRC Press; 2026. 41-77 p.

Recent advances in nanoscience and nanotechnology have made the development of novel materials with desired properties for targeted applications possible. Novel 0D, 1D, and 2D morphologies are continuously being synthesized and added to the already available wealth on interesting nano-morphologies. For example, recent additions to the same is MXenes, which are a class of 2D inorganic compounds consisting

of atomically thin layers of transition metal carbides, nitrides, or carbonitrides. In particular, they have a variety of hydrophilic terminations due to which these materials exhibit enhanced properties for various applications including gas sensors. An analog of MXene, namely MBenes, is 2D transition metal borides. Both of them share the same structure, that is, accordion-like 2D layered nanosheet structures. They have a common defect—the self-stacking effect, and their surface is characterized by the presence of abundant surface functional groups crucial for tailor-made sensor materials. Considering their wide potential for gas-sensing applications, it becomes important to understand the different ways in which the material can be used. For this, it is crucial to first know the classification of gas sensor devices, their fabrication process, and importantly the evaluation parameters for achieving a realistic commercially deployable sensor. Accordingly, the present chapter critically reviews and discusses the different classifications of gas sensors across several factors that influence the sensor's design application and performance. These includes form factor, detection principle, gas type, and application. The present chapter explains these with examples from the literature and discusses the evaluation parameters to realize a complete device with potential commercial deployability. More specifically, they are discussed against the 4S sensor selection criteria wherein each S stands for enhanced sensor response, selectivity, stability, and suitability. Sensor response also takes into account the speed of detection, that is, faster response kinetics in particular response and recovery times.

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Cheng, Y., Lei, J., Tian, X.

Collaborative optimization of environmental quality and energy consumption in shared space micro-environments based on machine learning models.

Building and Environment, Vol. **290**, (2026)

Current methods for creating differentiated micro-environments in shared spaces effectively balance personalized thermal preferences and energy efficiency but often neglect Indoor Air Quality (IAQ) integration when optimizing supply parameters. This study proposes a framework combining machine learning-based IAQ distribution models and regression-based thermal comfort distribution models to jointly optimize micro-environments. Two key air supply parameters-velocity and temperature-were evaluated across 19 cases, which included six experimental conditions and 13 Computational Fluid Dynamics (CFD) simulations, all conducted under cooling conditions in a room with eight manikins, using CO_2 as a tracer gas. For each case, four different infected source locations were assessed. Jet theory was applied to design cases and calculate the characteristic length (yb), defined as the vertical distance between the supply jet center and the breathing point. Initial attempts to predict contaminant concentration, intake fraction, and exposure index at target locations using linear and exponential regression proved insufficiently accurate. Instead, four machine learning models-Backpropagation Neural Network, Support Vector Machine, Random Forest, and XGBoost-were trained and hyperparameter-optimized, significantly improving validation accuracy. XGBoost achieved the best performance (validation R^2 up to 0.97). Using this model, IAQ distributions were predicted for 200 ventilation scenarios derived from prior thermal comfort research. Multi-objective optimization revealed critical trade-offs: lower yb values improved IAQ except when the source was within the supply jet, while higher yb values reduced energy consumption. When objectives are equally weighted, the optimal yb values are approximately 0.25 m for sources within the supply air jet and 0.13 m for other sources.

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Wiratama, C.

Comparative Analysis of HVAC Indoor Unit Placement in a Small Café Using OpenFOAM.

Research gate, (2025)

Computational Fluid Dynamics (CFD) is increasingly applied in HVAC design to evaluate airflow distribution,thermal comfort, and ventilation effectiveness. In this study, an HVAC CFD workflow based on OpenFOAM usingthe tensorHVAC template is presented and applied to a small café case study. Three

indoor unit placementconfigurations were investigated using blockMesh and snappyHexMesh for mesh generation, the buoyantSimpleFoamsolver, and the k–ω SST turbulence model. Indoor environmental performance was assessed using air velocity,temperature, Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), Draft Rate (DR), and air age. Theresults show that one configuration achieved more uniform airflow and temperature distribution, resulting in near-neutral thermal comfort, low draft risk, and well-distributed air age, while the other configurations produced localizeddiscomfort and ventilation inefficiencies. The study demonstrates that the tensorHVAC template provides a robust andpractical framework for simplifying OpenFOAM-based HVAC simulations and supporting informed indoor unitplacement decisions.

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Maurya, R., Indu, S.

Comparative quantification of aerosol-generating potential in various dental treatment procedures and their reduction measures: A quasi-randomised trial.

Medical Journal Armed Forces India, (2025)

Background Since aerosol and splatter generation are inevitable in modern-day dental treatment procedures, it has become essential to assess the comparative aerosol load of each treatment procedure by quantifying the particles based on size. Hence, the present study proposed measurements of particle numbers in aerosol-generating procedures (AGPs) during routine dental treatment, as well as assessing the effectiveness of commonly used mitigation measures. Methods Eighteen commonly used treatment procedures were evaluated thirty times each, first with and without any active aerosol reduction measures, i.e. test group and intervention group, respectively. Mitigation measures were micromotor, high volume intra/extra oral suction, rubber dam, negative air pressure room. Aerosol particles (PM0.3–10) were quantified at baseline (OP1), peak (OP2), and 30 min post-procedure (OP3) using a handheld particle counter. Statistical analysis was carried out using repeated measures ANOVA, Tukey's HSD, and independent t-tests ($p < 0.05$). Results All procedures generated aerosols with significant intra- and inter-group differences. Complete tooth preparations and ultrasonic scaling were classified as “very severe”, while impressions, arch-wire changes, and hand instrumentation were “minimal.” Mitigation strategies effectively reduced aerosol levels in minimal to moderate AGPs but showed limited efficacy in severe and very severe categories. OP3 values remained elevated, confirming persistence of aerosols post-procedure. Conclusion The study established a quantitative framework for AGP risk classification and demonstrated the effectiveness of mitigation strategies. Findings have direct relevance in oral health care by guiding triaging, procedural spacing, local environment-specific adaptations, including layout and physical barrier modifications, and policy for safe dental care delivery across varied practice setups.

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Rakotonirinjanahary, V. M., Crumeyrolle, S., Bogdan, M., Hanoune, B.

Comparison of two methods for evaluating the performance of particle filtration systems in underground railway stations.

Indoor Environments, Vol. **2** n°(4), (2025)

Filtration is one of the strategies that can be implemented to mitigate the public health challenge due to elevated concentrations of particles in underground railway stations (URS). During a particle (PM2.5 and PM10) monitoring campaign performed in a Paris URS over more than 5 years, two filtration systems were tested. One of these systems employs positive ionization (Experiment 1), the second one is based on water filtration (Experiment 2). The present study focuses on evaluating the performance of these experiments, using two distinct methods: the daily amplitude coefficient (DAC), and a generalized additive model (GAM). The DAC method requires only particulate matter measurements, while the GAM method necessitates additional measurements (indoor CO_2 concentration, temperature and humidity, outdoor pollutant concentration) as it analyses the nonlinear relationships between all these factors. The results show that both filtration technologies are more effective at reducing PM2.5 concentrations than PM10, but Experiment

2 was less efficient than Experiment 1. Specifically, DAC analysis leads to a reduction of 17.8 ± 3.2 % for PM10 and 25.9 ± 6.6 % for PM2.5 for Experiment 1, compared to only 0.4 ± 0.1 % for PM10 and 3.7 ± 1.0 % for PM2.5 for Experiment 2. GAM analysis gives similar results, with a reduction of 13.1 ± 0.8 % for PM10 and 26.0 ± 0.8 % for PM2.5 for Experiment 1, and for Experiment 2 a reduction of 1.3 ± 2.0 % for PM10 and 4.6 ± 1.3 % for PM2.5. Yet, because of differences in the filtration setups, such as the position of the modules and the maximal air flow capacity, and of unspecified internal characteristics of the systems, no conclusion can be drawn as to whether one of the filtration techniques is more efficient than the other. The two analysis methodologies lead to similar results and allow to fully and rigorously exploit long time series. The DAC method can be applied using only PM measurements, while the GAM method requires additional measurements, but at the same time provides valuable insights about the effects of each parameter considered.

