Rapport de veille n° 05-2022

Aéraulique

29/04/2022

Les bulletins de veille sont disponibles sur le portail documentaire de l'INRS. L'abonnement vous permet de recevoir une alerte mail lors de la publication d'un nouveau bulletin (bouton « M'abonner »).

WoS, Google Scholar et Lens

Lin, N., Zhong, L., Godwin, C., Batterman, S.
Be alert for vapor intrusion of 1,4-dioxane from contaminated groundwater.
Science of the Total Environment, Vol. **825**, (2022)

Vapor intrusion (VI) poses significant environmental problems that can degrade indoor air and pose human health risks. This study focuses on 1,4-dioxane, a widely-used volatile organic compound (VOC) that is found in groundwater, however, this compound has not received much attention in indoor air and measurement methods are not well developed. 1,4-dioxane is sufficiently volatile and highly mobile in groundwater, and thus can present a VI risk. In this study, we develop a sensitive analytical method for quantifying airborne 1,4-dioxane, provide a performance evaluation of the method, and initiate preliminary field measurements above a 1,4-dioxane groundwater plume. The method uses passive sampling, automated thermal desorption, and gas chromatography/mass spectroscopy. Numerous other VOCs can be simultaneously measured. A low detection limit (0.067 mu g/m3) is attained, which allows quantification at concentrations below health-based guidelines. The performance evaluation suggests limits to sampling times in high humidity environments and other means to ensure good performance. The scenario analyses demonstrate potential impacts from shallow plumes, especially in flooded basements, and thus monitoring of 1,4-dioxane vapor intrusion in the flood season is an urgent need.

****

Rey-Alvarez, B., Sanchez-Montanes, B., Garcia-Martinez, A.
Building material toxicity and life cycle assessment: A systematic critical review.
Journal of Cleaner Production, Vol. **341**, (2022)

This review systematically analyses the most relevant contributions published in the area of toxicity of building materials and their evaluation from the perspective of life cycle analysis to give a critical view of the relationship between the two fields. For this review, the systematic literature review methodology was chosen. With this methodology, it is possible to identify the most important sources and obtain a complete reading of the state of the question. The review shows that most articles on the toxicity of building materials focus on the usage phase, ignoring the life cycle perspective. On the other hand, the different Life Cycle Assessment methodologies start from different inventories, so the results will vary depending on the chosen method. In all cases, the predictions on toxicity are underestimated, so they are considered a secondary impact, and also the effects of bioaccumulation have not been integrated into the methodology. The main conflictive points found are discussed, such as the lack of coverage of substances widely used in the construction sector or the need to integrate new impacts.

****

Vasiliauskiene, V., Vasilis Vasiliauskas, A.
A Case Study on the Assessment of Chemical and Physical Pollution Levels during the Copying Process.
Sustainability, Vol. **14** n°(3), (2022)

In accordance with sustainable development goals (SDG's), urgent action should be taken to make the societal and natural environments better for human beings. People spend most of their time indoors, therefore growing attention is devoted to address indoor air pollution. When the sources of anthropogenic indoor air pollution (copiers, laser printers) are operated indoors, then chemical and physical indoor air pollution may be higher than air pollution outdoors. Ozone, aerosol particles and volatile organic compounds are the result of pollution caused by copiers and printers. The research was carried out in a copying room by recording chemical (ozone and aerosol particles) and physical (noise) environmental pollution. To determine instantaneous ozone concentrations in the copying room, an ozone analyzer O3 41M was used, while to evaluate the effect of ozone on the ambient air of the copying room, passive samplers were used. To determine the number and concentration of aerosol particles in the ambient air of the office, a particle counter AZ-5 was used. In addition, a DrDAQ data logger was used to measure noise emitted by the copier and ambient temperature as well as relative air humidity. It was found that the distribution of ozone and aerosol particles in the

copying room was mostly determined by the copying intensity. The maximum concentration of ozone and aerosol particles was determined during automatic copying (91-120 copies/min).

****

Khaki, S., Rio, M., Marin, P.
Characterization of Emissions in Fab Labs: An Additive Manufacturing Environment Issue.
Sustainability, Vol. **14** n°(5), (2022)

The emergence of additive manufacturing (AM) technologies, such as 3D printing and laser cutting, has created opportunities for new design practices covering a wide range of fields and a diversity of learning and teaching settings. The potential health impact of particulate matter and volatile organic compounds (VOCs) emitted from AM technologies is, therefore, a growing concern for makers. The research behind this paper addresses this issue by applying an indoor air quality assessment protocol in an educational fabrication laboratory. The paper presents the evaluation of the particle emission rate of different AM technologies. Real-time monitoring of multiple three-dimensional Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS) and Thermoplastic Elastomers (TPE) printers and Polymethyl methacrylate (PMMA) laser cutters was performed in different usage scenarios. Non-contact electrical detectors and off-line gas chromatography-mass spectrometry (GC-MS) were used to detect VOCs. The results show that the emitted particle surface area concentrations vary between 294 and 406.2 mu m(2)/cm(3) for three-dimensional printers, and between 55.06 and 92.3 mu m(2)/cm(3) for laser cutters. The experiments demonstrate that the emission concentrations were highly dependent on the filtration systems in place. The highest quantities of VOCs emitted included Cyclohexene and Benzyl Alcohol for PLA, ABS and TPE 3D printers, and formic acid and Xylene for PMMA laser cutters. The experiment concludes that signature emissions are detectable for a given material type and an AM technology pair. A suitable mitigation strategy can be specified for each signature detected. Finally, this paper outlines some guidelines for improving indoor air quality in such specific environments. The data provided, as well as the proposed indoor air quality protocol, can be used as a baseline for future studies, and thus help to determine whether the proposed strategies can enhance operator and bystander safety.

