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Opening remarks: Giorgio Buonanno (University of Cassino and Southern Lazio), Maria Neira (WHO), Maria Van Kerkhove (WHO), Enrica Porcari (CERN)

Giorgio Buonanno

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Molecular parameter prediction tools for calculating the partitioning of organic compounds between gas and particle phase indoors

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Objective: For the ecotoxicological assessment of a chemical substance in indoor spaces, it is important to know its partitioning behavior between gas phase, particle phase and settled house dust. Due to the complex interaction of molecules with the different compartments, the dynamics is usually modeled. However, this requires precise knowledge of the physical and chemical properties of the compounds and the respective matrices.
Methods: The following prediction methods were applied and compared: quantitative property-property relationships (QPPR), quantitative structure-activity relationships (QSAR), quantitative structure-property relationships (QSPR), linear free-energy relationships (LFER) and quantum mechanical (QM) tools.
Results: The prediction of molecular properties of chemical pollutants is now an indispensable part of tools for assessing their fate in the environment and their toxicity. Many organizations provide extensive information on this, although the quality of the data is not necessarily guaranteed. It is therefore up to the user to evaluate whether a value used is realistic or not. Computer-based models can be used to generate data quickly and easily, but the algorithms hidden behind them are practically impossible to trace. An assessment will therefore preferably be based on practical aspects and individual experience. In general, experimentally measured values are considered to be more reliable than computed values. However, this is only the case if the experiments are carried out with much care and precision.
The number and quality of prediction models is practically unmanageable. The most popular QSAR and LFER tools are SPARC, OPERA, the OECD QSAR Toolbox and the UFZ-LSER database. These allow reasonable molecular parameters to be obtained for many compounds. However, there are exceptions. It has been shown that molecules containing heteroatoms such as silicon and/or fluorine often cannot be treated with standard algorithms. Therefore, a QSAR or LFER algorithm may only be used for the specified substance group. It must also be made clear that the quality of a QSAR and LFER result depends heavily on the training set. SPARC for example fails at the vapor pressures of semi-volatile compounds and OPERA fails at the air/water partitioning coefficient of PFAS. It is therefore advisable to validate the result using a reference compound with known properties.
Quantum mechanical prediction tools are more reliable and flexible because each molecule is calculated individually. The result does not depend on the properties of other molecules. However, it is necessary to identify the dominant conformer ensemble in each phase. The currently most powerful method for this is the density functional theory (DFT) based so-called CRENSO workflow.
The errors of predicted values are very different. For quantum chemically generated data according to CRENSO, an uncertainty of 0.5 log units was reported. Small error ranges are often specified for QSAR and LFER algorithms, but, as already mentioned, these usually only relate to the respective training set. Realistically, errors of 1 - 2 log units must be expected here. However, this does not include possible outliers. Various databases are available to the user, in some of which the selected values are also commented.

Conclusion: Despite, or perhaps because, access to algorithms and databases is so easy today, scientific expertise can and must be expected. The user should still be able to evaluate the quality of predicted or experimentally determined molecular properties of organic compounds. This also applies to the fact that sometimes calculations on the partitioning behavior of substances are only possible with limitations. A recommendation as to which calculation tool or database should be chosen for a specific substance, a specific parameter and specific compartment cannot be given. This must be decided individually, taking into account all necessary and available information.

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Optimizing the Use of Room Air Purifiers in Combination with HVAC Filters for IAQ and Energy Efficiency for both PM 2.5 and UFP particles

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Summary: Indoor air quality is increasingly recognized as a serious health hazard in many international environments. The elevated impact of UFPs is also becoming more well understood. This paper investigates the dynamics between room air purifiers and HVAC systems, emphasizing their collective impact on Indoor Air Quality (IAQ) and energy consumption. We engage in an analysis of particulate matter, including a set of studies using PM 2.5 and UFP particles, and examine the subsequent effects under different HVAC operational circumstances. The primary objective is to identify an optimal balance where superior IAQ can be maintained while ensuring minimal energy usage. In addition, the objective is to understand how this balance is impacted by particle size. Our results could lead to actionable insights and pragmatic approaches for achieving optimal air quality and energy sustainability in both residential and commercial settings, enacting strategies in situations where there is particular concern around UFP contamination, ultimately contributing to enhanced health and wellbeing, and energy savings to standard air filters.
Objective: There is a growing awareness that particulates, and especially UFPs, pose substantial health risks, and that removal of these particles from indoor air can be a challenge for low MERV rated filters, especially if energy use is a factor as well. The purpose of this study is to compare the effectiveness and energy use of two strategies for reducing UFP's from indoor air: strategy one is to use higher MERV rated filters, strategy two is to use a lower MERV rated filter but add a free-standing room air purifier (in this case an electrostatic filter with an established UFP filtration rating).
Methods: To perform this study, a 25'X30'X10'test room was built with a VFD HVAC system and built in energy monitoring system. A spray gun, powered by a compressor, disperses dust evenly with the help of ceiling and ground fans. Once the particle counter shows stable concentrations of 15 million particles per cubic feet, testing begins. Data collection stops after 1 hour to ensure consistency through all experiments. Two sets of experiments were run. The first set of tests used standard PM 2.5 dust with a standard distribution of particles and a PM 2.5 particle counter that reports concentrations in 6 size ranges. The second set of tests used UFP dust and an UFP particle counter. In both cases, tests were run to establish the impact on particle reduction of MERV 8,11 and 13 filters with and without a free-standing room air purifier.
Results: The first set of tests demonstrated that pairing a basic MERV 8 filter with an in-room purifier can match the air quality offered by using just a MERV 13 filter for PM 2.5 particles.
The results of the second set of tests showed that the decay rates of UFP's were nearly identical when using only MERV 8,11, or 13 filters. The addition of an auxiliary air purifier significantly reduced the concentration of ultrafine particles, demonstrating that UFP collection is primarily achieved by the auxiliary air-purifier. In addition, energy use was calculated and results show that the use of auxiliary air purifier used less energy than a higher MERV rated filter in addition to being more effective at UFP removal.
Conclusion: In our research, we found clear benefits of combining in-room air purifiers with standard HVAC systems. By using this combined method with lower grade MERV filters, we can reduce energy costs and still maintain high indoor air quality. This approach is both practical and efficient. It suggests a balanced way to achieve cleaner indoor environments, especially in settings like offices or homes. Our results highlight an effective strategy for those seeking to optimize air quality without incurring significant operational challenges. This research can guide future decisions in indoor

air management, pointing towards a promising direction. In addition, this research indicates that for environments concerned with UFP's, the use of higher rated HVAC filters may in fact offer little protection while increasing energy use, and that use of an in-room air purifier with a known UFP removal rating may be a preferred solution.

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The effects of cleaning chemicals on indoor air quality and means to reduce harmful exposure in educational buildings

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Background: Cleaning activities commonly conducted in educational buildings are intended to promote hygiene and comfortable learning environments. However, using cleaning products can result in exposure to both primary and secondary indoor air pollutants. This exposure arises from the emission of various substances and their interactions with other compounds present in indoor environments, for example ozone. Many components found in cleaning products, such as fragrances, detergents, surfactants, solvents, pH stabilizers, and bases including glycol ethers, hydrocarbons, and carbonyl compounds, are deemed hazardous by the European Union.
Objective: The aim of this study was to summarize the effects of commonly used surface cleaning and disinfecting products on indoor air quality and the means to reduce the exposure in educational buildings.
Methods: The literature review was performed using Google Scholar, and PubMed. Altogether 10 search terms (cleaning agent, cleaning product, school, university, kindergarten, indoor air, indoor environment, exposure, chemical emissions, particles) and their combinations were used to identify scientific journal publications. The search included original peer-reviewed scientific journal articles, literature reviews, conference publications, theses and final reports published between 2014 and 2024. The search was then extended to the reference lists of relevant articles. From the publications identified in the initial search, we finally included 23¬¬¬¬¬¬ publications in the review.

Results: The literature review revealed that common cleaning and disinfecting products used in educational buildings can emit numerous volatile organic compounds including formaldehyde and terpenes like limonene and α-pinene. The application of cleaning products like waxes and polishes can also lead to increased concentrations of benzene, ethylbenzene, m/p-xylene, tetrachloroethylene, and styrene (Gabriel et al., 2021). Exposure to high levels of terpenes can occur even when products contain essential oils, and these compounds can react with oxidants like ozone to form secondary pollutants (Angulo Milhem et al., 2020). Deep cleaning methods such as steam cleaning can prompt the release of chemicals from carpets, which accumulate in indoor air, particularly if ventilation during and after cleaning is inadequate (Wakayama et al., 2019). Wet mopping, although reducing particle resuspension, can lead to higher VOC levels when cleaning products are used, as well as increase levels of viable bacteria in indoor spaces (Smedje and Norbäck, 2001; Wei et al., 2016). Using a detergent with limonene was shown to increase ultra-fine particle concentrations significantly (Morawska et al., 2009; Salonen et al., 2024). Monitoring of daily patterns of particulate matter in school classrooms has revealed the significant impact of cleaning activities, occupancy, and dust resuspension on increased particle concentrations (Faria et al., 2020).
To lower chemical exposure, it is advisable to enhance cleaning routines, switch to low-emitting cleaning products, alter cleaning techniques, and improve ventilation during and after cleaning. Major cleaning activities should preferably be conducted after school hours. Furthermore, it is highly

recommended to avoid using air fresheners or fragranced cleaning products in educational buildings.

Conclusions: The use of cleaning agents can lead to harmful exposure to chemical and particulate pollutants. It is essential to implement measures to minimize this exposure, particularly in educational settings with young children. Further studies should focus on analyzing the chemical composition of cleaning products and assessing exposure levels with targeted measurements rather than with questionnaire. Research is needed to examine the long-term health effects of these chemicals, compare potentially environmentally hazardous products with eco-friendly alternatives (such as citric acid, Na2CO3, NaHCO3, essential oils, and natural tensides), and evaluate the effectiveness of different ventilation strategies. Recognition of optimal cleaning techniques to substantially reduce chemical exposure is significant. Furthermore, studies exploring the interactions between cleaning product chemicals and other indoor pollutants are called for. Simultaneously, an exploration of new cleaning technologies, combined with a critical assessment of related regulations, is indispensably important for healthy learning atmospheres.

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SESSION 3b - Mitigation Measures and Strategies: Exploring environmentally sustainable solutions such as indoor ventilation and beyond, Oral Presentations / 12

FAR-UV Technology and Germicidal Ultraviolet (GUV): A Policy and Research Review for Indoor Air Quality and Disease Transmission Control

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The COVID-19 pandemic underscored the vital role of indoor air quality (IAQ) in reducing airborne disease transmission indoors. Far-Ultraviolet (FAR-UV) technology, emitting light between 200-235 nm, emerges as a promising alternative to traditional wavelengths of Germicidal Ultraviolet (GUV), promoting airborne disinfection without many of the safety concerns related to improperly installed

upper-room GUV systems. Studies indicate that FAR-UV effectively inactivates various pathogens, though questions remained around its safety, appropriate use cases, and the regulatory environment associated with this new technology. To understand these issues Johns Hopkins University Center for Health Security (CHS) recently convened a high-level working group to discuss the potential of FAR-UV technology as a public health tool. The meeting brought together interdisciplinary experts, including engineers, public health specialists, and policymakers, to evaluate current research findings and strategize on implementation pathways. Discussions emphasized the importance of FAR-UV as a scalable solution to enhance IAQ and reduce indoor disease transmission.