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Nagpal, R., Ababii, N., Lupan, O.

Comprehensive Advances in Gas Sensing: Mechanisms, Material Innovations, and Applications in Environmental and Health Monitoring.

Materials Today Electronics, (2025)

A novel strategy is required to address global concerns such as indoor air quality (IAQ) monitoring, outdoor pollution, battery monitoring, medical diagnosis, and industrial safety. Metal oxide semiconductor-based gas sensors are evolving by overcoming the associated challenges such as high operating temperature, poor selectivity, poor temporal, and chemical stability with the synergistic effect of Metal Organic Frameworks (MOFs). MOFs are ultra-high porous materials with appropriate morphology that help to improve the cross-sensitivity of the target analyte by tailoring the pore size and their ultra-high surface area. Noble metals with their catalytic effect create additional active sites by creating more oxygen vacancies on the surface. In this review, authors introduce novel high-performance gas sensor design and elaborate all possible sensing mechanisms for different structures including different factor dependence such as receptor factor, transducer factor, and utility factor. The effect of gas deployment methodology and preconcentrator choice on gas sensing measurement are demonstrated. The nature of signal processing and interfacing in smart sensor electronics is elucidated, highlighting their roles in analog-to-digital conversion, noise reduction, data transmission, and system integration for enhanced sensing accuracy and functionality. Ultrafast ultraviolet (UV) sensors and their sensing mechanisms are thoroughly elaborated, emphasizing their rapid response and high sensitivity. In nutshell, authors give a detailed insight to the gas sensing mechanism, technological development, and attempt to find an answer for the existing problems in the field of gas sensing by exploiting some new aiding tools.

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Malyan, V., Nawale, P., Sahu, M.

Design and Evaluation of a Calibration Chamber for Low-Cost PM Sensors–Part 1: Number Concentration-Based Assessment.

ACS ES&T Air, (2025)

Low-cost particulate matter (PM) sensors are widely deployed for air quality monitoring, but their accuracy varies significantly with aerosol properties and environmental conditions. This study presents a systematic intercomparison of two commercially available low-cost optical particle sensors viz., OPC-N3 and PMS5003 across a matrix of temperature and RH conditions in a calibration chamber. The calibration chamber provided stable and reproducible conditions with uniform flow, validated using CFD simulations. We evaluated the sensor-reported size-resolved particle number concentrations and their cumulative distributions to four aerosols with varied physicochemical properties, including PSL (inert, nonhygroscopic), NaCl and (NH4)2SO4 (inorganic, hygroscopic), and soot (organic, nonhygroscopic) aerosols under four distinct RH and temperature conditions. The results indicate that PMS5003 showed negligible sensitivity to aerosol type, concentration, or environmental conditions, suggesting that its number concentration

response depends largely on its restricted side-scatter geometry and internal transfer functions. Its agreement with the reference monitor was relatively better for cumulative fractions dominated by submicron particles (PM1). In contrast, OPC-N3 exhibited higher size-resolving capability with improved accuracy in the submicron range for nonabsorbing aerosols under high RH conditions. However, substantial deviations were observed for soot (errors > −400%) due to low scattering, coincidence and agglomeration effects. These findings highlight the importance of aerosol-specific assessment and correction strategies for reliable LCS measurements.

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Friebe, C., Grüttner, R.

Development of an optical, real time measurement method for Air Change Rates in indoor areas.

E3S Web Conf., Vol. **672**, (2025)

This paper describes the goals and results and discusses the requirements and marginal conditions for an optical measurement method that is currently being developed in a publicly funded research project. This method is based on measuring the light intensity of a laser beam absorbed by fog particles by using simple components such as a laser pointer and a webcam. The fog (e.g. commercially available disco fog) is uniformly distributed in the room to be examined. The concentration of the fog is reduced by the natural decay of the particles, mainly by the air conditioning system with fog-free outside air. The laser beam is positioned in the room so that it sufficiently represents the test area. The air change rate (ACR) can be determined by the increase in laser light intensity over time detected by the camera.

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Yakasai, A. S., Sani, U., Agaie, B. G., Muhammad, A. L.

Effect of inclined angle on air body force during air flow process induced in a rectangular building.

Science World Journal, Vol. **20** n°(3), (2025), 982 - 989 p.

This study investigates the effect of inclined airflow angles on the air body force and its influence on buoyancy-driven ventilation in an un-stratified cross-ventilated rectangular domain with three openings. The airflow is primarily driven by the stack effect, where temperature differences between indoor and outdoor create density gradients, resulting in natural convection with an opposing flow introduced through one of the upper openings to mimic realistic ventilation input. The study focuses on three inlet airflow angles: 30°, 45°, and 55°, to assess their impact on temperature and velocity distribution within the domain. The system is modeled using a single-zone, one-dimensional approach, governed by steady-state Navier–Stokes equations. The equations are expressed in dimensionless form and solved using analytical method for ordinary differential equations (ODEs) to derive explicit solutions. Results show that lower airflow angles (e.g., 30°) enhance airflow momentum along the primary flow directions, intensifying convection and promoting faster air exchange, while higher angles (e.g., 55°) reduce airflow efficiency and flatten temperature gradients. The analysis also reveals that effective thermal coefficient impacts buoyancy force magnitude, altering the flow dynamics, and Prandtl number affects how fast heat moves compared to velocity, influencing stratification and mixing. The findings provide insight into optimizing natural ventilation design in buildings and support the development of energy-efficient, passive cooling strategies in architectural and engineering applications.

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Yang, H., Sommer, M., Bauer, S., Lemmer, U.

Electronic Nose for Indoor Mold Detection and Identification.

Advanced Sensor Research, (2025)

Indoor mold infestations lead to adverse effects on air quality and thus pose significant health risks to humans. Traditional methods for mold detection and identification are time-consuming and costly. In this

study, the application of an electronic nose as a highly reliable tool for detecting and identifying mold is explored. Two common indoor mold species, Stachybotrys chartarum and Chaetomium globosum, each separately grown on two different substrates, are investigated. Our e-nose uses vapor-liquid-solid-grown, UV-activated SnO2 nanowires as the chemiresistive sensing material. Linear discriminant analysis (LDA) is used for classification. Moreover, novelty detection is enabled by default using decision boundaries. While the conventional LDA only shows mediocre classification results, improved versions can achieve an average F1-score of 98.37%. Therefore, our results demonstrate that the e-nose can not only detect but also identify different mold genera, and thus making a significant step toward fast, objective, and cost-effective indoor air quality monitoring.

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Baguley, D. A., Bard, D., Evans, G. S., Monks, P. S., Cordell, R. L.

An Experimental Study of Volatile Organic Compound (VOC) Emissions from a Resin 3D Printer to Assess Exposure and Exposure Mitigation.

ACS Chemical Health & Safety, (2025)

Recent increases in the popularity of affordable 3D printers necessitate research to investigate the potential volatile organic compound (VOC) exposure that an operator would experience. VOC emissions from a Formlabs Form 2 were tested using four different resins (Clear, White, Tough, and Elastic) across several time-resolved tests and exposure scenarios: an enclosed test chamber, and within a ventilated room at two distances, with an extraction hood to investigate “real-world” exposure scenarios and the impact of mitigation methods. 2-Hydroxypropyl methacrylate, 3-hydroxypropyl methacrylate, and 2-hydroxyethyl methacrylate were the prominent VOCs emitted from the resin 3D printing process, among other acrylic-based compounds. The composition of the VOCs was dependent on the type of resin: Elastic resin emitted a greater diversity of compounds, including the previously unreported isobornyl acrylate, while Tough resin emitted higher concentrations of smaller cross-linking compounds such as 2-hydroxyethyl methacrylate. VOC emissions peaked at the end of the active printing process when the build plate rose from the liquid resin bed. In the enclosed chamber scenario, total VOC (TVOC) concentrations exceeded 128,000 μg/m3, representing worst-case poorly ventilated conditions. Under realistic room conditions, TVOC concentrations reached 45–116 μg/m3 at 50 cm from the printer and returned to baseline within 2 h after printing ended. The TVOC emission concentrations were significantly reduced by 71–84% when the distance between the printer and the sampling position was increased from 0.5 to 2 m, or when an extraction hood fitted with a carbon VOC filter and particulate HEPA filter was used. These two exposure mitigation methods were considered practical options for home users, “maker” communities, and schools to use. While individual VOC concentrations remained well below established workplace exposure limits, many identified compounds lack published safety guidelines, making health risk assessment challenging, and both their acute and chronic health impacts remain unknown.