****

Zhao, Z., Pei, Y., Zhao, P., Wu, C., Qu, C., Li, W*., et al.*
Characterizing Key Volatile Pollutants Emitted from Adhesives by Chemical Compositions, Odor Contributions and Health Risks.
Molecules, Vol. **27** n°(3), (2022)

As one of the major sources of volatile pollutants in indoor air, gaseous emissions from adhesives during interior decoration have attracted increasing concern. Identifying major volatile pollutants and the risk in adhesive gaseous emissions is of great significance, but remains rarely reported. In the present research, we assessed the major volatile pollutants emitted from white emulsion adhesive and silicone adhesive samples (n = 30) from three aspects: chemical composition, odor and health risk contributions. The results showed that a total of 21 volatile pollutants were detected. Significantly, xylene was the most concentrated compound from white emulsion adhesives, accounting for 45.51 % of the total concentrations. Butanone oxime was the most concentrated compound in silicone adhesives, accounting for 69.86 % of the total concentrations. The trends in odor concentration (evaluated by the odor activity value method) over time were well correlated with the total chemical concentrations. Xylene (58.00 %) and butanone oxime (76.75 %) showed the highest odor contribution, respectively. Moreover, from an integrated perspective of chemical emissions, odor and health risk contributions, xylene, ethylbenzene, ethyl acetate and benzene were identified as the key volatile pollutants emitted from the white emulsion adhesives, while butanone oxime, butanone, and ethanol were the key volatile pollutants emitted from the silicone adhesives. This study not only identified the key volatile pollutants but also provided characteristics of odor and health risks of gas emitted from adhesives.

****

Madruga, D. G.
A Comprehensive Review on the Indoor Air Pollution Problem, Challenges, and Critical Viewpoints.
In: Integrating IoT and AI for Indoor Air Quality Assessment. Springer International Publishing; 2022. pp. 9-26

Over the last decades, environmental pollution has become the main environmental risk to human being health due to the rise regarding waste production, in particular toward the air matrix. At the legislative level, European Directives set

air quality objectives to prevent and protect human being health. Nevertheless, the European legislation only applies to outdoor environments, despite people pass ~90 % of their time in inside spaces. It exists scientific studies sustain the presence of higher air pollutant levels in indoor than outdoor locations. For this reason, research studies for enlarging knowledge on indoor air quality result priority. Within the previous frame, this chapter aims to provide an indoor air quality benchmark, in terms of potential emission focuses, concentrations, impact on health, and methodologies for measuring air pollutants, focused on indoor air quality managers, control technicians, and potential students. The impact of indoor air quality should be considered at the global level due to several factors, such as indoor pollution is particular for each location, indoor-outdoor air inter-change, and atmospheric pollution is cross-border. The application of new computer tools (IoT and AI) on current and novel measuring air pollution technologies offers a unique chance for inside air quality management.

****

Zhang, D., Ji, H., Li, Z., Ge, H.
Design of Building Environment Detection System for Architectures Based on Internet of Things.
Computational Intelligence and Neuroscience, Vol. **2022**, (2022)

In the process of urban building design, a new integrated system for monitoring the environment is developed and designed by using embedded development technology and sensor technology. The system uses a wireless sensor network environment monitoring system IoT platform with embedded internal processors. Analyze and design the system as a whole, including the construction of the basic platform of the system, the design of the internal plates and circuits of the system, the monitoring design of the input node, and the monthly design of the output interface calculation. Finally, a physical model is built, and data measurement and analysis are carried out under different conditions, and the evaluation and advantage analysis of the system's operating status are given. The system can carry out all-round, multilevel, and three-dimensional real-time monitoring of the construction site environment, including dust, PM2.5, temperature, humidity, wind speed, carbon dioxide, and other indicators in the construction site environment. In addition, the system can upload various monitoring data to the detection system through the internal network. The system has the functions of monitoring, alarming, recording, querying, and counting of the target monitoring station and can also be linked with the environmental control device. The construction site staff can conduct real-time supervision through the mobile terminal and computer terminal management platform. In addition, it can also meet the role of real-time remote monitoring and online guidance and regulation. It has reference value for the safety and management of the actual operation process of the project.

****

Jia, Z., Zhuang, P., Huang, Z.
Design of Remote Indoor Environment Monitoring System Based on STM32.
In: Communications, Signal Processing, and Systems. Springer Singapore; 2022. pp. 63-70.

With the development and progress of society, air quality issues have a greater impact on mankind. However, the number of indoor environment monitoring instruments currently on the market is small and the price is high, and among them, the remote monitoring function is almost missing. This makes it difficult for people to obtain the air pollution index conveniently and in real-time. Faced with such a situation, a remote indoor environment monitoring system was designed to promote the realization of the dream of the interconnection of everything in contemporary society. Compared with mainstream air monitors on the market, this remote indoor environment monitoring system not only has an LCD, but the biggest highlight is the realization of WIFI wireless transmission. People can remotely control the instrument through mobile phone software to realize monitoring and feedback the monitoring results immediately. The design can also realize interaction with the cloud, upload height information to the cloud for data analysis and storage.

****

Xu, B., Wang, Y., Guo, D., Gao, Y., Liu, W., Wu, W*., et al.*
Determination of the key parameters of VOCs emitted from multi-layer leather furniture using a region traversal approach.
Science of the Total Environment, Vol. **819**, (2022)

Volatile organic compounds (VOCs) emitted from indoor materials and products are one of the main factors affecting air quality and human health. Compared with building materials and wooden furniture, leather furniture has a more complex internal structure and uneven emission surfaces. The market share of leather furniture is relatively high, while investigation on this kind of furniture is relatively rare. In this study, we develop a region traversal method to measure the three key parameters of VOC emissions from typical two-layer leather furniture, i.e., the initial emittable concentration, the diffusion coefficient, and the partition coefficient. A series of experiments examining VOC emissions from a leather sofa under different conditions, were carried out in a 1 m(3) chamber. This method locks the upper and lower limits of an optimal solution through loop calculation in parameter intervals, and demonstrates high accuracy, efficiency and robustness. The good agreement (R-2 > 0.95) between model predictions and experimental data confirms the reliability of this method. In addition, the influence of temperature and air exchange rate on the key parameters is explored. Results indicate that, increasing the temperature leads to an increase in D-m and a decrease in K, and that air exchange rate does not affect the key parameters, which is consistent with physical principles. The region traversal method is further applied to analyze the emission scenarios for other furniture, which is very helpful for indoor air quality pre-evaluation.