Findings from this working group demonstrate that FAR-UV has high efficacy and low energy requirements compared to other disinfection methods or other engineering controls. FAR-UV could be a promising tool to combat disease transmission in high-risk indoor environments and improve IAQ, particularly when coupled with ventilation systems. Further research is necessary, however, to ensure the safe use of FAR-UV technology, including the development a clearer understanding of the chemical interactions between FAR-UV light, ozone, and volatile organic compounds, as well as the need to identify best practices to mitigate secondary organic aerosols generated by FAR-UV use. Further studies highlighting the best use cases and appropriate venues for FAR-UV deployment are also recommended. Finally, the regulatory landscape for FAR-UV technology remains underdeveloped. Establishing standardized guidelines and conducting comprehensive human health risk assessments are crucial steps for informing policy toward ensuring safe and effective implementation. Regulatory clarity for this novel technology would foster public trust and encourage more widespread adoption.

FAR-UV technology holds significant promise as an engineering solution to enhance indoor air quality and control disease spread. Its high efficacy in pathogen inactivation, coupled with a favorable safety profile, positions it as a valuable tool in public health strategies. Implementation of FAR-UV, as well as GUV, technology should be considered for locations that have high infection potential. However, we must address environmental concerns and establish robust regulatory frameworks to realize its full potential in diverse indoor environments.

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Multi-scale fluid dynamic analysis of indoor infection transmission risk by respiratory droplets

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Objectives. Indoor transmission of pathogens between hosts primarily occurs through exhaled respiratory droplets. Transmission mechanisms include direct or indirect contact with contaminated surfaces, and direct or indirect inhalation of droplet nuclei. Droplet trajectory depends primarily on their size among other factors such as ambient thermohygrometric conditions and transport charactersitics within the exhaled breath cloud. Large droplets are dominated by inertia and follow quasi-parabolic trajectories reaching the ground before their evaporation completes. On the contrary, small droplets are dominated by drag forces and are carried around indefinitely by local air streams. Inertia and drag compete over intermediate size droplets that change behaviour as they evaporate. Large droplets are among the prime responsible of fomite transmission, intermediate size droplets of direct inhalation transmission, and small droplet nuclei of airborne transmission. Droplet dispersion has been investigated in the literature by several numerical means including CFD simulations and analytical models. Objective of the present work is to present a novel multi-scale model combining the wide modelling capabilities of CFD analyses with the accuracy and reduced computational effort of analytical models. Assumptions on the saliva viral load and on the quantity of exhaled droplets allow spatial risk maps to be built able to discriminate between the various transmission routes for different types of respiratory events.

Methods. The authors recently developed an analytical model solving the equations of droplet transport, evaporation, energy, and chemical composition. The model also accounts for droplet turbulent dispersion using a random walk approach and implements a randomised droplet injection mechanism making it suitable for statistical analyses on the trajectories of large sets of droplet. The governing equations of the model depend on the varying local ambient conditions encountered by the droplet during its flight such as air velocity, temperature and relative humidity. This calls for detailed exhaled breath cloud models that cannot be simply obtained from jet theory empirical formulas. To overcome this limit, the analytical model is coupled to 3D U-RANS CFD simulations of the exhaled jet providing accurate representations of the buoyant breath cloud for various types of respiratory events. The analytical model is coupled one-way with CFD simulations: at each time step, the model queries the CFD results to get the local ambient conditions and use this information to update the droplet position and diameter. Droplet are simulated up to when they either settle to the ground or evaporation terminates and their solid nucleus is transported by local air flows with negligible terminal velocity. The multi-scale model thus built is used to analyse the droplet trajectories from different respiratory events. The scenarios investigated include mouth breathing, speaking, nose breathing, coughing, and sneezing. A SARS-CoV-2 infected individual not wearing a face mask is assumed, and the domain of the analysis is a large non-ventilated empty confined space.

Results. Droplet trajectories visualization provides an immediate qualitative representation of the infection risk area around the infected individual. With assumptions on the virus concentration in the saliva, the infectious dose likely to cause the disease if inhaled, and the quantity and size distribution of the droplets exhaled for each respiratory event, trajectory data is further processed to obtain practical quantitative spatial virus concentration maps. These maps are derived for the room volume and, by considering the droplets settling to the ground, for the floor surface in front of the individual thus providing means for quantifying the risks associated to both direct inhalation and fomite transmission routes. By assuming well-mixed airborne droplet nuclei after the simulation stops tracking them, Wells-Riley model further provides numerical evaluations for the background virus concentration responsible for airborne transmission. By estimating the breathing rate and the exposure time of a susceptible individual, information on the virus concentration is translated into virus inhalability spatial maps and, lastly, into infection transmission risk maps.

Conclusions. The multi-scale model proposed exploits the advantages of both CFD and analytical modelling providing accurate predictions of exhaled droplet trajectories. It also allows large sets of droplets to be evaluated with limited computational effort. The model was used to simulate different scenarios handling more than 40 thousand droplets each. This data allowed to investigate the main physical phenomena influencing the droplet motion. Above all, it allowed useful spatial risk maps to be derived that can quantify the risk of contagion in specific situations, helping in better calibrating prevention needs.

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Study of Reactions Between Ozone and VOCs Present in Work Atmospheres

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The COVID-19 pandemic has led to the proliferation of air purifiers employing various methods to remove volatile organic compounds (VOCs). However, the French Research and Safety Institute for the Prevention of Occupational Accidents and Diseases (INRS) has observed that some purifiers emit high concentrations of ozone (O3), ranging from 100 to over 1,000 ppbv. O3 triggers the oxidation

of VOCs rapidly forming of low-volatility, poly-oxygenated molecules which condense to become particle precursors [1-3]. These organic molecules and nano-sized particles in the air pose potential health risks. However, the chemical pathways leading from the first oxygenated intermediates to particle formation are still unknown: the challenge rests in identifying the structures of the maximum number of intermediates along the growth pathway, in order to understand the mechanisms involved.
This study aims to investigate the specific reactions of O3 with terpenes—VOCs representative of work environments—under ambient pressure and temperature conditions. Using gas flow tube reactors and analytical tools such mass spectrometry and gas chromatography, we identified and quantified gas-phase products. Based on literature and the characteristic aerosol appearance time from previous experiments, a quartz flow tube reactor was developed and dimensioned to achieve residence times of the order of one second.

Initial validation experiments focused on isoprene (C5H8), a fundamental building block of terpenes whose ozonolysis has been extensively studied, e.g. [4]. Key ozonolysis stable products—methyl vinyl ketone, methacrolein, and formaldehyde—were successfully identified, which provides confidence in the experimental method used. Additional products, including acetic acid, formic acid, oxygenated ring structures (e.g., furans), and various aldehydes (saturated, such as ethanal, and unsaturated, such as butenal and pentenal), were also detected.

Future studies will focus on aerosol quantification during isoprene ozonolysis and also on more complex terpenes, such as α-pinene and limonene, aiming to deepen the understanding of terpene ozonolysis mechanisms and inform health-related guidelines based on these findings.

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POSTER SESSION / 16

Challenges and Advancements in Environmental Monitoring at the Controlled Air Ventilation Environment (CAVE) Laboratory

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The CAVE (Controlled Active Ventilation Environment) laboratory is a purpose-built, climate- and ventilation-controlled indoor laboratory. With a plan area of 206 m² and a height of 10 m, CAVE has been designed to support full-scale "living labs," ranging from small buildings to vehicles and double-decker buses. With a fully furnished, two-story building inside, our laboratory HVAC systems can achieve completely independent "interior" and "exterior" environments, creating complex thermal and ventilation scenarios for each. The climate capabilities range between -5℃ to 43℃ in the "exterior"environment and 10℃ to 28℃ in the "interior", and both environments can be supplied with fresh or recirculated air or artificially generated pollutants.

Presented are the key challenges of sensor selection and management in such a complex setting. Consistently accurate monitoring of temperature, humidity, airflow, and pollutants (CO_2, particulate matter, VOCs, CO, NOx, etc.) requires rigorous sensor alignment, mapping, and calibration to ensure comparability across our +200 devices from multiple manufacturers. Demonstrated through several experiment case studies, CAVE allows us to track the alignment between reference-grade instruments and networks of low-cost sensors. Optimising placement with these sensors through partial collocation alongside these calibration instruments is crucial to accurately capturing spatial variability, airflow patterns, and pollutant distributions. Low-cost sensors, while key to achieving this high spatiotemporal resolution, require assiduous management to mitigate issues like baseline drift and false readings.

The data produced by CAVE is used to validate our in-house computational fluid dynamics (CFD) models, which simulate urban airflows, pollutant dispersion, and the indoor environment. This presentation also explores approaches to unifying diverse data streams into a real-time dashboard and leveraging kriging interpolation heat maps for visualisation. Early-stage data preparation for future machine-learning applications is also discussed. CAVE can provide full characterisation of physical and environmental parameters, which can be used to enhance computational modelling and advance research in the built environment.

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Use of Fluorescence Probe Spectroscopy to Characterize RH-Dependent Phase Transitions and Physicochemical Properties of Respiratory Aerosols

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Understanding the viability of viruses contained in respiratory particles and the connections between this viability and the relative humidity (RH)- mediated physicochemical properties of the aerosols themselves is critical to mitigate respiratory disease transmission. Here we present the use of fluorescence probe spectroscopy to investigate the phase state of model respiratory particles. In this technique, fluorescent molecules are incorporated into the particles of interest and their polarity-dependent emission properties are used to determine particle phase state. Particles consisting of mucin/salt mixtures, a growth medium, and simulated lung fluid were studied across an RH range of 30-80%. Phase separation between the organic and inorganic constituents was observed at an RH that was dependent on the chemical composition of the particles. The use and advantages of a range of different probe molecule classes, including solvatochromic and excited state intramolecular proton transfer will be discussed. Furthermore, we demonstrate that volatilization of probe molecules and subsequent condensation can be used to incorporate the molecules into preexisting unlabeled particles. This methodology enables the study of real exhaled respiratory particles using fluorescence-based measurement techniques. Finally, we discuss the outlook for fluorescence probe spectroscopy in the field, including its use to investigate other physicochemical properties such as pH and viscosity as well as its application more chemically-complex systems such as real respiratory and environmental aerosols.

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Respirable Crystalline Silica exposure during ceramic tile processing

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Objective: Respirable Crystalline Silica (RCS), classified as a Group 1 carcinogen by the International Agency for Research on Cancer, poses significant health risks when inhaled, including silicosis and lung cancer. Exposure to RCS can occur especially in occupational settings, including in the glass, ceramic, brick and tile industries, where materials are mechanically processed through cutting, grinding, crushing, drilling or abrasive blasting.
Activities related to the processing of ceramic tiles may vary considerably in terms of hours worked per day and days worked per week. This variability is high for craftsmen who carry out cutting, grinding or other processing of ceramic materials directly on site, during installation of tiles and not in a completely suitable environment, in terms of health and safety of the worker. In these situations, it may be difficult to control RCS exposure by means of dust extraction or abatement systems including wet processing. Further, actual working time for these operations is unpredictable. These uncertainties make it difficult to estimate the exposure to RCS of artisans/craftsmen, a critical factor for assessing occupational risks and implementing appropriate safety measures.
This study investigates the occupational risks associated with RCS exposure during ceramic tile installation, particularly focusing on cutting and grinding tasks.

Methods: Simulated RCS exposure evaluation were conducted to replicate real-world conditions where ceramic tiles are processed for installation by cutting and grinding. The tiles used in this study varied in composition (in term of formulations) and thickness (12 mm and 20 mm).
RCS exposure was measured using personal and environmental samplers, collecting respirable dust. Sampling occurred during 2-hour task durations, assuming no further exposure for 8-hour TWA calculations. Accredited gravimetric and X-ray diffraction techniques were used to quantify RCS concentrations. These measurements were compared against OELs, and task-specific durations were calculated for safe exposure levels. The efficacy of personal protective equipment (PPE), including FFP2 and FFP3 masks, was incorporated into the analysis by applying protection factors of 10 and 20, respectively.