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Chen, S., Feng, Y., Gu, J., Li, J.

Global optimization control based on dynamic constraint conditions of a dedicated outdoor air-conditioning system using machine learning and model predictive control.

Case Studies in Thermal Engineering, Vol. **77**, (2026)

The advantages of a dedicated outdoor air-conditioning system (DOAS) include lower operating energy consumption and better indoor air quality. The global operation optimization of DOASs has rarely been a focus of previous research, resulting in the inapparent energy-saving effect. In this paper, the machine learning-based model predictive control (MLB-MPC) with dynamic constraint conditions was proposed for optimizing the DOAS to obtain the highest operation efficiency. The support vector regression (SVR) was used to predict the total energy consumption of the DOAS and its disturbing factors. The particle swarm optimization was utilized to search for optimal setpoints of the crucial operating parameters. The dynamic constraint conditions were applied to ensure the cooling capacity of the DOAS. The case study based on

Modelica simulation demonstrated that: 1) The proposed MLB-MPC with dynamic constraint conditions can ensure robustness for the DOAS, e.g., the indoor temperature and humidity of different air-conditioning areas were stably controlled in ranges 25.4 °C–26.1 °C and 57 %–65 %, respectively, achieving a good indoor heat comfort. 2) The root mean squared errors using SVR for the outdoor wet-bulb temperature and the outdoor dew-point temperature were 0.21 °C and 0.36 °C, respectively; the mean absolute percentage errors using SVR for the cooling load and the DOAS energy consumption were 2.73 % and 3.12 %, respectively, obtaining high prediction accuracies. 3) The system performances were significantly improved after optimization, e.g., during the cooling season, the DOAS's COP enhanced from 3.14 to 3.91, with an improvement of 24.5 %, demonstrating a significant energy-saving effect. The proposed global optimization control would provide a valuable reference for optimizing the operation efficiency of DOASs.

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Impact of Air Temperature and Humidity on Sick Building Syndrome among Bank Employees.

Gema Lingkungan Kesehatan, Vol. **23** n°(4), (2025)

Sick Building Syndrome (SBS) is a condition in which inhabitants develop health problems or discomfort as a result of extended exposure to indoor surroundings. The purpose of this study was to investigate the association between air temperature and humidity in air-conditioned rooms and the prevalence of SBS, specifically mental weariness (burnout) instances, among employees of Bank Syariah Indonesia (BSI) in Banjarbaru City, Indonesia. The study followed a quantitative design with an analytical cross-sectional survey approach. Data were gathered using questionnaires and devices that measured air temperature and humidity. Univariate analysis defined the variable features, whereas bivariate analysis looked at the correlations between air temperature and humidity (independent variables) and the prevalence of SBS mental fatigue cases (dependent variable). The survey included 30 bank employees, with an average age of 32.4 years. The average air temperature was 25.8°C, with a relative humidity of 84.2%, which was outside of the permissible limit. The prevalence of SBS was 43.3%, with common symptoms including nose discomfort, eye irritation, headache, and fatigue. The prevalence of mental weariness was 36.7%. Pearson correlation analyses found significant positive relationships between air temperature and SBS prevalence ($r = 0.48$, $p < 0.01$), relative humidity and SBS prevalence ($r = 0.39$, $p < 0.05$), air temperature and mental fatigue ($r = 0.41$, $p < 0.05$), and relative humidity and mental fatigue. The findings emphasize the need of maintaining adequate indoor environmental conditions to reduce SBS risk and increase employee well-being in air-conditioned workplaces.

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Teor, W. H., Hariri, A.

The Impact of an Upgraded Ventilation System on Thermal Comfort in the Newly Renovated UTHM's Badminton Hall.

Research Progress in Mechanical and Manufacturing Engineering, Vol. **6** n°(2), (2025), 249-261 p.

This study investigates the impact of an upgraded natural ventilation system on thermal comfort within the newly renovated Universiti Tun Hussein Onn Malaysia (UTHM) badminton hall. Achieving sufficient thermal comfort is crucial for occupant performance and well-being, as athletic activities like badminton require a high metabolic rate. Previous assessments indicated that the original ventilation system failed to maintain appropriate indoor environmental conditions. This study aims to evaluate whether the upgraded system, which includes additional exhaust fans, improves thermal comfort. The findings showed that 90% of respondents experienced thermal conditions, with an average TSV of +0.5, that were within or close to the acceptable PMV range of -0.5 to +0.5. Compared to earlier studies, objective measurements indicated a reduction in extreme temperature fluctuations and a moderate improvement in air velocity. However, inadequate airflow persisted in certain localized areas. In conclusion, the upgraded ventilation system has contributed to improving the thermal comfort standards of the UTHM badminton hall. These results provide valuable insights for future enhancements in similar indoor environments and reinforce the importance of proper ventilation design and air flow in naturally ventilated sports facilities.

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Justo Alonso, M., Hutcheson Fisvikt, I., Liu, P., Martin Mathisen, H.

Impact of Recirculation Rates on Indoor Environment and Occupant Comfort: A Case Study in Norway.

E3S Web Conf., Vol. **672**, (2025)

The implementation of recirculation of return air has garnered significant attention as a energy-saving strategy in ventilation systems. It has gained widespread utilization in countries like the USA and China due the possibly to reduce energy use for heating and dehumidification. In contrast, Norway's guidelines recommend its application exclusively during periods of human absence or when ensuring satisfactory indoor air quality (IAQ). The Norwegian winter is characterized by low temperatures which induce low relative humidity (RH) indoor. Although low RH can impact thermal comfort, the implementation of humidification is generally discouraged. This study focuses on a laboratory-based experiences aimed at understanding the effects of varying exhaust air recirculation rates on both room occupants and visitors. For occupants, the investigation delves into comfort perception and typing performance. Visitors' experiences are assessed by odour perceptions upon smelling the air. The findings highlight that, in comparison to factors like the time of day, room temperature, and RH levels, variations in recirculation rates had a relatively minor influence on occupants' perception and performance. Therefore, employing this strategy as an energy-saving mechanism while upholding stringent IAQ standards is proposed particularly in cold climates to conserve energy and simultaneously ameliorate indoor RH levels.

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Sacht, H. M., Lukiantchuki, M. A., Bessa, S. a. L., Mata-Lima, H.

Improvement of Natural Ventilation Through Window-Sill and Cobogós.

Caderno Pedagógico, Vol. **22** n°(14), (2025)

<p>In tropical countries such as Brazil, natural ventilation is an efficient passive design strategy for the cooling of buildings. Natural ventilation in indoor environments may be increased according to windows type, size and configuration; and yet other strategies as ventilated window-sill and cobogós, a type of leaked block. The window-sill is a strategy of ventilation with the insertion of a horizontal and small opening in the sill on the main opening, whose purpose is to act as a complementary source of air movement. The hollow elements, well known in Brazil as cobogó, are also components that allow solar protection, natural lighting and permanent natural ventilation at the same time. This paper aims to evaluate the impact of ventilated window-sill and cobogós in natural ventilation performance in the internal spaces. The ventilation was evaluated under two external wind incidence angles: 0° and 45°. The methodology used was Computational Fluid Dynamic (CFD) simulation, using the CFX software. Quantitative and qualitative analysis was performed. The results indicate that the inclusion of both ventilated window-sill and the cobogó increased the internal airflow. In the case of a ventilated window-sill, the aerodynamic shape showed the best performance. Finally, the insertion of cobogó in the upwind façade significantly increased the indoor airflow velocity and & improved its distribution.</p>

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Barthwal, A., Kumar, N., Avikal, S., Wroye, N. D.