****

Wang, N., Ernle, L., Beko, G., Wargocki, P., Williams, J.
Emission Rates of Volatile Organic Compounds from Humans.
Environmental science & technology, Vol. **56** n°(8), (2022)

Human-emitted volatile organic compounds (VOCs) are mainly from breath and the skin. In this study, we continuously measured VOCs in a stainless-steel environmentally controlled climate chamber (22.5 m3, air change rate at 3.2 h-1) occupied by four seated human volunteers using proton transfer reaction time-of-flight mass spectrometry and gas chromatography mass spectrometry. Experiments with human whole body, breath-only, and dermal-only emissions were performed under ozone-free and ozone-present conditions. In addition, the effect of temperature, relative humidity, clothing type, and age was investigated for whole-body emissions. Without ozone, the whole-body total emission rate (ER) was 2180 ± 620 mug h-1 per person (p-1), dominated by exhaled chemicals. The ERs of oxygenated VOCs were positively correlated with the enthalpy of the air. Under ozone-present conditions (37 ppb), the whole-body total ER doubled, with the increase mainly driven by VOCs resulting from skin surface lipids/ozone reactions, which increased with relative humidity. Long clothing (more covered skin) was found to reduce the total ERs but enhanced certain chemicals related to the clothing. The ERs of VOCs derived from this study provide a valuable data set of human emissions under various conditions and can be used in models to better predict indoor air quality, especially for highly occupied environments.

****

Zhang, Q., Davis, A. Y., Black, M. S.
Emissions and Chemical Exposure Potentials from Stereolithography Vat Polymerization 3D Printing and Post-processing Units.
Acs Chemical Health & Safety, Vol. **29** n°(2), (2022), pp.184-191

Particles and volatile organic compounds (VOCs) have been detected emitting from material extrusion 3D printing, which is widely used in nonindustrial environments. However, vat polymerization 3D printing that is also commonly used has yet to be well-characterized for its emissions. In this study, we measured particle and VOC emission rates from stereolithography (SLA) 3D printing during print and post-processing wash and cure processes individually using a standardized testing method for 3D printer emissions in an exposure chamber. We observed minimal particle emissions and identified 30 to over 100 individual VOCs emitted from each operating phase, some of which accumulated after the printing ended. The total VOC emissions from SLA processes were higher than typical levels from material extrusion 3D printing, and the emission rate could be over 4 mg/h. Major VOCs emitted were associated with the resin and chemicals used in print and post-processing procedures, which included esters, alcohols, aldehydes, ketones, aromatics, and hydrocarbons. Emissions from post-processing units were lower than those from printing but also included chemicals with health concerns. The emitted mixture of sensitizers, carcinogens, irritants, and flammable chemicals may present a hazard for indoor air quality and human health. The estimated personal exposure to total VOC and some specific VOCs of concern to human health, like formaldehyde and naphthalene, exceeded the recommended indoor levels (e.g., California Office of Environmental Health Hazard Assessment), potentially causing irritation and other health impacts for 3D printer users.

****

Mirhadyan, L., Jafakesh, S., Pasha, A., Atrkar Roshan, Z., Golhosseini, M.
Evaluation of air quality in intensive care units and its relationship with sick building syndrome in nurses.
Occupational Medicine, (2022)

Introduction: Indoor air quality can lead to health problems such as Sick Building Syndrome among nurses who spend many hours in intensive care units.The aim of this study was to determine the relationship between Sick Building Syndrome in nurses and indoor air quality of intensive care units in educational hospitals in Rasht.
Materials and Methods: This cross-sectional analytical study was performed on 144 nurses in intensive care units who were randomly selected by quota random sampling. Some of the physical and chemical factors affecting indoor air quality including volatile organic compounds (Ethyl benzene, Xylene, Toluene), carbon monoxide, dust, temperature, humidity, brightness, noise,and airflow velocity were measured by calibrated equipment and symptoms of building syndrome were assessed by the MM040EA questionnaire.
Results: The chemical factors were lower; temperature, humidity and noise were higher and brightness was lower than the recommended minimum. However, no statistically significant relationship was observed between indoor air quality and Sick Building Syndrome.
Conclusion: Although the measured physical and chemical factors in intensive care units were often at the occupational limits. The studied nurses reported poor physical conditions in their workplaces. Identifying and controlling occupational hazards in intensive care units can improve nursing performance by increasing job satisfaction.

****

Mousavi, E., Bhattacharya, A.
Event based approach for modeling indoor airflow patterns.
Journal of Building Engineering, Vol. **51**, (2022)

People spend a significant proportion of their time indoors, where the quality of indoor air affects the productivity, efficiency, and well-being of occupants. One of the oldest challenges in building construction is designing a ventilation system that ensures optimum indoor air quality. Accept-able indoor air should provide thermal comfort and minimize human exposure to contamination. Characterizing these two elements requires information on both heat/mass transfer in the microenvironment and the time-specific activity of individuals who move among these micro-environments. While researchers have utilized simulation tools to investigate this complex human-environment interaction, current numerical techniques severely limit the simulations to overly simplified, unrealistic scenarios. To address these issues, this paper proposes a new and innovative approach called event-based modeling (EBM) to simulate airflow patterns for realistic human-environment interactions. EBM can provide an accurate approximation to simulate the patterns of air movement in indoor environments. EBM can also provide a path to simulate complex, random human-environment interactions that are pragmatically impossible to solve by current approaches. This paper formulates and evaluates this novel approach, and then validates it via simple cases of a door opening and human walking.

****

Sekar, A., Varghese, G. K., Varma, R.
Exposure to volatile organic compounds and associated health risk among workers in lignite mines.
International Journal of Environmental Science and Technology, (2022)

Volatile organic compounds play an important role in air quality and human health. In this study, the characterization of volatile organic compounds in three sites viz., Blast Hole Drilling Yard, Conveyor Belt Yard and Belt Reconditioning Plant in a lignite mine were carried out. The entire sampling and analysis were carried out as per the compendium of methods to determine toxic organic compounds in ambient air (Compendium method TO-17). Probabilistic health risk assessment for non-carcinogenic and carcinogenic risk was carried out using the Monte-Carlo method. The total volatile organic compounds present in blast-hole drilling, conveyor belt yard and belt reconditioning plant were observed to be 78, 57 and 2763.68 mu g/m(3), respectively. Chloroform was detected in higher concentrations in blast-hole drilling and conveyor belt yard, whereas toluene was detected at belt reconditioning plant. The levels of detected compounds were within the permissible limits as prescribed by the Indian and International agencies. The level of naphthalene is likely to cause non-carcinogenic and carcinogenic effects among the occupants of the belt reconditioning plant. The major contributor to the total carcinogenic risk in blast-hole drilling and conveyor belt yard was chloroform, contributing a

mean risk of 1.43E-04 and 1.5E-04, respectively. Sensitivity analysis showed that the concentration of pollutants is the most critical parameter in determining the output risk. The cleaning agents, degreasing agents, accelerators used in reconditioning, etc., may be the probable sources of volatile organic compounds in these microenvironments. The results obtained in the study highlight the requirement of a risk-based regulatory system.