Results: Principal results of this study (worst-case simulation) show that, during the processing of ceramic tiles releasing RCS, the worker exposure can be very high (average: 240.9 µg/m3; maximum: 889.3 µg/m^3), exceeding the Occupational Exposure Limit - OEL. In particular, even working for a few hours a day, the RCS 8-hour TWA (Time Weighted Average) OEL is likely to be exceeded. Furthermore, without respiratory protection, workers could perform cutting for only 54 minutes or grinding for 115 minutes daily before exceeding the OEL. Inhaled exposure concentrations can be reduced by using appropriate respiratory protection, by a factor equal to 10 or 20. However, the study emphasized that reliance on PPE alone could be insufficient due to potential misuse, failure to fit, or discomfort, underscoring the importance of engineering controls and administrative measures.

Conclusion: The findings confirm that ceramic tile processing poses a substantial risk of RCS exposure, especially in unstructured environments like construction sites where engineering controls are often lacking. Effective risk management must integrate a hierarchy of controls, prioritizing collective measures such as local exhaust ventilation and wet processing techniques, supported by appropriate use of PPE. Training workers in safe handling practices and ensuring regular maintenance of protective systems are critical to minimizing exposure. Additionally, task durations, material properties, and working conditions must be carefully assessed to develop tailored safety protocols.
The assumption of this work was that (i) the cutting/grinding times are not always necessarily equal to 2-hours, and that (ii) these processes are not characterized by pre-established and continuous processing times. For these reasons, it is important to evaluate carefully the duration of exposure to RCS during the various tasks/activities performed, as these may vary.

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A machine learning- based approach for PM source apportionment inside residences.

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Nowadays, the use of technically upgraded, cost-efficient, real-time, monitoring sensors has led to increased efficiency in indoor air quality (IAQ) data collection. Combined with the means of citizen science (i.e. collection of occupants activity data), the large amount of air quality data comprises a challenging opportunity to investigate further the factors influencing the quality of the indoor environment in terms of pollutants concentrations as well as occupants'health and comfort. Key-enablers in this direction are the advanced analytical tools such as predictive modeling algorithms, clustering techniques, and dimensionality reduction methods, which are capable of processing large datasets and uncovering complex patterns within the air quality data. The scope of the present study is to apply a combination of novel machine learning based techniques on IAQ data for identifying the main sources contributing to indoor PM levels inside residential environments and thereby inform strategies for improving IAQ and promoting healthier living spaces.
Targeted indoor PM measurements have been performed in 65 residences in Messinia, Greece during summer 2022 and winter 2022-23. A multi-sensor device (AIRTHINXiaq, UHOO) was placed inside each house, for continuous monitoring of PM, CO2, temperature and humidity. Outdoor monitoring was also performed in several sites in the area. A checklist and questionnaire for recording building characteristics, potential sources and occupants'activity was filled in for each house. QA/QC of the monitoring procedure included sensors'calibration and validation in the laboratory prior to the field measurements. Sensors'data were collected, stored and visualized through an online dashboard.
Prediction of air pollution in real indoor environments is a vital tool for providing data-driven insights for better environmental management while comprising an indispensable part of smart buildings design. By applying different Machine Learning algorithms (e.g. K-Means, Hierarchical Clustering, random forest, gradient boosting) on PM and associated features, similar patterns of indoor air pollution will be grouped. The clusters will be used to identify potential sources of indoor PM, based on explanatory variables (PM concentration, activity logs, building characteristics). It is anticipated that a new insight for on-line source apportionment will be given.
The present study was conducted in the frame of the national project ISEO: "Smart, specialized environmental observatory in Messinia, Greece".

SESSION 3b - Mitigation Measures and Strategies: Exploring environmentally sustainable solutions such as indoor ventilation and beyond, Oral Presentations / 23

Is the usual social distance sufficient to avoid airborne infection of expiratory droplets in indoor environments?

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As airborne transmission of expiratory droplets is one of the important pathways for viral respiratory diseases including the recent pandemic COVID-19 to infect healthy people, it is extremely important to explore and understand the detailed mechanisms of virus spread through airborne expiratory droplets. To reduce the risk of exposure to viral respiratory diseases, the World Health Organization recommends main measures, namely hand hygiene, social distancing, and wearing masks. Among

the recommended measures, there is a hot debate about social distancing related to the exposure risk, especially in indoor environments. Through expiratory activities, airborne virus-laden droplets may spread over long distances, such as tens of meters in indoor environments, and remain in the air for a long time, making it an important route of exposure. Unfortunately, the scientific evidence on many public health policies regarding social distancing is still fragmentary. The public has only a rudimentary understanding of airborne transmission of viral respiratory diseases and proper social distancing. To address the concern of "whether the usual social distance is sufficient to avoid airborne infection of expiratory droplets in indoor environments", this project uses systematic, multidisciplinary experimental, theoretical and modelling approaches. The spatiotemporal variations of size distributions, velocity vector fields and airborne dynamics of expiratory droplets generated from people infected with Influenza A or B, and the quantities of influenza virus at different distances from the test subjects are firstly measured using a suite of the state-of-the-art instruments and methods. Bacteriophage phi 6 is then used as a surrogate of coronavirus and other human pathogenic enveloped viruses to investigate the survivability and number of viruses in size-resolved droplets at different time and locations from the release point under different environmental conditions (e.g. temperature and relative humidity) with the aid of cultivation method and RT-qPCR technique. The outcomes of the project are the knowledge necessary to determine proper social distancing in various indoor environments, which will contribute to the control of respiratory infectious diseases.

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Evaluation of urban particulate matter atmospheric pollution influence on school classrooms' indoor air quality in Uruguay

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Introduction:

Indoor air quality has public health implications because people spend approximately 90% of their time in these environments. This project aims to gather an interdisciplinary team focused on indoor air quality, involving health, microbiology, architecture, and environmental, mechanical, and electrical engineering researchers. In this case, the indoor environments being analyzed are primary school classrooms. To date, there have been no similar analyses at the national level in Uruguay.

Aim:

From the environmental engineering perspective, the following research question is proposed: Does urban pollution from particulate matter (PM10 and PM2,5) affect indoor air quality in classrooms? Notably, in Montevideo (the capital of Uruguay), these pollutants' daily air quality objectives were exceeded on some occasions during 2023.

Methodology:

During 2023 and 2024, air quality was monitored both outside and inside classrooms simultaneously at two naturally ventilated school buildings in Montevideo (two classrooms per school were considered, one on the ground floor and one on an upper floor). Precisely, PM1, PM2,5, and PM10 concentrations were measured outside the schools (using an Aeroqual AQM10 device), and NO2, PM10, PM2,5, and CO2 concentrations were measured inside the classrooms (using Aeroqual S500 PM and NO2 devices, and a Senseair Sunrise 006-0-0008 device for CO2 concentration monitoring). In total, 22 weeks of data were collected for school building A and 10 weeks for building B. NO2 concentration measurement inside classrooms helps infer whether outside air is penetrating the indoor spaces, as there are no internal sources of this pollutant.
The equipment used outside the buildings was calibrated with simultaneous gravimetric measurements. The indoor and outdoor particle sensors were then operated together, resulting in different

correction curves for the indoor sensor based on the relative humidity (measured simultaneously). The NO2 concentration sensor was used with its factory calibration.
Based on the measurements, an exploratory analysis was carried out, including calculating daily cycles and Pearson, Spearman, and Kendall correlation coefficients using hourly averages of the analyzed variables.

Results:

The daily cycles reveal that NO2 concentrations greater than 0 μg/m³ were measured, indicating the penetration of outdoor air into the classrooms. On the other hand, indoor particle concentrations were usually higher than outdoor concentrations.
Therefore, it is suggested that indoor particle concentrations result from the influence of outdoor air entering the classrooms and indoor particle emission processes, such as the resuspension of particles deposited on the floor. The correlation analysis tends to confirm these statements. For example, positive correlation coefficients were obtained between indoor particles and CO2 concentrations, indicating that classroom ventilation improves indoor air quality. Additionally, for the ground floor classrooms, positive correlation coefficients between indoor and outdoor particle concentrations were obtained, possibly indicating the outdoor air influence on indoor air quality.

Conclusions:

This study is novel for Uruguay, presenting the first interdisciplinary analysis of indoor air quality conducted in the country. From an environmental engineering perspective, intensive monitoring of air quality parameters was carried out, providing information to begin understanding the processes that dominate the presence of particles inside school classrooms in Uruguay. This monitoring will continue in 2025, incorporating the analysis of official air quality records from the city monitoring network to evaluate their spatial coverage concerning the buildings under study.

SESSION 1b - Particles Emission: Understanding sources, estimation and measurements, Oral presentation / 27

Mitigating airborne pathogen transmission in indoor environments: Inactivation effects of environmental factors

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Objective: Urbanization and rising energy demand in buildings challenge public health by increasing airborne disease transmission risks in crowded indoor spaces. While improved ventilation has been recommended during the COVID-19 pandemic to lower infection risks, it also raises energy consumption, creating a trade-off between energy use and health protection. Current strategies like ventilation and portable air cleaners (PACs) are used to reduce indoor pathogens. However, factors like relative humidity (RH) and air composition have been studied in less detail, and they significantly affect pathogen inactivation by altering aerosol salinity and pH, to which pathogens are sensitive. Despite extensive biological research on the inactivation in droplets, their integration into indoor air studies remains limited. This study explores pathogen inactivation and removal through experiments examining how RH, air composition –particularly volatile ammonia, ventilation rates, and PACs impact pathogen survival. This abstract focuses on the inactivation effects of RH and air composition to develop sustainable infection control strategies.
Methods: In a biosafety level 1 chamber, experiments used *E. coli* as a surrogate for respiratory pathogens. Artificial saliva (AS) was aerosolized using a coughing machine to simulate respiratory emissions with 10 coughs per series. A factorial design was employed to study pathogen inactivation across three RH levels (30%, 50%, 70%) and distances (1m, 2m, 4m). Air temperature and air change rate were fixed at 23℃ and 1, respectively. Subsequent experiments will assess the effect of ammonia concentrations (3.65 ppb, 36.5 ppb, 365 ppb) on pathogen inactivation. Additional surrogates such as *Staphylococcus epidermidis*, Φ6, and MS2 will also be included. Pathogen removal experiments will vary ventilation rates, PAC placements (near the source, midway in the cough jet, and at certain distances), and source distances. Bioaerosol sampling occurred immediately after emission and after a decay period, using 6-stage Andersen impactors. GRIMM 11-D aerosol spectrometers and

MetOne HHPC+ optical particle counters continuously monitored size-resolved particle concentrations at the center of the cough jet, positioned at designated distances from the source. Particle concentrations at three locations, 1 m from the bioaerosol sampling point and outside the cough jet, were measured using Graywolf PC-3500 optical particle counters. Environmental parameters such as chamber relative humidity, CO_2, and ammonia levels were continuously recorded by an Onset HOBO Max CO_2 logger and a Picarro NH_3 analyzer, at locations unaffected by the cough jet.
Results: Over 90% of particles were below 2 µm, with only AS being expelled. When *E. coli* was present, 85% of the particles remained in that same size range. Adding *E. coli* reduced particle concentrations compared to pure AS due to viscosity changes. Coughing caused particle concentrations in the jet to spike, but they quickly decreased, indicating significant immediate exposure to pathogen-laden particles during coughing. In pathogen inactivation experiments, RH could affect pathogen survival by altering aerosol particle salinity and size. At low RH, particle evaporation accelerated, shifting size distribution toward smaller particles. Mid-range RH would promote supersaturation, enhancing pathogen inactivation, while salt efflorescence hinders further inactivation at low RH. As for volatile ammonia, high ammonia levels are expected to raise aerosol pH indoors, reducing acidity and potentially slowing inactivation. Unlike RH, ammonia does not directly affect particle sizes. As distance from the coughing machine increases, exposure to pathogen-laden aerosols decreases as the cough jet dissipates, becoming more susceptible to airflow disruption. This study emphasizes the distinct effects of RH and ammonia on the sensitivities of four pathogens. Optimizing RH and ammonia to establish aerosol pH and salinity that promotes pathogen die-off could yield energy-efficient inactivation strategies. Future experiments will further optimize ventilation rates and PAC usage to decrease airborne pathogens pathogens further.
Conclusion: Incorporating insights from indoor air science and biological studies offers a comprehensive approach to optimizing infection control strategies. This research addresses significant knowledge gaps by investigating the effects of RH, ammonia concentrations, ventilation rates, and PAC placements. The ongoing data analysis will yield findings that may inform energy-efficient strategies, thereby balancing health protection with sustainability. This research aims to promote sustainable indoor air quality management by providing practical, evidence-based recommendations supporting public health and energy conservation.