Indoor Environmental Quality Prediction Using Hybrid Deep Learning and a Comprehensive Environment Index.

Indoor Air, Vol. **2025** n°(1), (2025)

Maintaining a healthy indoor environment is crucial for a productive and well-balanced life. This study proposes a comprehensive indoor environment index (IEI) that integrates air quality, thermal, visual, and acoustical comfort indicators using sensor data. Major indoor pollutants (CO, PM2.5, and PM10), temperature, relative humidity, noise levels, and illuminance are combined through an analytic hierarchy

process to formulate the IEI. A hybrid deep learning model based on a CNN-GRU architecture is then used to forecast indoor environmental states across four categories (severe, very poor, poor, and satisfactory). ANOVA and Tukey?s HSD analysis confirmed significant differences among these categories. The model was trained on 80% of the dataset and tested on the remaining 20%, with performance evaluated using precision, recall, F1-score, and AUC-ROC. The proposed approach achieved a mean F1-score of 0.96, demonstrating high predictive accuracy and reliability. These results confirm the robustness and reliability of the proposed model. The study demonstrates its potential for supporting accurate indoor environmental quality prediction and providing a foundation for informed building management decisions.

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Vasile, V., Popa, I., Petcu, C., Dima, A., Ion, M.

Innovative Finishes Obtained by Integrating Agro-Industrial Waste into the Circular Economy and Their Impact on Indoor Air Quality.

Analytical and Experimental Methods in Mechanical and Civil Engineering. Olympiad in Engineering Science 2023

The integration of agro-industrial waste into the circular economy still needs to be improved. Using them in construction products can have some important advantages: low environmental impact, less energy demand, low cost, large-scale availability and good insulation properties. In this context, our research focused on integrating agro-industrial waste from sunflower oil production and sheep's wool, as additives in two types of water-based finishing/protection products (like binder). Among the sources of indoor air pollution, releasing volatile organic compounds (VOCs), the indoor finishing products count, along with furniture, cleaning products, activities of the occupants, etc. Hence, to evaluate the impact on indoor air quality, we monitored VOCs emissions from four types of innovative multi-layer finishes with different recipes (composite type) and contents of embedded agro-industrial waste, in the closed operation mode of the emission test chamber. The average values of the TVOC concentrations for the monitored finishes ranged between 724 ppb (1661 µg/m3 in isobutylene units) and 1687 ppb (3871 µg/m3 in isobutylene units), as a result of the multiple interactions between the composition of the binder, the characteristics of the additives (quantity, nature, size) from the applied composite materials and the structure of the multilayer systems generated by the embedded agro-industrial wastes. A healthy indoor environment in which to spend our lives is of great importance for all of us. Therefore, it is necessary to evaluate the pollutant emissions of finishing products, when designing them, in such a way as to have the lowest impact on indoor air quality, and implicitly on our health.

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Rao, R. R., Albertin, R., Gasparella, A., Pernigotto, G.

An Integrated Hybrid Ventilation Framework for the Optimization of Energy Efficiency and Indoor Air Quality.

Proceedings of the 15th REHVA HVAC World Congress - CLIMA 2025

Ventilation of office buildings affects the indoor air quality IAQ perceived by the occupants, their wellbeing, as well as their task performance. Although many offices are equipped with mechanical systems, new complex and hybrid solutions have been under consideration since the pandemic, combining for instance mechanical and natural ventilation with portable air-purifiers to ensure high IAQ and energy performance.

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Su, W., Ai, Z., Yang, B., Du, T., Liu, Z.

Integrating phase change material-based thermal energy storage with outdoor air systems for personalized wards: A conceptual framework.

Energy and Buildings, Vol. **352**, (2026)

Creating an efficient ward environment is crucial for the sustainable development of healthcare buildings. This study proposes a methodological framework integrating a phase change material-based thermal energy storage outdoor air system (PCM-TES-OAS) to enable personalized ward environments, aiming to enhance patient comfort and respiratory health with low energy consumption. Four representative cities from different building climate zones in China, namely Beijing, Shenyang, Chengdu, and Shenzhen, were selected for a conceptual case study. The proposed system was theoretically evaluated against a conventional fan coil unit (FCU) plus dedicated OAS (FCU + DOAS) for its summer operational performance, indoor air quality impact, and energy-saving potential. The results indicate that the PCM-TES system remains operational for over 60 % of the time across all four cities. Moreover, the new system achieves an air change rate (ACH) of 8 h−1 to 10 h−1 while maintaining ward CO2 concentrations consistently at a low level (below 500 ppm). In terms of energy performance, the total summer electricity savings are estimated to be no less than 60 kWh/m2 in all evaluated cities. These theoretical findings demonstrate the system's conceptual potential to simultaneously improve patient comfort, enhance inhaled air quality, and reduce energy consumption in ward environmental control. Additionally, it is recommended that the maximum cooling capacity of the OAS and FCU in the new system be approximately 3 times and 0.3 times that of the conventional system, respectively. This study is anticipated to offer a conceptual framework and a promising new approach to designing comfortable, healthy, and sustainable ward environments.

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Ramadan, M. N. A., Ali, M. a. H., Alkhedher, M.

Intelligent multi-pollutant prediction for indoor air quality management in industrial buildings using adaptive sensor fusion.

Journal of Building Engineering, Vol. **118**, (2026)

Maintaining healthy indoor air quality (IAQ) in industrial buildings is critical for occupant safety, regulatory compliance, and operational efficiency. This study presents a practical, sensor-driven framework for real-time prediction of indoor pollutants in industrial factory settings, aimed at supporting adaptive ventilation and building management. The system integrates multi-sensor data—including CO2, PM2.5, PM10, CH2O, O3, CO, TVOC, NO2, temperature, humidity, ventilation rates, and workforce density—collected across three factories (galvanizing, textile, and moulding) in Istanbul over four months, totaling more than 100,000 data samples. To handle sensor variability, environmental fluctuations, and data imbalance, a soft computing-based aggregation method was developed using a two-stage fuzzy inference system. This framework adaptively fuses local pollutant prediction models running on edge devices, enabling building-specific prediction accuracy and robustness. The system achieved up to 93 % local accuracy for key pollutants (CO2, PM2.5, PM10) and improved global prediction reliability under varying environmental stress conditions. Compared to conventional averaging methods, the proposed fusion method yielded higher consistency (90.4 %–92.57 % accuracy) and demonstrated statistical improvements in prediction fairness and adaptability ($p < 0.05$). By linking multi-pollutant forecasting with operational context, the framework supports intelligent HVAC control and contributes to improving environmental quality in industrial buildings.

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Gurung, M.

IoT Based Automatic Air Pollution Monitoring and Purification System.

International Journal for Research in Applied Science and Engineering Technology, Vol. **9** n°(9), (2021), 1378-1383 p.

This research presents the development of an intelligent air quality management system that leverages Internet of Things technology to monitor and improve indoor atmospheric conditions. The proposed solution addresses growing concerns about airborne pollutants in enclosed spaces by implementing real-time detection and automated purification. At the core of the system is an ESP32 microcontroller that processes

data from multiple environmental sensors, including a GP2Y1010 particulate matter detector and an MQ135 multi-gas sensor. These components work in tandem to identify harmful substances such as dust particles, carbon dioxide, carbon monoxide, and benzene derivatives. The architecture incorporates dual-mode operation, allowing either manual control through a mobile application or automatic adjustment of purification intensity based on contaminant concentration. Experimental validation demonstrates the system's capability to maintain air quality within safe parameters by dynamically modulating fan velocity in response to pollutant levels. This approach represents a significant step toward creating healthier indoor environments through accessible smart technology.