****

Pongboonkhumlarp, N., Jinsart, W.
Health risk analysis from volatile organic compounds and fine particulate matter in the printing industry.
International Journal of Environmental Science and Technology, (2022)

The association between the printing activity and the pollutant exposure of the workers was investigated in five consecutive working days, during 8 h work shift per day. Exposure concentrations of the total volatile organic compound and fine particulate matter were measured in the four voluntary printing factories in Thailand. Two types of the printing process, offset and digital printing, were compared. The 8 h average of particulate matter 2.5 in the field blank, Offset A, Offset B, Offset C printing and Digital printing D was 7.46, 21.51, 44.26, 77.92, and 42.08 mu gm(-3), respectively. The highest particulate matter level in the Offset printing C, 77.92 mu gm(-3) was due to the surrounded paper dust in the area. The 8 h average of total volatile organic compounds in field blank, Offset A, Offset B, Offset C printing and Digital printing D was 0.12, 2.68, 5.02, 21.86, and 0.67 ppm, respectively. The highest total volatile organic compound was 21.86 ppm in the Offset printing C because of the high production rate and the application of organic solvents in the cleanup process. Worker's exposure to total volatile organic compound and particulate matter 2.5 in the offset printings was higher than in the digital laser printing. From the health risk evaluation, the workers in offset printings were at risk from total volatile organic compound exposure, Hazard quotient > 1. However, workers exposed to particulate matter exposures were not at risk, Hazard quotient < 1.

****

Ismaeel, W. S. E., Alamoudy, F. O., Sameh, R.
How renovation activities may jeopardise indoor air quality: accounting for short and long-term symptoms of sick building syndrome in educational buildings.
Architectural Engineering and Design Management, (2022)

The study discussed how building renovation activities jeopardised Indoor Air Quality (IAQ) and caused several symptoms of Sick Building Syndrome (SBS). This postulation was investigated on a case study-renovated university building with different types of functional spaces. The research method comprised: (1) site inspection for renovation best practices, (2) Gas Chromatography lab tests to examine the types of pollutants (volatile organic compounds) caused by different types of finishing and comparing them to the international standards provided by the Leadership in Energy and Environmental Design (LEED), and finally (3) occupants' survey (labourers, staff and students) with variations in the magnitude and duration of their exposure to pollutants. The result of the lab tests exceeded the maximum threshold set by the LEED system which indicated a health risk. This was confirmed by the survey results showing associated symptoms of SBS during and after the renovation process noting that the symptoms escalated in confined places with poor ventilation. The conclusion indicated that material selection and renovation best practices were responsible for several health risks. Associated symptoms of SBS increased due to early occupancy and continued for three months after renovation completion. Eventually, the study recommended proper planning for IAQ during building renovation noting the interplay of causes and consequences of SBS: (1) during building renovation, (2) after completion, (3) before occupancy and (4) after at least one year of building operation. Further, it presented a set of recommendations for each phase across different project phases for the benefit of academic and industry outreach.

****

Bhardwaj, N.
Identification of Sources of Air Pollution Using Novel Analytical Techniques and Instruments.
Department of Chemistry and Biochemistry. Brigham Young University, États-Unis. Thèse 2022

This dissertation is a collection of studies that investigates the issue of air pollution in the field of environmental chemistry. My thesis consists of research works done to measure the concentration of particulate matter (PM) and gas-phase species in ambient air. High concentrations of PM is a significant problem in Utah and in other regions of the world. Particles having an aerodynamic diameter of 2.5 micrometers and smaller play a crucial role in air pollution and

pose serious health risks when inhaled. The organic fraction in PM ranges from 10-90 % of the total particle mass. Several methods have been employed to measure the organic fraction of PM, but these techniques require extensive laboratory analysis, and expensive bench top equipment. The Hansen Lab has developed a new instrument called the Organic Aerosol Monitor (OAM) which is based on gas chromatography followed by mass spectrometry detection platform for measuring the carbonaceous component of PM2.5 on an hourly averaged basis. Organic marker data collected in 2016 using the OAM was used in a Positive Matrix Factorization (PMF) analysis to identify the sources of PM in West Valley City, Utah. Additionally, data was collected in Richfield and Vernal, UT in 2017 – 2018 to quantitatively monitor the composition of organic markers of PM2.5. Some previously unidentified organic compounds in PM were successfully identified during this study.

****

Zubir, N., Jalaludin, J., Rasdi, I.
Indoor Air Quality and Psychosocial Factors Related to Sick Building Syndrome among Office Workers in New and Old Buildings of a Public University in Klang Valley, Malaysia.
Malaysian Journal of Medicine and Health Sciences, Vol. **18**, (2022), pp. 1-9

Introduction: Sick building syndrome (SBS) has been linked to poor indoor air quality (IAQ) and work-related stress. Objective: This research aims to determine the relationship between environmental and psychosocial factors with SBS among office workers in new and old buildings in Universiti Putra Malaysia, Serdang. Methods: A cross-sectional comparative study was conducted among 120 office workers in new and old buildings in UPM. SBS symptoms and psychosocial factors were identified using validated questionnaires modified from IAQ and work symptoms survey, and Job Content Questionnaire (JCQ). The IAQ parameters measured using IAQ devices. Results: The air velocity, air humidity, temperature and indoor air pollutants level in the new building were significantly higher compared to old building. The prevalence of SBS was significantly higher in the old building compared to the new building ($\chi 2=31.44$, $p<0.001$). There were significant associations between SBS prevalence with temperature (OR=4.02, 95 % CI=1.02-15.85), TVOC (OR=4.55, 95 % CI=1.12-18.48); UFP (OR=4.63, 95 % CI=1.25-17.21); PM2.5 (OR=5.06, 95 % CI=1.36-18.89); PM10 (OR=4.80, 95 % CI=1.33-17.29) and job insecurity (OR=4.08, 95 % CI=1.03-16.23). The findings showed that the indoor air pollutants influenced the old building's SBS symptoms and job insecurity influenced SBS in the new building after controlling the confounders. Conclusion: The prevalence of SBS among office workers is influenced by indoor air quality and psychosocial factors. Further assessment and preventive steps should be taken to reduce risk factors in the workplace.