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Commensal respiratory bacteria stabilize influenza A virus in exhaled droplets and aerosol particles

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Introduction

Aerosol transmission is a major challenge for control of respiratory viruses, particularly those causing recurrent epidemics like influenza A virus (IAV). Besides physical virus removal, inactivation of infectious viruses within exhaled aerosol particles and droplets is a crucial process to limit viral spread. However, we have an incomplete understanding of virus survival within these complex environments. Among the many factors that influence respiratory virus stability, the role of commensal bacteria has received little attention to date. Commensal bacteria colonize the respiratory tract and can co-localize with viruses in exhaled aerosol particles and droplets, yet the impact of virus-bacteria interactions on the stability of exhaled viruses remains understudied. Here, we assessed whether the presence common commensal respiratory bacteria could influence the stability of IAV within droplets deposited on surfaces and within airborne aerosol particles.

Methods

Inactivation kinetics of IAV (strain A/Puerto Rico/8/34) we measured in deposited 1 µL droplets (phosphate-buffered saline solution or artificial saliva) in an environmental chamber at 40 and 75% RH, in the presence and absence of five different species of commensal respiratory bacteria. Commensal bacteria included both Gram-positive and Gram-negative species. Additional experiments in the presence of inactivated, structurally intact or inactivated, lysed bacteria were performed to investigate the mechanism of virus protection. The onset of efflorescence during droplet drying was determined by means of videography. Finally, the effect of commensal bacteria on IAV inactivation in small particles was determined in an aerosol chamber at 40% RH.

Results
Bacterial presence within droplets resulted in persistence of 10- to 100-fold more infectious IAV after 1 h of droplet drying, whereby Gram-positive bacteria offered more stabilization to IAV than Gram-negative bacteria. Among the bacteria tested herein, *Staphylococcus aureus* and *Streptococcus pneumoniae* were the most stabilizing compared to other commensals at equivalent density. Bacterial viability wasn't required for viral stabilization, though maintained bacterial morphology seemed essential. The stabilizing effect of bacteria could partly be explained by their effect on the droplet shape: in the presence of bacteria droplets flattened, which caused faster drying and earlier efflorescence. This, in turn, shortened the time during which the virus was exposed to supersaturated salt molalities, which are known to be inactivating. However, even when no efflorescence occurred at 75% RH, or the bacteria-induced changes in droplet morphology were abolished by aerosolization instead of deposition on a well plate, the bacteria remained protective, albeit to a lesser extent.

Conclusions
The respiratory microbiota stabilizes IAV in exhaled aerosol particles and droplets and therefore may be a previously unconsidered contributing factor toward efficacy of respiratory virus transmission. Given that different bacteria stabilize IAV to different degrees, the composition of a person's respiratory microbiota likely influences the efficacy of expelled viral spread and may help explain differences in virus transmission among individuals. Our findings are also relevant to enteric aerosol particles and droplets, such as those generated from wastewater or toilet facilities, where bacterial loads are significant. Finally, this work highlights the need to examine the stability of expelled pathogens in microbially complex matrices to better understand the variability of pathogen transmission in human populations.

SESSION 5a - Way Forward, Keynote Speakers / 29

Indoor Airborne Pathogen Transmission and Mitigation, a Multidisciplinary Review, Remaining Gaps and Actionable Improvements

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Improving indoor air quality (IAQ) can result in a range of measurable health benefits, including reduction of infectious disease risks, and cognitive performance improvements. Using engineering controls to minimize the indoor transmission of airborne pathogens saves lives and improves health cost-effectively. Despite a strong evidence base, gaps remain in understanding disease transmission. To understand these gaps, the Johns Hopkins Center for Health Security (CHS) recently convened an interdisciplinary group of experts, including engineers, public health specialists, and policymakers.

We assessed pathogen transmission mechanisms across engineering and health sciences considering how pathogens are emitted from different parts of the respiratory tract and how many pathogens are emitted in this way; how pathogens are transmitted from one person to another in the air; how long pathogens may remain infectious in the air; the quantity of pathogens produced; and the relationship between exposure dose and the likelihood of infection. Addressing knowledge gaps and how they inform practices is important for future advances in IAQ engineering interventions to reduce disease transmission.

Our convening resulted in several key findings: (1) While increasing air changes per hour and improving filtration can reduce disease transmission, these interventions alone may be insufficient, particularly for close-proximity transmission; (2) Layered interventions combining multiple strategies show promise but require further study; (3) Current mathematical models of airborne disease transmission face limitations and could benefit from further integration of biological, physical, and epidemiological factors; (4) Far-UVC technology shows potential as a safe air disinfection method but requires additional research regarding ozone generation and other air quality impacts; (5) Personal air filtration devices demonstrate early promise in computational fluid dynamics studies.

This research highlights the critical need for breaking down disciplinary silos to advance our understanding of indoor airborne pathogen transmission. We identified specific knowledge gaps that require interdisciplinary collaboration, particularly in understanding the complex interactions between pathogen biology, physical transmission mechanisms, and building systems. Future research should focus on developing integrated approaches that combine expertise from multiple disciplines to create more effective, evidence-based interventions for improving indoor air quality and reducing disease transmission. This work provides a foundation for future collaborative research efforts and highlights the importance of considering both engineering and health perspectives in developing practical solutions for indoor air quality challenges.

We provide actionable insights for policymakers and building designers, offering a roadmap to implement cost-effective, evidence-based strategies that enhance indoor air quality, reduce disease transmission, and improve public health outcomes.

SESSION 3b - Mitigation Measures and Strategies: Exploring environmentally sustainable solutions such as indoor ventilation and beyond, Oral Presentations / 31

Crowd-Data Collection of Indoor CO_2-Levels using Portable CO2-Sensors and a Mobile App

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High CO_2 levels in indoor spaces not only have direct adverse affects on human wellbeing but are also, in most cases, a reliable indicator of the amount of rebreathed air and thus for the risk of spread of airborne diseases. Despite its importance, large-scale datasets on indoor CO_2 levels across diverse, publicly accessible spaces remain scarce.

Existing research on indoor CO_2 levels so far focuses mostly on a narrow range of environments such as hospitals, schools, or residential homes. While these studies provide valuable insights, they are frequently constrained by limited sample sizes, narrow geographic coverage, or short observation periods. This leaves a substantial knowledge gap regarding CO_2 levels in a broader range of public indoor spaces, such as restaurants, shops, museums, public transport, and other high-traffic areas, which the IndoorCO_2Map project attempts to close.

IndoorCO2Map.com is an open source and open data citizen data collection project that enables individuals to measure and share CO_2 concentration data using portable sensors. Participants can contribute data from all kinds of publicly accessible indoor locations, creating a comprehensive and diverse dataset of real-world indoor CO_2 levels. This crowd-sourced approach is designed to scale geographically and temporally, overcoming many resource constraints of traditional studies.

The project combines accessible technology, including low-cost CO_2 sensors, with an intuitive and privacy respecting mobile app where users can record and upload their measurements. Each data point is timestamped, and annotated with geodata about the location type using OpenStreetMap, facilitating detailed analysis of spatial and temporal trends in indoor air quality.

The project is currently still in beta testing and little effort has been taken to increase the user base. Nevertheless around 7000 measurements, ranging from the minimum 5 minutes to hour long recordings, have been already taken as of January 10th, making it the largest publicly available dataset. Currently around 30 to 50 measurements per day are taken in average, with around 80% of them being in Germany so far.
Preliminary results from the dataset will be discussed, highlighting patterns of CO_2 concentrations

across various public indoor spaces. For instance, Variation of CO_2 levels by venue type, time of day, week of day and season.

Key challenges will also be addressed, such as ensuring data quality and reliability in a crowd-sourced dataset, addressing privacy concerns, and fostering sustained engagement from contributors. Biases resulting from differences between the general population and app users will also be discussed.

Furthermore, it will be discussed how this data can complement other studies, inform public health initiatives, urban planning, and provide guidance for policy-making. For example, insights from IndoorCO$_2$Map.com could guide ventilation standards, identify high-risk locations and provide guidance for individual decision-making of visitors/customers. It can also be used for hypothesis generation for scientific studies.

By leveraging citizen data collection, IndoorCO2Map.com already demonstrates a scalable, community-driven approach to tackling data gaps in regards to indoor air quality. The project not only fills an important data gap, but also raises public awareness about the significance of ventilation in maintaining safe and healthy indoor environments. Because the data and code is open source, it can also be adapted by others for specific research questions, be expanded in the future to other indoor pollutants or, if necessary, a stricter approach to user verification can be implemented.

SESSION 3b - Mitigation Measures and Strategies: Exploring environmentally sustainable solutions such as indoor ventilation and beyond, Oral Presentations / 32

Carbon Dioxide Measurements at Multiple Points in an Elementary School Classroom And Risk Estimation of Airborne Transmission: A Two-Month Field Campaign

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Introduction:
The concentration of carbon dioxide (CO2) is commonly used as a proxy for indoor air quality, particularly for assessing ventilation in indoor environments and estimating the risk of airborne transmission. Ventilation rates are commonly estimated using the mass balance equation under the assumption of a well-mixed environment. To estimate transmission risk, the Wells-Riley models are frequently employed as a balance between accuracy and computational efficiency. These models account for the estimated ventilation rate or utilize the rebreathing fraction of air, which is derived from CO2 concentration (Rudnick & Milton, 2003). However, in most cases, a single CO2 measurement point is used for both purposes.

Motivated by the COVID-19 pandemic, recent studies have explored the use of multiple measurement points in school classrooms, although these efforts have typically been limited to periods shorter than a week.

Aim:
The objective of this study is to evaluate, over a relatively long measurement campaign, the spatial variability of CO2 concentration within a naturally ventilated elementary school classroom and assess their impact on estimating the risk of airborne transmission.

Methodology:
The study was conducted in a naturally ventilated classroom in Montevideo, Uruguay, measuring

8 m × 6 m × 3.5 m (length × width × height). The classroom features four windows on one wall, a door, and an upper window on the opposite wall. It operates in two shifts: a morning session (8:00 a.m. –12:00 p.m. with a 30-minute break at 10:00 a.m.) and an afternoon session (1:00 p.m. –5:00 p.m. with a 30-minute break at 3:00 p.m.), hosting fifth-grade students aged 10–11 years (25 students in the morning, 30 in the afternoon).
Over two months, 13 monitoring devices were deployed in the classroom. Four devices were installed on each of the side walls at two different heights (1 m and 2.2 m), one on the front wall at a height of 2 m, one on the back wall at a height of 2.2 m, and three along the classroom axis at a height of 2.4 m. Each device recorded data every 30 seconds, measuring CO2 concentration using an NDIR sensor (Senseair Sunrise 006-0-0008), air temperature, and relative humidity (Sensirion SHT40-AD1B-R2).
The differences in CO2 concentration, based on daily averages for each occupancy period, were analyzed. Additionally, the daily risk of airborne transmission, estimated from the rebreathed fraction of air measured by each device, was evaluated for different quanta emission rates, ranging from 1 quanta/h to 100 quanta/h.