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Alanis Ruiz, C., Van Hooff, T., Blocken, B., Van Heijst, G.

Large eddy simulation of optimized air curtain separation via secondary co-flowing jets.

Developments in the Built Environment, Vol. **25**, (2026)

Unconditioned air infiltration through frequently used entrance doors can degrade building energy performance, indoor air quality, and thermal comfort. Air curtains mitigate these effects and are also critical in smoke and dust control, cleanrooms, and cold rooms. Their performance is commonly expressed as separation efficiency, which depends on jet dynamics and entrainment. While most studies consider single-jet air curtains, this work investigates secondary co-flowing jets as a design strategy to reduce entrainment and enhance separation efficiency. Large eddy simulations (LES), validated against a dedicated particle image velocimetry (PIV) dataset of plane turbulent impinging co-flowing jets, assess the influence of key jet parameters: velocity ratio (R), secondary-jet width (Ws), and inter-jet spacing (d). The results indicate that incorporating secondary jets under suitable discharge conditions increases infiltration-based separation efficiency by up to 5.4 % without compromising the combined infiltration–exfiltration metric; the latter can also improve by up to 3 %. Given baseline efficiencies of 86.2 % (infiltration) and 78.7 % (combined) for an optimized single-jet curtain, these gains are significant.

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Lyu, T., Sun, Y., Liu, S., Guo, T., Meng, Y., Ma, J.*, et al.*

Microenvironments outweigh mobility in PM2.5 exposure inequality: A case study of Beijing commuters.

Journal of Cleaner Production, Vol. **538**, (2026)

PM2.5 exposure poses significant public health risks by contributing to respiratory and cardiovascular diseases. Traditional static PM2.5 exposure assessments, which focus on residential or workplace locations, overlook human mobility and microenvironmental variations, leading to biased estimates. To address this, we developed the Microenvironment-bAsed Dynamic Exposure (MADE) framework to assess PM2.5 exposures for Beijing commuters. Using mobile phone signaling data and fuzzy mathematics, we simulated spatiotemporal behaviors across residential, occupational, commuting, and other microenvironments. The MADE framework integrates geographic PM2.5 variations and indoor-outdoor concentration differences, achieving precise, large-scale exposure estimates. The mean PM2.5 exposure estimated by the MADE framework (40.82 μg/m3) is 6.9 % lower than that estimated by the static model (43.86 μg/m3). The PM2.5 exposure concentrations present a geographic pattern of being higher in the south and lower in the north, which is consistent with the static model but with smaller values. The reductions in exposure concentrations for individuals living in southern areas with high PM2.5 concentrations are slightly greater than for those living in northern areas with low PM2.5 concentrations. Differences in indoor-outdoor concentrations are the primary drivers of disparities, challenging the notion that geographic variations in PM2.5 concentrations dominate exposure inequality. Commuting, owing to its limited time proportion, contributes minimally to overall exposure. These findings correct overestimations in static models and highlight the need to incorporate indoor environmental complexity and diverse population activities for accurate exposure assessments. By addressing these factors, the MADE framework advances environmental justice and informs equitable public health policies.

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Wang, X., Hayashi, T., Ito, K.

Modeling the impact of humidity gradients on ammonia gas transfer in hydrous materials for energy recovery ventilation systems.

Building and Environment, Vol. **290**, (2026)

The performance of ventilation systems has a critical influence on indoor air quality, with energy recovery ventilators (ERV) playing a key role in reducing energy consumption by recovering heat and moisture from exhaust air. However, the same materials that enable efficient energy recovery can also facilitate the transfer of pollutants, particularly when humidity levels fluctuate. This study presents a newly developed mathematical model describing gas-phase transport through paper-based hydrous materials that explicitly incorporates the effects of both material water content and humidity gradients. The model combines convective transfer, solution-diffusion mechanisms, and interactive moisture–gas coupling, and was validated through laboratory experiments measuring NH_3 permeation under carefully controlled humidity conditions. Results demonstrate that increased water content markedly enhances NH_3 permeability by up to 1000 times under high humidity compared to dry states. Furthermore, humidity gradients significantly influence transfer rates; co-directional vapor flow promotes gas permeation, whereas counter-directional flow suppresses it, with the effects intensifying at higher moisture levels. The model accurately predicted gas transfer across a range of humidity conditions, providing a valuable tool for optimizing ERV systems. Performance analysis of a cross-flow total heat exchanger further demonstrated that variations in ambient humidity and airflow rates collectively influence both latent heat exchange efficiency and NH_3 transfer. The model proved to be effective in predicting interdependent behaviors under diverse operational scenarios. These insights provide a foundation for designing smarter ERV systems that maintain high energy efficiency without compromising indoor air quality, highlighting the potential of humidity control as a strategy for mitigating pollutant transfer.

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Gola, M., Capolongo, S., Settimo, G.

Monitoring of VOCs in Indoor Air Quality: Definition of an ISO 16000-Based Sampling Protocol for Inpatient Wards.

Pollutants, Vol. **6** n°(1), (2026)

Indoor Air Quality (IAQ) is a major public health concern, as prolonged exposure to indoor environments can significantly affect users' well-being. In this context, the research proposes a sampling protocol, developed in compliance with ISO 16000 principles, for the assessment of key chemical and physical parameters influencing air quality in inpatient rooms. These spaces host fragile users, while also requiring adequate protection for healthcare staff. Referring to the scope of the paper, the study outlines a comprehensive methodology for monitoring selected volatile organic compounds (VOCs) and microclimatic factors—temperature and relative humidity—using passive samplers and/or active sensors. The protocol also integrates outdoor measurements to better understand the contribution of internal emission sources. Monitoring activities are scheduled over one year, with regular sampling campaigns (at least one week per month) to analyze seasonal variations and long-term trends. The flexible structure of the protocol allows it to be adapted to different research objectives and types of healthcare facilities. Overall, the proposed approach provides a replicable framework for assessing IAQ in healthcare settings and identifying the main factors affecting indoor environmental performance. This supports improvements in both environmental quality and health protection within healing spaces.

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Shrestha, S., Sapkota, S., Kong, M., Choi, J., Hong, T., Choi, J.-K.

A multi-agent deep deterministic policy gradient method with hybrid action space for energy-efficient HVAC control.

Building and Environment, Vol. **290**, (2026)

Heating, ventilation, and air-conditioning (HVAC) systems represent one of the most energy-intensive components in buildings, yet existing control strategies often fail to jointly optimize thermal comfort, indoor air quality (IAQ), and energy efficiency. This study presents a hybrid-action multi-agent deep deterministic policy gradient (MADDPG) framework for intelligent HVAC control, integrating discrete heater actuation and continuous airflow regulation within a unified reinforcement learning environment. The proposed architecture enables cooperative decision-making between specialized agents through centralized training and decentralized execution, thus capturing the mixed discrete-continuous nature of real HVAC operations. The agents interact with a physics-based single-zone office model that captures coupled temperature-CO2 dynamics at 5-minute timesteps, driven by Ohio 2024–2025 cold-season outdoor temperature profiles and realistic occupancy schedules. MADDPG is trained for 200 episodes using experience replay, with actor-critic learning rates and target-update coefficients selected via a validation study over 12 hyperparameter configurations that maximized average episodic reward on a separate dataset. Final performance is evaluated on unseen November-February 2024–2025 weather and compared against a single-agent deep Q-network (DQN) baseline that controls only the heater under fixed airflow. Relative to DQN, MADDPG reduces total energy consumption by 7–10%, and discomfort hours by 38% on average across all months, while maintaining IAQ close to the threshold at the cost of modestly higher CO2 violations during extreme cold conditions. These results indicate that the hybrid-action multi-agent reinforcement learning is a promising pathway for energy-efficient, comfort-aware HVAC control in intelligent buildings.