****

Baudet, A., Baures, E., Blanchard, O., Le Cann, P., Gangneux, J.-P., Florentin, A.
Indoor Carbon Dioxide, Fine Particulate Matter and Total Volatile Organic Compounds in Private Healthcare and Elderly Care Facilities.
Toxics, Vol. **10** n°(3), (2022)

Poor indoor air quality can have adverse effects on human health, especially in susceptible populations. The aim of this study was to measure the concentrations of dioxide carbon (CO2), fine particulate matter (PM2.5) and total volatile organic compounds (TVOCs) in situ in private healthcare and elderly care facilities. These pollutants were continuously measured in two rooms of six private healthcare facilities (general practitioner's offices, dental offices and pharmacies) and four elderly care facilities (nursing homes) in two French urban areas during two seasons: summer and winter. The mean CO2 concentrations ranged from 764 +/- 443 ppm in dental offices to 624 +/- 198 ppm in elderly care facilities. The mean PM2.5 concentrations ranged from 13.4 +/- 14.4 mu g/m(3) in dental offices to 5.7 +/- 4.8 mu g/m(3) in general practitioner offices. The mean TVOC concentrations ranged from 700 +/- 641 ppb in dental offices to 143 +/- 239 ppb in general practitioner offices. Dental offices presented higher levels of indoor air pollutants, associated with the dental activities. Increasing the ventilation of these facilities by opening a window is probably an appropriate method for reducing pollutant concentrations and maintaining good indoor air quality.

****

Lv, M., Liu, S., Cao, Q., Zhang, T., Liu, J.
Influence of Ventilation on Indoor Air Quality.
In: Handbook of Indoor Air Quality. Springer Singapore; 2021. pp. 1-38

Ventilation is to provide unconditioned outdoor air or conditioned, combined, outdoor, and recirculated air for suitable indoor comfort and acceptable air quality. Ventilation can be categorized into natural ventilation, mechanical ventilation, and their hybrid form. Due to the pros and cons of each ventilation mode, a ventilation mode may suit to a pertinent indoor space in a specific climate region or location. The purpose of this chapter is to examine the impacts of ventilation modes on indoor air quality in different indoor spaces, such as residential buildings, office buildings, and transportation vehicle cabins with the dense commercial aircraft cabin as an example. The evaluated ventilation modes include natural ventilation, mechanical ventilation, and the occasional hybrid ventilation. The mechanical ventilation is further divided into mixing ventilation, displacement ventilation, stratum ventilation, and personalized ventilation in an office building or aircraft cabin. Ventilation of residential buildings in the situation with outdoor PM2.5 pollution has been systematically addressed. The indoor air quality performance in terms of ventilation rate, concentrations of CO2, formaldehyde, TVOC, and PM2.5 was evaluated. In addition to indoor air quality, the possible airborne infection transmission, thermal comfort, energy consumption, and affordability of each ventilation mode have also been examined.

****

Jahanbin, A., Semprini, G.
Integrated effects of the heat recovery ventilation and heat source on decay rate of indoor airborne particles: A comparative study.
Journal of Building Engineering, Vol. **50**, (2022)

Given the high concentration of indoor airborne particles during the winter and their harmful effects on human health, it is of great importance to examine combined effects of the ventilation and heat source on indoor particle dispersion. The present study aims to investigate transient dispersion and deposition of indoor particles under the heat recovery ventilation (HRV). Five groups of particles with different diameters ranging from 0.1 to 10 mu m were taken into account, representing the inhalable indoor airborne particles. By considering three different heating systems, including the radiator, floor heating system and fan coil, the integrated ventilation-heating effects on particle dispersion were evaluated and compared. An Eulerian-Lagrangian CFD model was developed to predict turbulent characteristics of the airflow field and unsteady particle trajectories. The role of particle size, air change rate and outdoor temperature was addressed. In addition, influence of the heat source position on the particle decay rate and removal efficiency was investigated. The results indicated that the impact of heating system on the particle decay rate is weakened by increasing the ventilation rate. Among all heating systems, the radiator renders the highest dispersion rate and the slowest decay rate, even lower than a single HRV unit. It was revealed that, for an intermediate ventilation rate, the particle deposition rate in fan coil system is 3.6 and 2.4 times faster than the radiator and floor heating systems, respectively. It was also found that displacing the radiator to the opposite side of the ventilation unit quadruplicates the removal efficiency and leads to 146 % enhancement of the decay rate coefficient.

****

Jung, C., Al Qassimi, N.
Investigating the Emission of Hazardous Chemical Substances from Mashrabiya Used for Indoor Air Quality in Hot Desert Climate.
Sustainability, Vol. **14** n°(5), (2022)

Dubai has the reputation of a continuously growing city, with skyscrapers and mega residential projects. Many new residential projects with poor choices of material and ventilation have led to a faster rise in sick building syndrome (SBS) in Dubai than in any other country, and the IAQ (indoor air quality) has become more critical. Volatile organic compounds (VOCs) and formaldehyde (HCHO) affect the health of residents, producing the phenomenon known as SBS (sick building syndrome). It has been reported that wood materials used for furniture and wooden windows and doors are a significant source of indoor air pollution in new houses. This paper aims to identify the factor elements emitting harmful chemical substances, such as VOCs and HCHO, from wooden mashrabiya (traditional Arabic window) by examining the characteristics of the raw and surface materials through test pieces. As a methodology, a small chamber system was used to test the amount of hazardous chemicals generated for each test piece. For Total volatile organic compounds (TVOC) and HCHO, the blank concentration before the injection and the generation after seven days were measured. The results showed that to reduce TVOC, it is necessary to secure six months or more as a retention period for raw materials and surface materials. The longer the retention period, the smaller the TVOC emission amount. In the case of mashrabiya, an HCHO low-emitting adhesive and maintenance for one month or more are essential influencing

factors. It was proven that using raw materials with a three-month or more retention period and surface materials with a one-month or more retention period is safe for indoor mashrabiya. This study is the first study in the Middle East to identify factors and characteristics that affect the emission of hazardous chemicals from wood composite materials, such as wood mashrabiya, that affect indoor air quality in residential projects in Dubai. It analyzes the correlation between emission levels and the retention period of raw and surface materials, in order to provide a new standard for indoor air pollutants.