Results:
When comparing the daily averages of each device, there is greater variability in the morning shift than in the afternoon shift. In contrast, the minimum and maximum daily CO2 concentrations are similar for both shifts. The ratio between the maximum and minimum daily averages across the different devices ranges from 1.05 to 1.47. The minimum daily average is most frequently measured by one of the devices installed on the side wall with windows (100% and 89% of the days for the morning and afternoon shifts, respectively), as expected. Meanwhile, the maximum daily average is typically recorded by the devices installed at higher positions, particularly those along the classroom axis (60% of the days).
Regarding the risk of airborne transmission, the variation in estimated risk across devices for each day is greater than the variation in daily average CO2 concentration. The ratio of the minimum to maximum estimated risk can reach as high as 2.7. Interestingly, this difference in estimated risk is not observed on the day with the largest variation in daily average CO2 concentration across devices; instead, it occurs on the day with the lowest average CO2 concentration. This is consistent with the model equation, which shows that for the same ratio of mean CO2 concentrations measured by two sensors, the corresponding ratio of estimated risks is larger at lower CO2 concentrations.

Conclusions:
A two-month measurement campaign was conducted in an elementary school classroom, recording CO2 concentration, air temperature, and relative humidity at 13 points. The daily average CO2 concentration during occupied hours was analyzed, and its spatial and temporal distribution was evaluated. The estimated risk of airborne transmission and its variability across devices were assessed. The results show that daily CO2 averages can differ by up to 47%, while the estimated risk can vary by as much as 170%. The variation in risk across devices depends on the CO2 concentration, decreasing as the concentration increases. Consequently the influence of the measurement point on the estimated risk decreases with higher CO2 concentrations. Additionally, the observed variability is relatively low compared to the uncertainty associated with other factors, like quanta emission rate.

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Aerosol Sampling and Cytotoxicity Assessment on a Single Filter: „Cells on Particles“Platform

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Introduction/Objective:
Air pollution significantly harms human health, contributing to respiratory and cardiovascular diseases as well as overall declines in well-being. There is a growing need for more effective and comprehensive methods to assess the toxicity of air pollutants. Typically, the evaluation of particle toxicity has relied on in vitro methods, using cell cultures exposed to particles (such as air-liquid interface) or their extracts (submerged exposure). However, these approaches result in trade-offs in terms of particle transformations during sampling/delivery to cells. To address this gap, new methods for capturing particles and assessing their direct impact on living cells may be suggested. This study aimed to test and validate a novel "Cells-on-Particles" integrated aerosol sampling and in vitro cytotoxicity testing platform under both indoor and outdoor conditions.
Methods:
The "Cells-on-Particles" integrated platform serves the dual purpose of particulate sampling and cytotoxicity testing. The key element of the platform is a nanofibrous layer, consisting of fibres smaller than 1 μm in diameter. This creates a fibre network sufficiently dense to capture fine particles with high efficiency. Simultaneously, the nanofibrous matrix provides a cell-friendly surface for attachment while preventing cell penetration into deeper layers. Selecting the optimal dose of pollutants for the cytotoxicity study is paramount to achieving a meaningful cell response. In the case of the "Cells-on-Particles" platform, the dose is adjusted by controlling the amount of aerosol particles deposited on the platform, as cells are placed directly onto the platform without further extraction or dilution.
This platform was tested under two types of aerosols –exhaled tobacco smoke and urban outdoor aerosol. The platform was inserted as a 37 mm sampling filter aerosol to Personal Environment Monitors (SKC Inc, USA) with a cut-off size of 2.5 um. The generation and sampling of exhaled tobacco aerosol were performed in a small-scale chamber. A human subject used either a conventional cigarette (CC) or a heated tobacco product (HTP) and exhaled the aerosol through an inlet into the chamber. For outdoor conditions, fine particulate matter (PM2.5) samples were during winter period near a averagely loaded urban street.
The human bronchial epithelial cell line (BEAS-2B) was used for cytotoxicity assessments. Fibrous substrates exposed to aerosols were cut into 6.4 mm diameter discs. These discs were placed at the bottom of 96-well plates, with the particle-coated surface facing upward. BEAS-2B cells were seeded directly onto the fibrous matrix discs at a density of 6,000 cells per well in 100 μl of culture medium. Cell viability was assessed using the RealTime-Glo™ MT Cell Viability Assay. The cytotoxicity of the particles was evaluated by measuring the release of lactate dehydrogenase using the LDH-Glo™ Cytotoxicity Assay.
Results:
Exhaled HTP aerosol particles at doses of 49.2 and 73.5 μg/cm² did not reduce cell viability. After 48 hours of exposure, viability remained higher compared to untreated (control) BEAS-2B cells but slightly decreased compared to 24-hour exposure. Exhaled aerosol particles from CC and HTP had significant but opposing effects on cell viability-complete loss of cell viability with CC versus stimulation of proliferation and metabolic activity with HTP. The results showed that for HTP aerosols, particle surface densities in the range of 50-70 μg/cm² appeared suitable to obtain biological indicator values. For CC, the dose had to be adjusted to less than 30 μg/cm² to avoid complete cell death.
In the case of outdoor aerosol, the viability of BEAS-2B cells exposed to varying concentrations of PM2.5 demonstrates a clear dose-dependent cytotoxic effect. After exposure, cell viability decreased progressively with increased concentrations of PM2.5, with a decline observed even at 11 μg/cm² and a near complete loss of viability at 33 μg/cm². Concentrations of 93 μg/cm² and higher result in complete cell death, highlighting the severe impact of PM2.5 on cell health.
Conclusions:
The "Cells-on-Particles" platform enables the direct exposure of cells to particles, eliminating the need for extraction or resuspension processes. This approach not only provides a more rapid and sensitive toxicity screening but also allows for a more representative comparisons across various particle types and exposure conditions, including complex environmental aerosols.

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Exploring the protective effect of salt against pH-mediated inactivation of Influenza A virus

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Introduction

Respiratory viruses, including influenza virus and SARS-CoV-2, primarily transmit via the airborne route as aerosolised particles and droplets. The chemical composition of aerosol particles undergoes rapid changes as they enter and persist in the environment, which in turn can impart effects on the viruses contained within these particles. Depending on air composition, aerosols can acidify on exposure to indoor air , which can inactivate those enveloped viruses which are sensitive to acidic pH as a trigger for cellular entry.
We have previously developed and utilised a biophysical model to demonstrate the relationship between acidifying respiratory aerosols and Influenza A virus (IAV) inactivation, wherein particles become mildly acidic following exhalation and inactivate IAV within minutes. Aside from acidic pH, we have also identified high salt molality, primarily that of sodium chloride (NaCl), as a stressor of IAV in drying droplets. Having identified high NaCl molality and acidic pH as independent stressors upon IAV, we sought to explore and define the effect of simultaneous IAV exposure to both acidic pH and high NaCl molality, as such conditions reflect those encountered by IAV in aerosol particles in indoor air.

Methods

Using bulk-phase experiments, we exposed the typical Influenza A lab strain PR8 to a range of pH values within the mildly acidic range, coupled with a range of NaCl molality from zero to saturation (6.1 molal). We measured inactivation kinetics in the order of both minutes and hours, to define the decay rate of infectivity for each condition. We then investigated the mechanism of inactivation using immunofluorescence. Using antibodies specific to the pre- and post-fusion conformations of IAV haemagglutinin (HA), we assessed conformational changes elicited by the combination of pH and NaCl molality.

Results

Somewhat surprisingly, we found a protective effect of high NaCl molality when viruses were incubated at mildly acidic pH including that below the fusion (and thus inactivation) pH of IAV. The addition of NaCl to acidic buffers reduced the inactivation rate of viruses and drastically extended the time for which viruses remained infectious. Specifically, in the presence of 2.8 molal NaCl , the fusion pH shifted down by at least 0.3 pH units, and in fully saturated NaCl solutions a similar effect was seen when compared to solutions with physiological salt concentrations. The change in fusion pH may be explained by the ability of NaCl to stabilize HA in its pre-fusion confirmation, such that a lower pH is required to trigger the conformational change to the post-fusion state.

Conclusions

We have previously shown that acidic pH is inactivating towards IAV, as well as high salt molality at neutral pH. Until now, these conditions have only been studied in isolation. Here we demonstrate that salt is protective of IAV infectivity in acidic conditions, potentially due to a stabilising effect on HA. It is thus our belief that pH and salt should be considered jointly when assessing the inactivating kinetics of IAV in respiratory aerosols.

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Performance of ventilation mechanical filters for particles smaller than 300 nm MPPS

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In the workplace, air quality measurements have revealed a growing presence of ultrafine particles in ambient air. These are mainly due to the growing use of nanoparticles in industry and to dust emissions during manufacturing processes. These ultrafine particles have a very high specific surface area, and numerous studies have shown that some have, for the same mass, increased biological activity, leading to higher toxicity than particles of the same chemical composition, but larger in size. Emissions of these ultrafine particles require the implementation of appropriate exposure control strategies in the workplace. In most situations, contaminant reduction through the use of ventilation systems is the most practical solution. Filtration on fibrous media can achieve high efficiencies in the presence of ultrafine particles, making it the most widely used process in industrial environments. However, according to current standards (ANSI/ASHRAE 52.2 or ISO 16890), ventilation filters efficiency is tested for particles ranging from 0.3 to 10.0 micrometers. Performances of entire filters for nanoparticles are still very limited and particle size of 300 nanometer (0.3 micrometer) is commonly used as the most penetrating particle size (MPPS) for mechanical media.

The main purpose of this project was therefore to develop a measurement procedure to evaluate performance of filters used in ventilation systems for filtering particles smaller than 300 nanometers, including ultrafine particles. The originality of this work is based on obtaining reproducible size-dependent efficiency measurements for particles smaller than 300 nm. To this end, a test bench was designed and validated, and a measurement procedure developed to determine the performance of mechanical filters. The performance of five different mechanical filters (from MERV 8 to HEPA) was then evaluated in terms of penetration and pressure drop and for a large range of particle size.

Experimental data permit to evaluate the MPPS for these mechanical filters. The results have shown that the data are in good agreement with the MPPS theory. It has also been shown that the 150-500 nm range provides a better estimation of the MPPS under the conditions tested. In addition, filtration velocity influences efficiency for nanoparticles at 50 nm but no effect was observed for MPPS. In the context of workplaces, exposures to nanometric materials thus seems effectively reduced by the use of these mechanical filters. However, the question remains as to what is the acceptable performance value for filters that would protect workers in the case of nanoparticle exposure.