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Next-Gen Eco-Friendly, Low-Odor Paint with Zero VOCs and Emissions.

Materials Performance, Vol. **64** n°(12), (2025), 44-44 p.

Benjamin Moore (Montvale, New Jersey, USA), a leader in paint, color, and coatings, announced the launch of the next generation of Eco Spec, the brand’s greenest and lowest odor paint. Blending both exceptional performance with eco-responsible innovation, Eco Spec achieves beautiful results with zero volatile organic compounds (VOCs) and zero emissions, even after tinting, for both consumers and professionals. In addition to meeting the strictest VOC regulations, Eco Spec features a low odor that completely dissipates within an hour after application, so that spaces painted with Eco Spec can be reoccupied sooner, providing minimal disruption and fast return to space for residential or commercial spaces. It also has superior chemical resistance, withstanding repeat washing from common disinfectants and cleaning agents; and is formulated with antimicrobial additives, preventing the buildup of mold and mildew on dry paint film. Backed by Benjamin Moore’s Green Promise, Eco Spec meets—and often exceeds—some of the highest standards for environmental and performance criteria regarding VOCs, emissions, application, washability and scrubbability. It has been tested by multiple independent green certifying organizations, including the Asthma and Allergy Friendly Certification Program, Green Seal, LEED Indoor Air Quality Standards, and Master Painter Institute Green Performance.

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Sharma, A., Goyal, I., Sonawane, P., Devi, P.

Next-Generation Nanohybrids for Efficient Indoor Air Purification.

In: Advanced Nanohybrids for Sustainable Environmental Solutions. CRC Press; 2025. 152-174 p.

This chapter presents the prospective development and application of nanohybrid materials as innovative and sustainable solutions to the pressing issue of indoor air pollution. Nanohybrids are combinations of distinct nanomaterials designed to harness synergistic functionalities. Particular attention is directed toward two-dimensional materials and metal oxide hybrids, recognized for their tunable optical, electrical, and structural attributes that lend themselves well to air purification technologies. Despite ongoing research into various material systems, current approaches often suffer from limitations such as inefficient charge separation, inadequate light harvesting, surface passivation, and misaligned energy bands. This chapter underscores the potential of nanohybrids to address these challenges through rational design and

functional integration. It further explores the practical aspects of incorporating these materials into real-world air purification systems, considering factors such as scalability, cost-efficiency, and compatibility with conventional heating, ventilation, air conditioning infrastructure. The chapter also includes the advantages of nanohybrids for indoor air purification and the practical implications along with the future scope.

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Park, J., Baek, S. J., Kim, J.

Optimization and performance evaluation of a portable GC for the detection of volatile organic compounds and its compatibility with APCI-MS.

Talanta, Vol. **300**, (2026)

Conventional gas chromatography–mass spectrometry (GC-MS) systems are often bulky and unsuitable for on-site analysis. In this study, we evaluate the performance and field applicability of a newly developed portable GC instrument. Method optimization and reproducibility tests were conducted for the detection of 20 volatile organic compounds (VOCs), and both their retention times and corresponding Kovats retention indices were determined. Furthermore, the instrument's compatibility with atmospheric pressure chemical ionization mass spectrometry (APCI-MS) was investigated to enable confident identification of VOCs by systematically optimizing ionization parameters—such as sheath gas-based sample injection, minimal auxiliary gas flow, and controlled discharge current—in order to determine the optimal interface configuration and enhance both sensitivity and stability. This optimized configuration significantly improved the ability to verify chromatographic peaks by providing molecular ion information and structural specificity, thereby enhancing compound identification accuracy. The results demonstrate the potential of portable GC–MS systems for effective field analysis of VOCs in environmental and forensic applications.

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Bouzeriba, L., Sellaoui, S., Adjroudi, R., Alloui, N.

Pollutant Emissions in the Poultry Farms Environment: A Literature Review.

Preprints, (2025)

The combination of intensive poultry production and certain environmental factors in poultry houses can sometimes lead to poor indoor air quality and pollutant emissions. Gases present in the indoor air of poultry houses, such as ammonia (NH3), methane (CH4), hydrogen sulfide (H2S), carbon dioxide (CO2) but also dust, are of particular importance given their adverse effects on production performance and poultry health.The gases originate from biodegradation of fecal matter accumulated under anaerobic conditions inside poultry houses. Regular assessment of indoor air quality allows for planning waste disposal and thus ensures clean air for poultry and workers.In today context, all operations carried out to optimize environment in poultry farms are of capital importance to guarantee the welfare and poultry health.

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Whitaker, R. S.

Predictive and Intelligent HVAC Systems: Integrative Frameworks for Performance, Maintenance, and Energy Optimization.

International Journal of Modern Computer Science and IT Innovations, Vol. **2** n°(10), (2025), 108-113 p.

This research article presents a comprehensive exploration of advanced predictive and intelligent Heating, Ventilation, and Air Conditioning (HVAC) systems, integrating state-of-the-art machine learning, predictive maintenance, digital twins, energy forecasting, and smart building strategies. The HVAC domain is undergoing a transformation driven by the convergence of artificial intelligence (AI), Internet of Things (IoT), and data analytics. Understanding the nexus among predictive maintenance, energy optimization, smart sensor networks, and occupant comfort is critical to advancing building performance. This article synthesizes theoretical frameworks and empirical findings from seminal and contemporary literature to

construct a nuanced understanding of how deep learning, autoencoders, Bayesian networks, digital twin frameworks, weather-driven energy predictions, and early warning systems can be harnessed for HVAC performance enhancement. The work also examines challenges associated with data imbalance, system integration, and real-world deployment barriers. By discussing energy consumption modeling, health prognostics classification, machine learning-driven fault detection, and Bayesian predictive maintenance, the article offers an integrative architecture that bridges theoretical innovation with practical implementation. The synthesis extends toward sustainable HVAC design rationales, renewable integration imperatives, and IoT enabled energy forecasting. Methodological insights encompass descriptive analyses of deep learning methods, autoencoder architectures, Bayesian inference, digital twin methodologies, and weather forecast-based models. The interpretative sections evaluate the implications of algorithmic transparency, sensor data quality, and adaptive control strategies on HVAC system reliability and efficiency. The discussion concludes with a roadmap for future research, highlighting areas such as enhanced data fusion, occupant-centric optimization, eco-friendly refrigerants, and scalable predictive maintenance frameworks. This article contributes to the field by providing a theoretically grounded yet practice-oriented treatise aimed at researchers, industry professionals, and policy designers engaged in building performance and intelligent facility management.

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Desauziers, V., Le Bot, B., Le Cann, P., Plaisance, H., Costarramone, N., Raffy, G.*, et al.*

QAI * -Sport project: Characterization of Indoor Air Quality in sports facilities.

E3S Web Conf., Vol. **672**, (2025)

The aim of this study was to characterise the indoor air quality (IAQ) of 10 sports halls of different activities with regard to target pollutants: Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs) and micro-organisms. Targeted and non-targeted analytical approaches were applied to provide the broadest possible screening with a focus on emerging pollutants. Two sampling campaigns were performed in unoccupied and occupied rooms to assess the impact of sporting activity on IAQ.

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Reda, I., Soultanzadeh, M. B., Taha, A., Zheng, K., Qi, D., Ouf, M. M.*, et al.*

Rapid indoor airflow prediction using a hybrid residual learning regression model.