****

Arar, M., Jung, C., Qassimi, N. A.
Investigating the Influence of the Building Material on the Indoor Air Quality in Apartment in Dubai.
Frontiers in Built Environment, Vol. **7**, (2022)

The residents of Dubai spend more than 90 % of their time indoors and this lifestyle makes them easily exposed to Sick Building Syndrome (SBS). Even though Dubai Municipality strictly apply the IAQ (Indoor Air Quality) stipulation, indiscreet use of unproven finishing materials has been increased to deteriorate the health of residents in Dubai. The objective of this paper is to investigate the degree of influence of building material on indoor air pollutants concentration by measurement and prediction. As a methodology, indoor pollutants concentration was measured and investigated, variables were extracted through emission intensity experiments, and the indoor concentration was predicted by applying the double exponential decay model. The result had shown that electronic products, furniture, and textile products become new sources of indoor air pollution. The difference in emission patterns of wallpaper and flooring is confirmed via the emission rate test. It is statistically proven that Formaldehyde (CH2O) and VOCs showed a difference in the cumulative emission amount within 100 h but after that, it was confirmed that the difference in emission amount between materials became very small. In case of CH2O, the cumulative emission of the flooring material is greater than that of the wallpaper. This study will serve as a basic data to explore the cause of indoor air pollutants in daily life to reduce SBS symptoms in Dubai.

****

Kapoor, N. R., Kumar, A., Kumar, A., Kumar, A., Mohammed, M. A., Kumar, K., *et al.*
Machine Learning-Based CO2 Prediction for Office Room: A Pilot Study.
Wireless Communications & Mobile Computing, Vol. **2022**, (2022)

Air pollution is increasing profusely in Indian cities as well as throughout the world, and it poses a major threat to climate as well as the health of all living things. Air pollution is the reason behind degraded indoor air quality (IAQ) in urban buildings. Carbon dioxide (CO2) is the main contributor to indoor pollution as humans themselves are one of the generating sources of this pollutant. The testing and monitoring of CO2 consume cost and time and require smart sensors. Thus, to solve these limitations, machine learning (ML) has been used to predict the concentration of CO2 inside an office room. This study is based on the data collected through real-time measurements of indoor CO2, number of occupants, area per person, outdoor temperature, outer wind speed, relative humidity, and air quality index used as input parameters. In this study, ten algorithms, namely, artificial neural network (ANN), support vector machine (SVM), decision tree (DT), Gaussian process regression (GPR), linear regression (LR), ensemble learning (EL), optimized GPR, optimized EL, optimized DT, and optimized SVM, were used to predict the concentration of CO2. It has been found that the optimized GPR model performs better than other selected models in terms of prediction accuracy. The result of this study indicated that the optimized GPR model can predict the concentration of CO2 with the highest prediction accuracy having R, RMSE, MAE, NS, and a20-index values of 0.98874, 4.20068 ppm, 3.35098 ppm, 0.9817, and 1, respectively. This study can be utilized by the designers, researchers, healthcare professionals, and smart city developers to analyse the indoor air quality for designing air ventilation systems and monitoring CO2 level inside the buildings.

****

Carslaw, N., Shaw, D.
Modification of cleaning product formulations could improve indoor air quality.
Indoor Air, Vol. **32** n°(3), (2022)

Abstract Cleaning products contain numerous individual chemicals, which can be liberated on use. These species can react in air to form new chemical species, some of which are harmful to health. This paper uses a detailed chemical

model for indoor air chemistry, to understand the chemical reactions that can occur following cleaning, assuming cleaning products with different proportions of limonene, α-pinene, and ?-pinene are used. The tests included the pure compounds, 50:50 mixtures and mixtures in proportion to the rates of reaction with ozone and the hydroxyl radical. For the 3 h following cleaning, pure α-pinene was most efficient at producing particles, pure limonene for nitrated organic material, and a 50:50 mixture of ?-pinene and limonene for formaldehyde, leading to enhancements of 1.1 ?g/m3, 400 ppt, and 1.8 ppb, respectively, compared to no cleaning. Cleaning in the afternoon enhanced concentrations of secondary pollutants for all the mixtures, owing to higher outdoor and hence indoor ozone compared to the morning. These enhancements in concentrations lasted several hours, despite the cleaning emissions only lasting for 10 min. Doubling the air exchange rate enhanced concentrations of formaldehyde and particulate matter by ~15 % while reducing that of nitrated organic material by 13 %. Changing product formulations has the potential to change the resulting indoor air quality and consequently, impacts on health.

****

Yu, J., Wania, F., Abbatt, J. P. D.
A New Approach to Characterizing the Partitioning of Volatile Organic Compounds to Cotton Fabric.
Environmental Science & Technology, Vol. **56** n°(6), (2022), pp. 3365-3374

Chemical partitioning to surfaces can influence human exposure by various pathways, resulting in adverse health consequences. Clothing can act as a source, a barrier, or a transient reservoir for chemicals that can affect dermal and inhalation exposure rates. A few clothing-mediated exposure studies have characterized the accumulation of a select number of semi-volatile organic compounds (SVOCs), but systematic studies on the partitioning behavior for classes of volatile organic compounds (VOCs) and SVOCs are lacking. Here, the cloth-air equilibrium partition ratios (K-CA) for carbonyl, carboxylic acid, and aromatic VOC homologous series were characterized for cellulose-based cotton fabric, using timed exposures in a real indoor setting followed by online thermal desorption and nontargeted mass spectrometric analysis. The analyzed VOCs exhibit rapid equilibration within a day. Homologous series generally show linear correlations of the logarithm of K-CA with carbon number and the logarithms of the VOC vapor pressure and octanol-air equilibrium partition ratio (K-OA). When expressed as a volume-normalized partition ratio, log K(CA_V)values are in a range of 5-8, similar to the values for previously measured SVOCs which have lower volatility. When expressed as surface area-normalized adsorption constants, K(CA_S)values suggest that equilibration corresponds to a saturated surface coverage of adsorbed species. Aqueous solvation may occur for the most water-soluble species such as formic and acetic acids. Overall, this new experimental approach facilitates VOC partitioning studies relevant to environmental exposure.