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Quantifying surrogate respiratory pathogen inactivation in respiratory droplets

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Objective:
Respiratory pathogens, including viruses, bacteria, and fungi, are transmitted through respiratory droplets and aerosol particles and exhibit significant variation in their airborne stability. Prominent examples such as influenza viruses, Mycobacterium tuberculosis, and SARS-CoV-2 highlight this diversity and their potential for widespread transmission and outbreaks. To better understand the viability range of airborne pathogens, this study investigates the inactivation rates of three surrogate organisms—Escherichia coli (representing gram-negative bacteria), Staphylococcus epidermidis (representing gram-positive bacteria), and MS2 coliphage (representing viruses)—chosen for their differing susceptibilities to pH and NaCl molality. These non-pathogenic surrogates are used instead of actual pathogens to enable downstream experimentation outside of biosafety confinements. Building on these inactivation kinetics, a secondary objective is to integrate the derived relationships into the Respiratory Aerosol Model (ResAM), a comprehensive shell-diffusion framework, to predict pathogen viability in respiratory droplets under different relative humidities. The model predictions

are then validated via controlled droplet experiments conducted in an environmental chamber.
Methods:
To obtain the inactivation rate constant as a function of pH and salt, solutions of 0.1M Citric Acid and 0.2M Trisodium Phosphate at varying volumes to obtain a specific pHs between 2-10. Additionally, each solution had a parallel containing 5m NaCl to investigate the synergistic effects of pH and salt. Samples were taken at different time points and residual infectious concentrations were enumerated. For each experiment, an inactivation rate was calculated assuming pseudo first order kinetics using least-squares regression in R. Then each rate constant was plotted versus pH and salt molality and a surface regression was performed to obtain k=f\left(pH,\ \left[NaCl\right]\right), also performed using R.
Droplet experiments were performed in an environmental chamber where temperature and relative humidity are kept constant. Relative humidity levels of 30%, 50%, and 70% were tested. Artificial saliva was used as the droplet media to simulate realistic respiratory conditions. At specified time intervals, samples of the drying droplet were resuspended and enumerated by both infectivity assay, as well as quantitative PCR. Additionally, droplets were filmed under different conditions in order to determine the change in the particle radius and to detect the onset of efflorescence. The numerical relationship derived in from the bulk experiments was then encoded in ResAM where the droplets from the bulk experiments were modeled.
Results :
Among the surrogates tested, E. coli is the most sensitive to pH and is stable around pH 4-9. It is more sensitive to alkaline pH levels compared to acidic ones making it comparable to influenza. S. epidermidis is also stable around pH 4-9 and is less sensitive to extreme pH levels comparable to rhinovirus. MS2 is significantly less sensitive to extreme pH and is stable from pH 3-10. This is comparable to coronaviruses like SARS-CoV-2 and HCoV-229E. With the additional of NaCl, a synergistic effect was observed for E. coli at acidic pH ranges where the inactivation was enhanced. This synergistic effect was not observed for S. epidermidis and MS2.
For both E. coli and S. epidermidis, inactivation in droplets is increased as the relative humidity decreased, due to high supersaturation of salt prior to efflorescence. This rapid change in salt molality in the droplet is associated with inactivation. For MS2, higher inactivation is seen in the middle relative humidity range. Efflorescence was observed at all three relative humidities for both E. coli and S. epidermidis due to the bacteria acting as nucleation points –while only observed at 30% for MS2. The observed inactivation was compared to the predicted one using ReSAM and exhibited a good correspondence.
Conclusion:
These results highlight the complex nature of pathogen inactivation in respiratory droplets, where factors such as pH, salt concentration, and relative humidity play pivotal roles. The differing sensitivities of E. coli and S. epidermidis to high salt concentrations, contrasted with MS2's relative resilience, underscore the importance of using multiple surrogate organisms to reflect the diversity of pathogen responses. By integrating these experimental inactivation rates into the Respiratory Aerosol Model (ResAM) and validating them through droplet experiments, this study provides a strong framework for predicting pathogen viability under real-world conditions. Ultimately, these insights can inform more effective strategies for infection prevention and risk assessment, contributing to better control of respiratory pathogen spread.

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Evaluation of the risk of airborne transmission in an elementary school classroom under intermittent ventilation through large eddy simulation

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Introduction:

The Wells-Riley (W-R) models are commonly used to estimate the risk of airborne transmission in indoor environments, balancing model fidelity and computational efficiency. These models rely, to varying degrees, on the well-mixed hypothesis. Based on this assumption, a mass balance equation for pathogen or quanta concentration can be formulated and solved, incorporating additional assumptions about ventilation and emission rates. The W-R models have been applied to both steady-state and transient conditions, including intermittent ventilation in naturally ventilated spaces such as school classrooms.

Computational fluid dynamics (CFD) simulations have been applied in numerous contexts, including the evaluation of airborne infection risks in various indoor spaces, under different uses and ventilation configurations. To model the presence of pathogens, two primary strategies have been employed: Eulerian and Lagrangian approaches. The literature indicates that, despite their potential to underestimate risks in certain scenarios, W-R models are a practical and efficient alternative for estimating the overall risk of airborne transmission. However, to the best of our knowledge, a direct comparison between W-R models and CFD simulations under intermittent ventilation conditions has not yet been performed.

Aim:
The objective of this study is to compare the risk of airborne transmission estimated using the W-R model with the risk calculated from CFD simulations under intermittent ventilation conditions.

Methodology:
A naturally ventilated classroom in an elementary school in Montevideo, Uruguay, was chosen as the case study. The classroom dimensions are 8 m × 6 m × 3.5 m (length, width, and height, respectively). It features four windows on one side wall, as well as a door and an upper window on the opposite wall. The classroom typically accommodates up to 30 students and one teacher.

The airflow pattern within the classroom was simulated using Large Eddy Simulation (LES), with the occupants represented using the immersed boundary condition method. Ventilation was modeled as occurring between windows on one wall and a door and window on the opposite wall. Two ventilation cycles—low and high rates—were considered, with fixed durations for each phase. The ventilation rate was imposed by prescribing air velocity at the open windows. Pathogen and carbon dioxide concentrations were modeled as passive tracers, and the scenario assumed the presence of three infected individuals in the classroom.

Results:
The velocity field as well as the passive tracers fields, including CO2, are evaluated. From those results, it is clear that the airflow pattern is governed by the interaction of the ventilation, for both ventilation rates levels, and the thermal plumes generated by the presence of the persons within the space. Inhomogeneities in the passive tracers fields are visualized and characterized, considering the different phases of the ventilation cycle.
Regarding the risk of airborne transmission, despite local under and overpredictions, the overall results of the W-R model are in an acceptable agreement with the ones from the CFD simulation, at least for the simulated scenario.

Conclusions:
Both W-R models and high-fidelity CFD simulations are valuable tools for estimating the risk of airborne transmission. While the latter is more time-consuming, it is particularly useful for analyzing complex or sensitive scenarios. Intermittent ventilation appears to be an effective strategy for reducing infection risk.

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Indoor air quality assessment through relationships between fungal and bacterial loads and physical parameters in primary school classrooms in Montevideo, Uruguay

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Exposure to bacteria and fungi in enclosed spaces for long periods of time has been associated with adverse health effects. Airborne fungi can cause lung disease and irritation of the mucous membrane and airborne bacteria are possible catalysts for conditions such as asthma, rhinitis and bronchitis. The issue of healthy educational buildings is a global concern because children are particularly at risk not only of lung damage and infection but also present a decreased cognitive performance and reduced productivity caused by poor indoor air quality (IAQ). In this study, the relationships between bacterial and fungal loads and physical parameters are sought in order to have a better understanding and offer alternatives that improve the IAQ in classrooms.

Four bacterial and fungal culture campaigns were conducted in 11 classrooms distributed in four schools in a humid subtropical climate zone like Montevideo, Uruguay during 2023-2024. Environmental parameters (outdoor temperature, relative humidity, season), ventilation and comfort parameters (indoor CO2, temperature and humidity, fungal and bacterial cultures) and other parameters (occupancy, open windows and doors, air-conditioning operation, buildings, among others) were taken during biological data collection periods. Microbiological sampling was carried out biannually (winter and spring), using air filtration by CAPTUS system (AravanLabs). The CFU (colony-forming unit) count for both fungi and bacteria was performed on samples taken from five classrooms across two different school shifts.

The Spearman correlation matrix, along with the Mann-Whitney and Kruskal-Wallis tests, were used to assess the correlation between bacterial and fungal loads and physical parameters.

There were significant correlations between bacterial loads and mean CO2 ($r = 0.30$, $p < 0.03$), and mean outside temperature ($r = -0.27$, $p < 0.05$) values. A significant difference was found between the bacterial count and a CO2 value of 800 ppm ($U = 196.0$, $p = 0.016$), reported by Morawska et al. 2024 as a threshold to maintain a low infection risk under standard classroom conditions. There is an increase in the average bacterial count of 56% in the winter season while only an increase of 9% is observed in the average fungal count compared to the values reported in spring. No significant differences were found between the biological counts and parameters such as building, season, and schedule (morning/afternoon) based on the Kruskal-Wallis test ($p>0.05$). Results highlight the importance of continuous monitoring of CO2, temperature, and relative humidity in schools as a simple yet effective mechanism that can be used to make various decisions that promote better IAQ in classrooms.

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Biophysical Respiratory Aerosol Model (ResAM): composition and pH of exhaled aerosol and application of airborne virus inactivation

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The exhaled aerosol plays a crucial role in the transmission of respiratory viruses. It has been found that the inactivation of viruses (influenza A virus and SARS-CoV-2) depends crucially on the pH value and on the salt concentration in the exhaled aerosol particles (Luo et al. 2023, Haddrell et al. 2024, Schaub et al. 2024). During exhalation, particles shrink by losing water and CO_2, interact with semi-volatile atmospheric trace gases such as HNO_3, NH_3, and organic acids, and eventually may undergo efflorescence, which changes both pH and salt concentration. Under dry conditions, the exhaled aerosol can become highly viscous, so that uptake and loss of gases from/to the ambient air via condensation and evaporation become diffusion-limited in the liquid phase.
The evolution of pH depends critically on the initial composition and size distribution of the exhaled aerosol as well as the ambient conditions (temperature, relative humidity and trace gas concentration). We have developed the biophysical Respiratory Aerosol Model ResAM to study pH and composition of the exhaled aerosol based on thermodynamic and kinetic measurements of synthetic lung fluid (SLF), and subsequently the inactivation of pathogens based on virological measurements in SLF bulk solutions (Klein et al. 2022, Luo et al. 2023, David et al. 2024, Schaub et al. 2024). Here we present a description of ReSAM and some application examples, with a focus on the pH evolution of exhaled aerosols during exhalation.
ResAM is a kinetic and thermodynamic model with spherical geometry with several shells. The main species of inorganic ions that acounted for in the model are H^+, NH4$^+$, Na^+, Mg^2+, Ca^2+, OH^-, $NO_3{}^-$, Cl^-, HSO4$^-$, $SO_4{}^{2-}$, $HCO_3{}^-$, $CO_3{}^{2-}$, $H_2PO_4{}^-$, $HPO_4{}^{2-}$.
ResAM takes the following physical and chemical processes into account:

1. Condensation/evaporation kinetics of H2O, CO2, HCl, NH3, and some organic acids such as acetic acid, lactic acid, oxalic acid.
2. Equilibrium dissociation of H2O, HCO3-, HSO4-, H3PO4, H3PO4-, and of the organic acids. Dissociation/association kinetics of CO2 from HCO3- with and without enzymatic acceleration.
3. Diffusion between shells in the liquid phase using the Ernst-Planck equation, which describes the Fickian diffusion of ions and allows to ensure charge neutrality.
4. Formation of various solids, e.g. NaCl, $CaCO_3$, MgCO3, NaHC2O4, (NH4)2C2O4
5. Activities and vapor pressures calculated using the Pitzer ion interaction model.

With this model we can analyze data collected in the laboratory on aerosols and µL-droplets. Finally, the model enables us to estimate the transmission risk under various environmental conditions using the inactivation rates of different pathogens measured in bulk solutions as a function of composition and pH can be used, towards developing a strategy to prevent airborne transmission of viruses and other pathogens.