Energy and Buildings, Vol. **352**, (2026)

Ventilation performance and resulting indoor airflow patterns influence indoor air quality, thermal comfort, and energy consumption, particularly in densely occupied spaces such as classrooms. Nonetheless, accurate airflow prediction remains a challenge. Computational Fluid Dynamics (CFD) provides detailed predictions but is computationally intensive, while machine-learning (ML) models, though faster, operate as black boxes and are limited to the geometry used for training. To address this, we propose a physics-guided ML model termed Residual Learning Regression (RLR), which integrates Multivariate Linear Regression (MLR) with Extreme Gradient Boosting (XGB) residual correction. This hybrid model was trained on 149 validated classroom CFD simulations spanning the effect of diffuser geometry, air change rate, inlet temperature, and occupancy level on airflow patterns. From the RLR, four equations were derived to predict the spatially averaged values of airflow mixing, ventilation effectiveness, temperature, and velocity at the breathing level. Further, geometry-based correction factors were introduced, extending equations' applicability to room volumes of 25–532 m3. Results show that the RLR improves baseline MLR accuracy by about 10 % and achieves airflow prediction comparable to XGB, while maintaining interpretability. Independent experimental validation and uncertainty analysis showed deviations within credible bounds, confirming the model's robustness. The developed RLR equations offer a scalable and reliable alternative to CFD and black-box ML, bridging the gap between high-fidelity modeling and rapid ventilation assessment. Importantly, its transparent structure and predictive accuracy highlight the RLR model's potential to inform future ventilation design standards and guidelines, supporting healthier and energy-efficient buildings.

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Zhang, S., Lin, Z.

Review and prospect on advanced ventilation strategies for livable and sustainable buildings.

Building and Environment, Vol. **289**, (2026)

Ventilation systems are widely implemented to provide clean and conditioned air for indoor air quality and thermal comfort, but are also responsible for the substantial energy consumption and carbon emissions of buildings. This study reviews the advanced ventilation strategies to promote the livability and sustainability of buildings. The advanced ventilation strategies are categorized into air distribution methods (i.e., improvements in existing air distribution method for heating, and newly developed air distribution methods including interactive cascade ventilation, graded ventilation, and adaptive ventilation), air supply methods (i.e., swirling air supply, vortex-ring air supply, co-flow air supply, targeting air supply, one dimensional dynamic air supply, and two dimensional dynamic air supply), air exit methods, ventilation control methods (i.e., control for vertically and horizontally non-uniform environments, intermittent demand-controlled ventilation, and occupancy-aided demand-controlled ventilation), and ventilation performance indices (highlighting elevated air velocity for thermal comfort, cooling effect of air movement for energy efficiency, and airborne infection risk control for indoor air quality). Mechanisms underlying the advanced ventilation strategies for high ventilation performance are revealed regarding five-level deepened demands and three extended demands. Research gaps and future work are outlined, targeting occupant demands centered, air utilization efficient, and adaptive advanced ventilation strategies with the aid of artificial intelligence technologies.

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Sinquin, J., Sachot, A., Entine, F., Mullot, J.-U., Valente, M., Dekali, S.

Submarine Indoor Air Quality and Crew Health: A Critical Narrative State-of-the-Art Review of Respiratory and Cardiovascular Risks.

Toxics, Vol. **14** n°(1), (2026), 33 p.

Background: Submarines represent extremely confined environments where breathing air is continuously recirculated for extended periods with minimal renewal, generating complex multipollutant atmospheres. Objectives: This critical narrative review aims to (i) summarize sources and composition of submarine indoor air, (ii) evaluate respiratory and cardiovascular risks for crews, and (iii) assess current purification technologies. Methods: A narrative review was conducted following PRISMA recommendations applicable to non-systematic reviews. The PubMed search covered all years from inception to September 2025, complemented by backward citation tracking and technical reports. Results: Eligible studies consistently report elevated levels of CO2, VOCs, NOX, CO, PM2.5, and bioaerosols aboard submarines. Evidence from submariner cohorts and toxicological studies indicates risks of airway irritation, impaired mucociliary defenses, endothelial dysfunction, cardiovascular stress, and neurobehavioral alterations. Conclusions: Submarine indoor air quality is a credible determinant of crew health. Existing filtration systems mitigate some risks but do not address multipollutant mixtures adequately. Improved real-time monitoring, advanced filtration, CFD-guided airflow optimization, and longitudinal medical surveillance are necessary.

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Alessia, N., Fabrizio, R., Livia, O., Buratti, E., Giorgia, M., Roberto, Z.*, et al.*

Sustainable silk fibroin filtration solutions for healthier environments.

14th World Filtration Congress. 30 June - 4 July 2025, Bordeaux, France

AIM Traditional filtration materials, predominantly composed of non-biodegradable synthetic fibers, often fall short in capturing ultrafine particulate matter and contribute to environmental pollution. Our research addresses these challenges by incorporating sustainable materials into the filtration process. Our innovative membranes, derived from a Silk Fibroin-based matrix, exhibit exceptional performance in

pollutant capture while being biodegradable, thus minimizing ecological impact. METHODS Silk fibroin (SF) is extracted from silkworm cocoons and processed into nanofibers using a green electrospinning technique, utilizing water as the solvent. Various chemicals can be added to the spinning solutions to modulate the desired functionality of the nanofibers. Finally, the SF-based nanofibers are deposited onto a natural-based support, creating an entirely eco-friendly filtration medium. The filtration performance is assessed by measuring the penetration of NaCl aerosol particles at a velocity of 5.3 cm/s, in analogy with EN149:2001 standard. By employing Design of Experiments (DOE) methodologies, we optimized the electrospinning parameters to develop membranes that excel in filtration efficiency and functional properties, ultimately aiming to improve indoor air quality in various environments. RESULTS In this study, we present the mechanical, morphological, and functional characterization of electrospun SF-based nanofibrous filters, highlighting the versatility gained from incorporating various chemicals into the spinning solution, including natural antimicrobial agents. Key outcomes include the development of high-efficiency membranes achieving over 98% filtration efficiency for fine particles, enhanced antimicrobial activity against common pathogens, and comprehensive evaluations of compostability and environmental safety. CONCLUSION This research introduces a sustainable air filter fabricated from electrospun silk fibroin, demonstrating high filtration efficiency and low pressure drop, making it a viable candidate for various air filtration applications. Our innovative membrane not only promotes economic growth through the valorization of industrial by-products but also contributes to public health by improving indoor air quality and fostering a circular economy, positioning Silk Fibroin at the forefront of sustainable air filtration innovation. This presentation will elaborate on our methodology, anticipated results, and the transformative potential of SF nanofibers in addressing both environmental sustainability and public health challenges.

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Barrera, A. I. P., Peralta, L. M. R., Beas, E. R.

Tabular Data-to-Image Methods for Improved Indoor Air Quality Analysis and Risk Detection.

Proceedings of the 2025 8th International Conference on Systems Engineering - Cybersecurity & AI: Building a reliable digital future

This study explored the effectiveness of transforming tabular indoor air quality (IAQ) data into visual representations to enhance analysis and classification using machine learning and deep learning models. The primary objective was to address the challenge of classifying indoor air quality environments based on global IAQ risk levels. Three methodologies were applied: Refined, DeepInsight, and Vortex Feature Positioning. All approaches achieved acceptable classification performance, with DeepInsight yielding consistently solid results. Refined Mapping and Vortex Feature Positioning performed comparably, although the latter achieved slightly higher accuracy. Findings suggest that visual transformations of tabular data can uncover meaningful patterns, even when using low-resolution images (4x4 pixels). These image-based representations enhance compatibility with deep neural networks, facilitating improved classification performance and deeper insights into air quality characteristics. Future research will explore alternative deep learning architectures, such as Vision Transformers, EfficientNet, DenseNet, and Capsule Networks, to the image-based datasets. These architectures offer potential improvements by capturing global dependencies, achieving high performance with fewer parameters, enabling layer-wise feature reuse, and preserving spatial hierarchies in data, respectively

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Guichard, R., Robert, L., Klingler, J.

Towards a new index to qualify indoor air quality and thermal comfort in storage areas.