****

Parhizkar, H., Fretz, M., Laguerre, A., Stenson, J., Corsi, R. L., Wymelenberg, K. G. V. D.*, et al.*
A novel VOC breath tracer method to evaluate indoor respiratory exposures in the near- and far-fields.
Research square, (2022)

Several studies suggest that far-field transmission (> 6 ft) explains the significant number of COVID-19 superspreading outbreaks. Therefore, quantitative evaluation of near- and far-field exposure to emissions from a source is key to better understanding human-to-human airborne infectious disease transmission and associated risks. In this study, we used an environmentally-controlled chamber to measure volatile organic compounds (VOCs) released from a healthy participant who consumed breath mints, which contained unique tracer compounds. Tracer measurements were made at 2.5 ft, 5 ft, 7.5 ft from the participant, as well as in the exhaust plenum of the chamber. We observed that 2.5 ft trials had substantially (~36-44 %) higher concentrations than other distances during the first 20 minutes of experiments, highlighting the importance of the near-field relative to the far-field before virus-laden respiratory aerosol plumes are continuously mixed into the far-field. However, for the conditions studied, the concentrations of human-sourced tracers after 20 minutes and approaching the end of the 60-minute trials at 2.5 ft, 5 ft, and 7.5 ft were only ~18 %, ~11 %, and ~7.5 % higher than volume-averaged concentrations, respectively. Our findings highlight the importance of far-field transmission of airborne pathogens including SARS-CoV-2, which need to be considered in public health decision making.

****

Considine, B., Mcnabola, A., Kumar, P., Gallagher, J.

A numerical analysis of particulate matter control technology integrated with HVAC system inlet design and implications on energy consumption.
Building and Environment, Vol. **211**, (2022)

This paper examines and outlines the development of a novel inlet for an air handling unit (AHU) which controls PM concentration entering mechanically ventilated buildings. The aspiration efficiency reducer (AER), can reduce the ambient PM concentrations drawn into a building ventilation system. The AER device incorporates an array of cylindrical tubed orifices, which create conditions for potential improved indoor air quality (IAQ) and energy savings. Prototypes were designed by reverse-engineering the aspiration efficiency (AE) concept, creating new inlets for AHUs using Computational Fluid Dynamics. This approach helps achieve low AE values and reduce PM concentrations entering the AHU and filter loading rates. 3D k-omega SST models were used to simulate particle laden fluid flow around an AHU with AER attachments. The investigation found that the engineering of wind flow around the AHU and its inlet resulted in lower levels of particles with diameters <= 10 mu m entering the AHU. The difference in AE for particles within the PM10 range for the passive AER prototypes in comparison to a commercial rainhood ranged from 5 to 35 % for various inlet designs. This translated into increased energy savings of 15.2-20.6 % and extended fabric filter lifespan of up to an additional 100 hundred days until saturation. The AER has the potential to reduce energy consumption, minimise waste generation and present cost savings whilst improving IAQ, through a reduction in maintenance activities and the number of filter replacements. This novel technology requires low-capital investment to deliver environmental, energy and economic savings in this sector.

****

Kezic, S., Nunez, R., Babić, Ž., Hallmann, S., Havmose, M. S., Johansen, J. D., *et al.*
Occupational Exposure of Hairdressers to Airborne Hazardous Chemicals: A Scoping Review.
International Journal of Environmental Research and Public Health, Vol. **19** n°(7), (2022)

Introduction: Exposure to hazardous chemicals released during hairdressing activities from hair care products puts hairdressers at risk of adverse health effects. Safety assessments of hair products are mainly focused on consumers, but exposure for professional hairdressers might be substantially higher. Objective: To identify and assess available research data on inhalation exposures of professional hairdressers. Methods: A systematic search of studies between 1 January 2000 and 30 April 2021 was performed in Medline, Embase, Web of Science and in Cochrane registry, toxicological dossiers of the Scientific Committee on Consumer Safety (SCCS) of the European Commission as well as the German MAK Commission. Studies reporting quantitative data on airborne concentrations of chemicals in the hairdresser’s workplace were considered. The outcome was an airborne concentration of chemicals in the working environment, which was compared, when possible, with current occupational exposure limits (OEL) or guidance levels. Results: In total, 23 studies performed in 14 countries were included. The average number of hairdressing salons per study was 22 (range 1–62). Chemicals most frequently measured were formaldehyde (n = 8), ammonia (n = 5), total volatile organic compounds (TVOC) (n = 5), and toluene (n = 4). More than fifty other chemicals were measured in one to three studies, including various aromatic and aliphatic organic solvents, hydrogen peroxide, persulfate, and particulate matter. Most studies reported environmental air concentrations, while personal exposure was measured only in seven studies. The measured air concentrations of formaldehyde, ammonia, and TVOC exceeded OEL or guidance values in some studies. There was large variability in measuring conditions and reported air concentrations differed strongly within and between studies. Conclusion: Hairdressers are exposed to a wide spectrum of hazardous chemicals, often simultaneously. Airborne concentrations of pollutants depend on salon characteristics such as ventilation and the number of customers but also on used products that are often country- or client-specific. For exposure to formaldehyde, ammonia, and TVOC exceeding OELs or guidance values for indoor air was observed. Therefore, occupational exposure should be taken into account by safety regulations for hair care products.

****

Stinson, B., Laguerre, A., Gall, E. T.
Per-Person and Whole-Building VOC Emission Factors in an Occupied School with Gas-Phase Air Cleaning.
Environmental Science & Technology, Vol. **56** n°(6), (2022), pp. 3354-3364

Using real-time measurements of CO 2 and volatile organic compounds (VOCs) in the air handler of an occupied middle school, we quantified source strengths for 249 VOCs and apportioned the source to the building, occupants and their activities, outdoor air, or recirculation air. For VOCs quantified in this study, there is a source to the outdoors of 8.6 +/-

1.8 g/h in building exhaust air, of which 5.9 +/- 1.7 g/h can be attributed to indoor sources (the building and occupants and their activities). The corresponding whole-building area emission factor from indoor sources is 1020 +/- 300 mu g/(m(2) h), including reactive VOCs like isoprene and monoterpenes (33 +/- 5.1 and 29 +/- 5.7 mu g/(m(2) h), respectively). Per-person emission factors are calculated for compounds associated with occupants and their activities, e.g., monoterpenes are emitted at a rate of 280 +/- 80 mu g/(person h). The air handler included carbon scrubbing, reducing supply air concentrations of 125 compounds by 38 +/- 19 % (mean +/- std. dev.) with a net removal of 2.4 +/- 0.4 g/h of organic compounds from the building. This carbon scrubber reduces steady-state indoor concentrations of organics by 65 mu g/m(3) and the contribution of indoor sources of VOCs to the outdoor environment by similar to 40 %. These data inform the design and operation of buildings to reduce human exposure to VOCs inside buildings. These data indicate the potential for gas-phase air cleaning to improve both indoor air quality and reduce VOC emissions from buildings to the outdoor environment.