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What role do acidic and alkaline pH levels in exhaled aerosol particles play in Influenza A Virus infectivity?

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Using thermodynamic and kinetic data for respiratory fluids as input to the biophysical respiratory aerosol model ResAM (Luo et al., 2023; 2025), we show that exhaled particles rapidly desorb H_2O and CO_2, becoming alkaline, and then absorb gaseous nitric acid (HNO_3) and other acidic substances from the ambient air, becoming acidic. The rate of these processes depends primarily on particle size. Large droplets (> 50 µm) remain alkaline for days due to the loss of bicarbonate, whereas submicron particles turn acidic in less than 1 minute at typical concentrations of gaseous acids and bases in indoor air (Nazaroff and Weschler, 2020), with alkaline ammonia playing only a secondary role. Subsequently, we use virus inactivation measurements in bulk solutions of synthetic lung fluid acidified to different pH values (from acidic pH2 to alkaline pH11) to calculate the inactivation times of Influenza A Virus (IAV) in exhaled particles of different sizes (Klein et al., 2022). The results compare well with IAV inactivation measurements in an aerosol chamber (Motos et al., 2024; 2025) at different relative humidities (RH) and HNO_3 concentrations, provided that certain assumptions are made about the diffusivities of molecules and ions in the liquid phase. By weighting the results with size distributions characteristic of aerosol in exhaled breath (Pöhlker et al., 2023), changes in relative transmission risk as a function of RH and pH can be estimated and applied to typical indoor conditions in single-family homes and public spaces, such as schools, libraries, and museums, where acidic gases could be partially removed by air filtration. In doing so, the distribution of viruses in particles of different sizes with a preference for small particles (< 5 µm) must be factored in (Milton et al., 2013; Yan et al., 2018). Our results suggest that achieving indoor concentrations of gaseous acids at levels found outdoors leads to rapid inactivation of IAV. Conversely, indoor concentrations, as we typically encounter them in winter, delay inactivation. This effect is enhanced by the seasonality in RH, which can slow or even inhibit the uptake of acidic gases under dry winter conditions. Therefore, indoor air acidity and humidity are important factors in understanding seasonal influenza. We discuss the implications of these results for risk assessment of airborne transmission and possible public health measures.

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A Blueprint for Far-UVC Use in Sustainable Air Disinfection

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Objective: Protecting indoor air from infectious aerosols is both a significant challenge and a remarkable opportunity for improving public health. Recent standards, such as ASHRAE 241, set equivalent clean air delivery rate targets to reduce airborne transmission risk. While increased ventilation and added filtration can meet these targets in some settings, many environments—such as classrooms, gyms, and restaurants—require impractically high ventilation rates to achieve sufficient infection risk mitigation. This creates substantial energy and infrastructure costs that may be unsustainable long-term. This gap highlights the need for additional strategies to supplement traditional air quality interventions. Far-UVC –an emerging type of germicidal UV light –could provide a more sustainable and practical approach when integrated with existing technologies.

Methods and Results: To develop an actionable roadmap for far-UVC disinfection, we conducted extensive literature reviews, semi-structured interviews with over 100 experts from academia, industry, government, healthcare, and the non-profit sector, and performed parametric modeling using the Wells-Riley infection risk framework. This multidisciplinary effort evaluated far-UVC's potential to inactivate pathogens in diverse settings, focusing on technical domains such as disinfection efficacy, photobiological safety, materials compatibility, and indoor air chemistry.

Our analysis found that far-UVC can be both safe and effective when properly implemented. Current evidence supports its safety below existing exposure guidelines, with studies showing minimal DNA damage in skin and eyes due to limited tissue penetration. When integrated with other air cleaning technologies, far-UVC offers several advantages: it can reduce the ventilation rates needed to achieve equivalent clean air delivery targets, operates with lower energy consumption than equivalent ventilation, and may be more practical to implement in spaces where traditional interventions face limitations.

Conclusions: The COVID-19 pandemic has created unprecedented momentum for improving indoor air quality, but sustaining these improvements requires solutions that are both effective and practical to maintain long-term. Our comprehensive assessment suggests that far-UVC, as part of an integrated approach with traditional interventions, could help address this challenge. However, realizing this potential requires coordinated action across multiple stakeholders to address remaining technical and implementation barriers. This work provides a roadmap for that coordinated action, with the goal of supporting sustainable improvements in indoor air quality that can protect against both routine and epidemic respiratory diseases.

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Airborne Microbial Burden in School Classrooms: A Multidisciplinary Study of Indoor Air Quality and Health Implications

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Introduction: Respiratory infections are a leading cause of morbidity in pediatric populations, with airborne transmission playing a significant role. The COVID-19 pandemic has underscored the impact of indoor air quality on human health, particularly in school environments, where children spend a substantial amount of time. Addressing this issue, an interdisciplinary group—the "Indoor Air Quality Group"—comprising microbiologists, pediatricians, architects, and engineers, was formed to investigate air quality in schools.
One of the group's primary objectives was to perform a microbiological analysis of airborne bacteria and fungi under varying environmental conditions. The study focused on five classrooms within a single school building in Montevideo, Uruguay, operating in two shifts. Sampling was conducted on a single day in November 2023 (spring). Microbial assessments included sedimentation on exposed petri plates and air filtration using the CAPTUS system (AravanLabs). Exposed plates containing Trypticase Soy Agar (TSA, for total bacteria), Sabouraud Agar, and Malt Extract Chloramphenicol Agar (SDA and MCA, for total fungi) were placed in two locations within each classroom. Air filtration lasted 10–20 minutes, with filters processed in PBS buffer and plated on TSA, SDA, and MCA. Plates were incubated at 37℃ for 2 days (TSA) and at 30℃ for 7 days (SDA and MCA). Microbial colony-forming units (CFUs) were quantified, and fungal colonies were identified at the genus level using macro- and micromorphological characteristics. Bacterial isolates from TSA were further identified through 16S rRNA sequencing. Environmental data, including CO_2 concentration, temperature, and humidity, were recorded using sensors and compared to microbial counts and classroom variables such as size and shift.
Results: The counts from the exposure plates in all samplings were similar for bacteria and fungi. The average bacterial counts in Trypticase soy agar were 2.5×10^3 CFU/m³ (range: 0–6259), and the average fungal count in Malta chloramphenicol medium was 1.1×10^3 CFU/m³ (range: 0–5995). The change of shift in the school did not affect the number of bacteria or fungi. A median CO_2 concentration of 1140 ppm (range: 530–2019 ppm), a temperature of 20℃ (15–24℃), and a humidity of 67.6% (51–86%) were recorded. A significant correlation ($p < 0.001$) was observed between elevated CO_2 levels and increased microbial CFUs, reflecting the impact of occupant activity on indoor air quality. Fungal genera identified included Penicillium, Alternaria, and Rhodotorula, with potential pathogens such as Aspergillus also detected. Bacteria isolated from filtered air were primarily from the genera Staphylococcus (e.g., S. hominis, S. epidermidis, S. capitis, S. saprophyticus) and Micrococcus. Opportunistic bacteria and pathogens, including Pseudomonas and Moraxella, were also identified.

Conclusions: These findings highlight a measurable correlation between increased CO_2 levels, indicative of poor ventilation, and higher microbial counts, underscoring the importance of air quality monitoring in schools. The interdisciplinary approach employed in this study enhances understanding of airborne microbial dynamics in educational settings. Future research should incorporate methods to detect non-culturable microorganisms and identify common airborne pathogens that children are exposed to during school hours. This knowledge is critical for developing evidence-based interventions to improve indoor air quality and safeguard children's health.

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Multidisciplinary Study of Air Quality in Schools: multiple approaches to a single problem

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Introduction:
In recent years, the scientific community has shown growing concern regarding the effects of indoor air quality on health. The COVID-19 pandemic has also highlighted the importance and necessity of addressing these issues through interdisciplinary approaches. In this context, we formed a team of engineers, architects, microbiologists, and physicians to study air quality in educational settings in Uruguay, where no similar analyses have been conducted at the national level.
Aim:
This initiative aims to develop diagnostic tools and generate knowledge about the relationship between air quality, ventilation, thermal comfort, and health in elementary schools in Uruguay.
Methodology:
The study, conducted from 2023 to 2024, involved two naturally ventilated school buildings with two shifts each, encompassing four elementary schools. Continuous monitoring of carbon dioxide (CO_2) concentration, air temperature, and relative humidity was performed in all classrooms over two years. Five classrooms in each building were selected for microbiological air sampling; two classrooms for particulate matter ($PM_{2.5}$ and PM_{10}) and nitrogen dioxide measurements; and three classrooms for thermal comfort assessments. Outdoor particulate pollution was also monitored.
Microbiological sampling was conducted biannually using air filtration and sedimentation plates, followed by colony-forming unit (CFU) counts at 48 hours for bacteria and 168 hours for fungi. Hygrothermal comfort was evaluated through surveys and thermal condition assessments. Additionally, interviews with families captured data on children's health. Computational fluid dynamics (CFD) simulations were used to model airflow patterns and pathogen dispersion indoors.
Results:
Each classroom housed an average of 23 children (range: 0–31) and 3 adults (range: 2–6). The average classroom conditions were 20℃ (18–22℃), 68% humidity (51–86%), and 1079 ppm CO_2 (530–2019 ppm), with only 13% of samples using air conditioning.
The children surveyed were between 5 and 12 years old. The average bacterial counts in Trypticase soy agar were 1324.3 CFU/m³ (range: 0–5040), and the average fungal count in Malta chloramphenicol medium was 98.0 CFU/m³ (range: 0–909). We found a positive correlation between CO2 levels

and bacterial counts.
Surveys indicated low comfort levels, likely due to poor ventilation, high temperatures, and odors. In spring of 2024, 50% of the families reported infectious symptoms the week before the microbiological monitoring (mainly respiratory symptoms) with a school absenteeism rate of 20%.
Regarding criteria for atmospheric pollutants monitoring, it is suggested that indoor particle concentrations result from the influence of outdoor air entering the classrooms and indoor particle emission processes, such as the resuspension of particles deposited on the floor.
Based on the CFD simulations, the airflow pattern is influenced by two main factors: the ventilation configuration and the thermal plumes generated by the presence of occupants. Certain inhomogeneities, represented as passive tracers, appear in the concentration field when simulating pathogen dispersion. Nevertheless, calculating the infection risk using the well-mixed hypothesis provides a conservative yet cost-effective initial approach compared to the infection risk estimated directly from the CFD simulations.
Conclusions:
This pioneering study offers critical insights into the interplay between indoor air quality, ventilation, and health in elementary schools in Uruguay. By combining environmental monitoring, microbiological assessments, and computational simulations, we have developed a robust framework for diagnosing and addressing air quality issues in educational settings. The observed correlations between CO_2 levels, microbial load, and health outcomes underline the importance of adequate ventilation to mitigate pathogen transmission and improve thermal comfort. Additionally, the integration of CFD simulations provides a valuable tool for designing ventilation strategies tailored to reduce infection risk. Notably, this work is pioneering in our country, as it addresses air quality through an interdisciplinary approach.