E3S Web Conf., Vol. **672**, (2025)

Recent works have highlighted the poorer indoor air quality in storage areas compared to sales areas of stores or office premises, due both to the high quantity of newly manufactured products, having high volatile organic compound (VOC) emission capacities like tires, shoes or furniture, and the absence of mechanical ventilation. These buildings are also rarely heated or cooled, leading to a potential occupant

discomfort. Because workers can spend a large amount of time in such environments, receiving and unpacking goods, placing products on shelves or collecting them, the first step for preventing their occupational exposure is to assess the risks associated with their activities. Full-scale measurement campaigns are difficult to achieve at an affordable cost in these environments due to the specific equipment and skills required for measuring different VOC concentrations and ambient air conditions, and the potential variability of the amount and the nature of products stored. This paper proposes an approach for constructing a new index to help preventers assessing indoor air quality and thermal comfort in storage areas.

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Brun, A., Awada, M., Becerik-Gerber, B.

Towards Unveiling the Interplay of Occupant Health, Comfort, and Building Energy Consumption.

In: Computing in Civil Engineering 2024. 2025. 299-304 p.

Promoting healthy indoor environment conditions for office workers, in line with reducing building energy consumption, requires thoughtful design choices. While researchers have been attentive to workers? comfort in the built environment, the health-comfort relationship has often been overlooked, and the energy consequences of meeting well-being and comfort needs are not well understood. We aim to investigate the complex interplay between an office worker?s health and comfort and their relationship with building energy consumption. As a preliminary investigation, we analyzed the data collected from an office worker over a 16-week period using two different types of data streams: worker?s perceived physical and mental health symptoms through hourly Ecological Momentary Assessments (EMAs) and continuous indoor air temperature measurements in their office spaces. We first identify healthy temperature ranges that support workers? health, and we then evaluate the impacts of these healthy setpoints on energy consumption. This paper is a preliminary attempt at investigating the interplay of occupant health, comfort, and building energy consumption.

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Ali, U., Tariq, S., Kim, K., Chang-Silva, R., Yoo, C.

Transfer learning-informed sensor validation for detecting and diagnosing unseen air quality faults in underground building environment.

Tunnelling and Underground Space Technology, Vol. **169**, (2026)

In modern underground building environments, data-driven integrated systems are necessary for accurate early warning and health risk assessment. However, sensor validation frameworks in both existing and newly deployed monitoring networks often face challenges due to data insufficiency and unseen fault scenarios, leading to increased energy consumption resulting from inaccurate ventilation control. To address these issues, this study proposes a sensor validation framework that integrates a gated residual network (GRN) with an autoencoder and network adapted transfer learning (TL) to ensure reliable performance under faulty conditions. Fault detection, diagnosis, and identification were initially performed on the source station using the squared prediction error and sensor validity index. Subsequently, a TL-based scheme was applied to adapt the model to the target station, mitigating the impact of data scarcity and unseen fault types on validation accuracy. Finally, the influence of faulty sensor measurements and AE-based TL-GRN reconstructions on ventilation control performance was assessed. The proposed TL-GRN achieved a 94.79% fault detection rate for unseen scenarios, significantly outperforming the GRN-AE (78.65%). Moreover, the proposed framework reduces overall resource usage and lowers carbon emissions by decreasing energy consumption by 13.8% and 19.9% compared to GRN-AE and the faulty condition, respectively. Overall, the proposed framework makes a significant contribution to the development of resilient and self-regulating ventilation systems for next-generation smart and sustainable buildings.

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Qadir, G., Baseer, M., Haddad, M., Kachalla, I. A.

A Unified Framework and Synergy Performance Index for Integrated Energy–Water–Ventilation Systems in Buildings: A Systematic Review.

Research Square, (2025)

Integrated management of energy, water, and ventilation (E–W–V) systems is increasingly recognised as a critical pathway for advancing sustainable development by reducing environmental impacts, improving resource efficiency, and strengthening climate resilience in the built environment. Despite growing interest, existing research remains fragmented, with limited attention to cross-domain synergies and a lack of standardised approaches for evaluating integrated system performance. This study addresses these gaps by introducing the Unified E–W–V Integration Framework (UEVIF) and the Synergy Performance Index (SPI), which together constitute the first combined methodological tools for systematically characterising and assessing multi-domain E–W–V interactions in buildings. A PRISMA-based systematic review of 107 peer-reviewed studies published between 2015 and 2025 was conducted to identify dominant integration typologies, resource-flow interdependencies, enabling technologies, and reported performance outcomes. The proposed SPI provides a normalised metric for evaluating synergy effects across energy demand, water use, and indoor environmental performance, enabling consistent cross-study comparison and benchmarking. The reviewed evidence indicates that integrated E–W–V strategies can achieve energy-use reductions of 30–70%, water-consumption savings of 20–40%, and measurable improvements in indoor air quality across diverse building types and climatic contexts. Nevertheless, the analysis reveals persistent limitations related to empirical validation, cross-domain modelling, and the absence of unified performance metrics. By offering a transferable analytical framework and a standardised synergy indicator, this review supports evidence-based design, research, and policy interventions aimed at accelerating the transition toward climate-aligned, net-zero, and circular built environments.

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Cho, J., Liang, W., Cheng, S., Chong, A., Heo, Y.

Weather-adaptive rule-based mixed-mode ventilation in a tropical climate: simulation and real-world validation.

Energy and Buildings, Vol. **352**, (2026)

This study proposed and validated a weather-adaptive, fan-assisted mixed-mode ventilation (MMV) strategy for reducing energy consumption in a tropical office building. The strategy integrates adaptive window-opening thresholds, a weather-adaptive cooling setpoint, and an optimal fan speed function in a hierarchical rule-based control manner. Its performance was first optimized in simulation and then tested in a high-metered office testbed. To ensure robust evaluation under limited baseline data, energy savings were quantified using an Elastic Net–based measurement and verification model that mitigates overfitting through combined L1/L2 regularization. The proposed strategy was benchmarked against two baselines: (1) fixed cooling at 26 °C with fan assistance, and (2) setpoint relaxation between 26–28 °C with fan assistance but without NV. Simulation predicted 48.9 % energy savings, while field validation achieved 31.2 % savings against fixed cooling baseline for the proposed strategy during occupied periods. In contrast, Simulation predicted 31.7 % energy savings, while field validation achieved 11.4 % savings for the proposed strategy against fixed cooling baseline during occupied periods. The additional savings (17 %) relative to the relaxation baseline were driven by MMV operation, with natural ventilation (NV) covering up to 25 % of occupied hours without exceeding thermal comfort limits (>30 °C). These findings confirm that adaptive, fan-assisted MMV control can deliver substantial and reliable energy reductions under real-world tropical conditions, providing a practical and interpretable alternative to complex controls.

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Narojczyk, M., Ratajczak, K., Sinacka, J.

Wykorzystanie materiałów zmiennofazowych (PCM) do odzysku ciepła w wentylacji mechanicznej w warunkach polskich (Utilisation de matériaux à changement de phase (PCM) pour la récupération de chaleur dans la ventilation mécanique dans les conditions polonaises.).

Ciepłownictwo, Ogrzewnictwo, Wentylacja, Vol. **56** n°(12), (2025)

The use of phase change materials (PCM) for heat recovery in mechanical ventilation systems is becoming increasingly popular. This is driven by the need to seek energy-saving solutions as well as by climate change, which leads to more frequent use of air-conditioning systems. Aim: The aim of this article is to analyze the possibilities of using phase change materials (PCM) in heat exchangers in decentralized ventilation systems, particularly in the Polish climate, and to assess the potential of PCMs for both cooling and heating functions, including how to select a PCM appropriate for local conditions. Methods: A review of 16 scientific publications on the use of PCM in ventilation systems was carried out. An analysis of PCM parameters was performed (melting temperature, stability, safety of use, toxicity), and temperature ranges enabling PCM regeneration in day–night cycles during summer and winter were identified. Conclusions and relevance to practical applications: The use of phase change materials (PCM) can improve the energy efficiency of decentralized ventilation systems, which is especially important in retrofitted buildings. It was shown that the optimal melting temperature of PCM is 16–20°C for summer (cooling mode) and 7–16°C for winter (heating mode), and that PCM selection must be based on local weather data (preferably hourly). It was also assessed that using a single PCM material for both modes is possible but requires a design compromise.

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