****

Kristak, L., Antov, P., Bekhta, P., Lubis, M. a. R., Iswanto, A. H., Reh, R.*, et al.*
Recent progress in ultra-low formaldehyde emitting adhesive systems and formaldehyde scavengers in wood-based panels: a review.
Wood Material Science & Engineering, (2022),pp. 1-20

Traditional wood-based panels are produced with synthetic, formaldehyde-based adhesives, commonly made from fossil-derived constituents, such as urea, phenol, melamine, etc. Along with their numerous advantages, such as chemical versatility, high reactivity and excellent adhesive performance, these adhesives are characterized by certain problems, connected with the hazardous volatile organic compounds (VOCs), mostly free formaldehyde in the adhesives and the formaldehyde emission from the finished wood composites, which is carcinogenic to humans and harmful to the environment. The growing environmental concerns and stringent legislative requirements to the formaldehyde emission from wood-based panels have posed new challenges to researchers and industrial practice, related to the development of sustainable, eco-friendly wood-based panels with close-to-zero formaldehyde emission. The most common methods to reduce the formaldehyde emission from wood-based panels have been to decrease the free formaldehyde in the adhesive by modifying the adhesive (like lowering the molar ratio of formaldehyde to urea in UF resin) or by using formaldehyde scavengers, one group of scavengers being for adhesives by mixing or reacting and the second one scavengers for wood-based panels as post-treatments. Another way is to use alternative bio-based adhesives, however, there are still substantial challenges for the complete replacement of formaldehyde-based adhesives with bio-based adhesives, mainly because of their relatively low bonding strength, poor water resistance, etc. This article presents a review and analysis of the current state of research in the field of low formaldehyde emission wood adhesives and formaldehyde scavengers for manufacturing low-toxic, eco-friendly wood composites.

****

Calvo, I., Espin, A., Miguel Gil-Garcia, J., Fernandez Bustamante, P., Barambones, O., Apinaniz, E.
Scalable IoT Architecture for Monitoring IEQ Conditions in Public and Private Buildings.
Energies, Vol. **15** n°(6), (2022)

This paper presents a scalable IoT architecture based on the edge-fog-cloud paradigm for monitoring the Indoor Environmental Quality (IEQ) parameters in public buildings. Nowadays, IEQ monitoring systems are becoming important for several reasons: (1) to ensure that temperature and humidity conditions are adequate, improving the comfort and productivity of the occupants; (2) to introduce actions to reduce energy consumption, contributing to achieving the Sustainable Development Goals (SDG); and (3) to guarantee the quality of the air-a key concern due to the COVID-19 worldwide pandemic. Two kinds of nodes compose the proposed architecture; these are the so-called: (1) smart IEQ sensor nodes, responsible for acquiring indoor environmental measures locally, and (2) the IEQ concentrators, responsible for collecting the data from smart sensor nodes distributed along the facilities. The IEQ concentrators are also responsible for configuring the acquisition system locally, logging the acquired local data, analyzing the information, and connecting to cloud applications. The presented architecture has been designed using low-cost open-source hardware and software-specifically, single board computers and microcontrollers such as Raspberry Pis and Arduino boards. WiFi and TCP/IP communication technologies were selected, since they are typically available in corporative buildings, benefiting from already available communication infrastructures. The application layer was implemented with MQTT. A prototype was built and deployed at the Faculty of Engineering of Vitoria-Gasteiz, University of the Basque Country (UPV/EHU), using the existing network infrastructure. This prototype allowed for collecting data within different

academic scenarios. Finally, a smart sensor node was designed including low-cost sensors to measure temperature, humidity, eCO(2), and VOC.

****

Kuncoro, C. B. D., Asyikin, M. B. Z., Amaris, A.
Smart-Autonomous Wireless Volatile Organic Compounds Sensor Node for Indoor Air Quality Monitoring Application.
International journal of environmental research and public health, Vol. **19** n°(4), (2022)

Several studies reported the significant effect of indoor air quality on human health, safety, productivity, and comfort because most humans usually conduct 80 %-90 % of their activity inside the building. This is generally due to the fact that indoor pollution is associated with volatile organic compounds (VOCs), pollutants with chronic health effects, both non-carcinogenic and carcinogenic, on humans. Therefore, this study focused on developing wireless VOCs sensor nodes with a low-power strategy feature to perform an autonomous operation in indoor air quality monitoring (IAQM). The sensor node mainboard consists of a microcontroller-based AVR (ATmega-4808) that supports a low power mode and low-power IAQ-Core sensor for VOCs detection. The low-power sensing algorithm developed also allowed the sensor node to consume a total power of 0.22 mAh for one cycle of operation, which includes the initial process, TVOCs value reading process, data transmitting process, and low power mode process at a time interval of 30 min. The most significant power was observed to be consumed in the data transmitting process with 0.13 mAh or 58 % of total power consumption in one cycle of sensor node operation. Furthermore, the 10F capacitance of the supercapacitor was able to drive the VOCs sensor node for 139 s and it was recommended that further studies use micro energy harvesting (from an indoor environment) to extend its lifetime. The 1541-minute field experiment conducted also showed that TVOCs and CO₂ values were successfully measured and displayed over an internet connection on the monitoring terminal dashboard. The recorded real-time TVOCs value of 175 ppb (<200 ppb) indicates good air quality.

****

Wallenius, K., Hovi, H., Remes, J., Mahiout, S., Liukkonen, T.
Volatile Organic Compounds in Finnish Office Environments in 2010-2019 and Their Relevance to Adverse Health Effects.
International Journal of Environmental Research and Public Health, Vol. **19** n°(7), (2022)

We gathered recent (2010–2019) data on the VOC and formaldehyde levels in Finnish non-industrial indoor work environments. The data comprised 9789 VOC and 1711 formaldehyde samples collected from the indoor air of offices, schools, kindergartens, and healthcare offices. We assessed the health risks by comparing the measured concentrations to the health-based RW I/II and EU-LCI reference values. The concentrations of individual VOCs and formaldehyde in these work environments were generally very low and posed no health risks. Total VOC concentration (TVOC) as well as concentrations of several individual compounds, including aromatic compounds, alkanes, 2-ethyl-1-hexanol, and formaldehyde, showed clearly decreasing trends. In contrast, several aldehydes, acids, and a few other compounds showed increasing trends. However, the increasing trends did not seem to affect the higher ends of the distributions, as the 95th percentile values remained fairly stable or decreased over the years. The VOC patterns in the environments of the offices, schools, kindergartens, and healthcare offices varied, probably reflecting the differences in typical activities and the use of materials. However, we do not expect these differences to be relevant to health outcomes.

****