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Investigation of collection methods of At-211 used for targeted alpha therapy from the viewpoint of radiation management

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Astatine-211 (^{211}At), with a half-life of 7.216 hours, which is produced via the ^{209}Bi(α,2n)^{211}At reaction using accelerator is one of the promising radionuclides for targeted alpha therapy. At the accelerator facilities, measurements of airborne radioactivity are required using an ionizing chamber or radioactive aerosol monitor to manage the risk of radiation exposure to workers. Alpha-emitting radionuclides such as ^{211}At contribute more to internal exposure than beta and gamma-emitting radionuclides, and the legal-airborne radioactivity concentration limit in Japan is set about two orders of magnitude lower than that of beta-emitting radionuclides. However, rapid and accurate detection is impossible with conventional methods due to the natural background caused by beta and gamma-emitting radionuclides. Therefore, in order to avoid internal exposure of workers, it is necessary to quickly and accurately detect the ^{211}At concentration in the atmosphere even under the influence of beta and gamma-emitting radionuclides. In this study, we investigated the optimal collection and measurement method of astatine using a radioactive aerosol monitor.
For the selection of suitable filters for the radioactive aerosol monitor, the ^{211}At collection efficiency of commercially available filters was evaluated experimentally. Three types of filters were selected: membrane filter, glass-cellulose fiber filter, and activated charcoal filter. Membrane filters, which are thin-film filters with a thickness of about 0.1 mm, are recommended for use in radioactive aerosol monitors for long-lived alpha-emitting radionuclides due to their high surface collection efficiency. The use of the thin filter prevents distortion of the alpha energy spectrum obtained by the radioactive aerosol monitor and provides a high accuracy in nuclide identification. Glass-cellulose fiber filters

are about 0.4 mm thick and are commonly used as radioactive aerosol monitor filters in Japan. Activated charcoal filters are about 2.8 mm thick. It is usually used to collect radioactive iodine. Since astatine is also a halogen element, we also conducted a study using the activated charcoal filters.
Experiments were conducted using ^{211}At produced via the ^{209}Bi(α,2n)^{211}At reaction at the RIKEN AVF cyclotron. The ^{209}Bi target (> 99.999%, 20 mg/cm2), vacuum-evaporated on an Al plate, was irradiated with an alpha beam of 28.0 ± 0.2 MeV. After irradiation, ^{211}At is separated by dry distillation technique. The separated ^{211}At is dissolved in methanol, and the volatile components from the methanol are passed through a filter.
In order to evaluate the collection efficiency of the filter accurately, an experimental system was constructed using a plastic cylinder and a filter holder. The collection efficiency was evaluated using following equation.

\begin{equation}
ε={A_f}/({A_{bef}-A_{aft}-A_d})
\end{equation}

where A_f is the radioactivity of ^{211}At collected by filter. A_{bef} and A_{aft} are the ^{211}At radioactivity in a vessel before and after the experiments. A_d is the ^{211}At radioactivity which is deposited on the inner wall of cylinder.
First, ^{211}At was added in the vessel with methanol, and measured the radioactivity using Ge detector. Second, the vessel containing ^{211}At was set inside the plastic cylinder so as not to leak out the volatile components. The inner wall of the plastic cylinder was covered with a thin film to evaluate the astatine deposition on the wall. Using this system, a pump draws in air containing ^{211}At and a filter collects ^{211}At. This collection was carried out until the methanol evaporated. Third, after the collection, the ^{211}At radioactivity of the vessel, filter, and film was measured with a Ge detector. The experiments were conducted in a glove bag for safety. Moreover, two 20 mm thick activated charcoal cartridges were installed behind the filter holder to ensure that the ^{211}At in the exhaust air from the experimental apparatus was sufficiently reduced. A glove bag was supplied with clean air through a HEPA filter.
Details of the results will be reported.
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A machine learning practice of predicting CO2 levels with the measurement data from university departmental offices

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Introduction:
In office spaces, users spend around 1/3 of their daily time, thus maintaining good air quality is an important aspect of keeping a healthy and efficient working environment. As office occupants usually have a regular daily and weekly schedule, machine learning can be a useful method to find the air quality pattern. Its result can benefit the indoor activities to improve the indoor activities and even further development on the smart buildings when the building infrastructure is ready.
In a department area of Politecnico di Milano, multiple low-cost air quality sensors have been installed since September 2023 which measure parameters mainly including temperature, humidity, radon, CO2, VOCs, air pressure and light. In this research, the CO2 data measured in the selected offices are used in this analysis practice.
This research aims to explore how machine learning can benefit long-term monitoring in improving

air quality in the offices, taking CO2 as a practice, and how the existing monitoring system in the building can be improved to response to the changing indoor air quality (IAQ) level according to the model training process and the prediction performance.

Methodology:
This research tried to apply the regression learner from MATLAB to train the models based on the data collected from the selected offices respectively in the past 1 year (from 2023 Sep 05 to 2024 Sep 05). The training used the basic information as a predictor including the date of the year, time of day, room code, and day of week. Meanwhile, the level of CO2 is selected as the response in training. After the comparison of the results in RMSE (Root-mean-square Error) with different models, the training eventually selected the bagged tree model in terms of its performance and the total training time.
The trained model then was optimized by the Experiment Manager tools from MATLAB with 50 trials by tuning the 4 hyperparameters of the bagged tree model, including method, number of learning cycles, learn rate and min leaf size. The one with the best performance in RMSE was selected in the validation session.
The validation was the comparison between the measured data from Sep 06 to Oct 30 2024 and the prediction from the trained and optimized model. The performance of the validation and the model were interpreted in terms of their RMSE, residuals, and coefficient of determination (R2).

Result:
The model of rooms has RMSE results between 14.95 to 16.09 after the training and optimization varying from different rooms. Then, in comparisons between the original and model predicted CO2 values, the predicted CO2 levels basically follow the schedule of the rooms, with similar variation rates at the beginning and end of the working hours. This means that the model is able to catch the features of CO2 level variations in the selected offices based on the historical data.
However, the predictions show differences from the measurements with the dates as predictors in 2024, with RMSE from 100.52 to 107.74. These differences lay in the daily variations, especially the peaks of several days, which are much higher than the prediction results. These are due to several realistic reasons such as the number of occupants in 2024 being more than in 2023 and the schedule of occupants changing each week, etc. which are not included in monitoring and training.

Conclusion:
In general, the performance of this model currently is limited by the predictor parameters from the historical data monitored in the past 1 year, but it can already be useful in reflecting the CO2 variations in these offices. The training process also shows the 3 types of information that could be added to the monitoring system to help benefit and respond to the IAQ level changes more smoothly and accurately, including the daily number of people, the occupancy schedule, and the ventilations by window operations.
During this training, it can be found that, in the model training for CO2 level in these offices, the number of occupants and their ventilation behaviours are the 2 influential factors that are important but not measured in the existing monitoring system, especially the number of occupants which dynamic during the year and highly related to the CO2 increasing rate and the peak level. The number of occupants and the schedule can be added as one monitoring parameter in the future to make the prediction more accurate.
On the other hand, other factors such as the dimensions of the room are less influential and can be simulated based on the calculation with the CO2 historical records and the number of occupants.
In addition, this method can be used in spaces with more occupants, such as classrooms, open offices or shopping centres with large numbers of occupants by minimizing the influence of the changes on the average number of occupants on the CO2 prediction.

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Performance evaluation of two real-time fluorescent particle monitors in an office environment: measurements, comparisons and main evidence

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Introduction
Bioaerosols represent a relevant component of both indoor and outdoor environments with the potential to cause serious adverse effects on human health [1,2]. Therefore, bioaerosols monitoring becomes a key element in risk evaluation and assessment. To date, new real-time instruments based on the induced fluorescence have been developed, allowing continuous monitoring as opposed to the traditional sampling methods (such as plate count) [3]. However, these innovative approaches also present new challenges concerning data acquisition, elaboration and analysis.
Objective
In this research, the main objective was to evaluate the performance of two instruments for real-time bioaerosol monitoring, specifically a WIBS-5/NEO and a Rapid-E+, in terms of comparability concerning total and fluorescent particles (assumed as proxy for the bioaerosols), within an office context considering its background conditions.
Methods
A monitoring campaign was performed in a university basement office in Como, during 31 July –7 August 2024, through a WIBS-5/NEO, a Rapid-E+ and an Optical Particle Counter (OPC), assumed as the reference for the total particle count. Data were collected and compared across four different particle size fractions (0.3-0.5 µm, 0.5-1 µm, 1-5 µm, >5 µm). For each size fraction the following analyses were performed: 1) comparison of total particles concentration and temporal trend measured by WIBS and Rapid-E+ respect to the OPC; 2) comparison of fluorescent particle concentrations and temporal trends between WIBS and Rapid-E+; 3) evaluation of fluorescent particle concentrations based on different boundary conditions (activities performed, n° of people, office door open/closed).
Results
Concerning total particles, it was observed that Rapid-E+ recorded lower concentrations across all fractions, while WIBS measured more similar concentrations to OPC for the two intermediate fractions, much lower for particles in the 0.3-0.5 µm size range and slightly higher for those >5 µm. Despite these differences in the magnitude of particle count, comparable temporal trends were observed across all the size fractions, as further supported by linear regressions, most of them with a R2 higher than 0.8.
The same analyses were performed for fluorescent particles. Overall, it was observed that WIBS measured higher concentrations than Rapid-E+ for each size fraction, with the smallest differences observed for the coarsest particles (1-5 µm and >5 µm). For these two fractions, the instruments also exhibited a comparable temporal trend, with the R2 from linear regressions exceeding 0.7. Instead, the finer fractions, WIBS and Rapid-E+ measured different trends over time, as highlighted by the extremely low correlations (R2 lower than 0.1).
Finally, fluorescent particle concentrations were measured for each boundary conditions. Results indicated that "more dynamic activities"(e.g., movement within the office, lunch time and breaks) led to higher fluorescent particle concentrations compared to the more static desk work, except for the fine fractions for which no clear differences were observed. Similar outcomes were noted considering the number of people in the room. Especially, higher fluorescent particle concentrations were observed as the number of people increased when considering three different "cluster": no people, 1-6 people, 7-9 people. Lastly, with respect to open- or closed-door condition, higher concentrations were clearly observed for larger particles (1-5 µm and >5 µm) measured with both instruments and for particles in the 0.5-1 µm size range measured with the Rapid-E+, while for the other finer fractions a more variable and less clear situation is observable.
Conclusion
To conclude, this study highlighted the potential of the new real-time instrument in detecting the variability of fluorescent particles concentration (as surrogate of bioaerosols) but also pointed out some limits. According to the results, WIBS and Rapid-E+ allow to observe a real-time continuous temporal trend concerning the bioaerosols concentrations, offsetting the disadvantages of the traditional sampling methods, and therefore to analyse the variations during different conditions with a high time-resolution. This applies for all total particles and for fluorescent particles larger than 1 µm, but not for finer fluorescent particles. Moreover, a relevant aspect is the differences in terms of

magnitude of concentrations measured by the different instruments, with the Rapid-E+ showing a lower counting efficiency, both for total and fluorescent particles, may lead to an underestimation in the risk assessment. This highlights the need to improve these new measurement techniques or, at least, the data analysis, for example, through a correction factor.

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SESSION 1b - Particles Emission: Understanding sources, estimation and measurements, Oral presentation / 55

Indoor Air Quality of Offices: Beyond CO2 to Chemical Pollutants

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Objective
Poor indoor air quality (IAQ) can impact health, a concern emphasized during the COVID-19 pandemic. Belgium's Federal Public Services (FPS) of Health launched the Indoor Air Quality Platform to address this. This platform unites public agencies, academics, and industry representatives to enhance IAQ in public enclosed spaces (e.g., restaurants, hotels, cultural and sports venues) through knowledge-sharing, research, and policy support. Sciensano, Belgium's national public health institute, supports the FPS and the Platform by conducting IAQ studies in office environments and publicly accessible enclosed spaces.
Methods
Low-cost sensors measured the indoor and outdoor air quality in both office spaces and publicly accessible areas inside these office buildings across public entities. Monitoring the publicly accessible areas ensures a focus on environments with significant public interaction, while including office spaces added valuable data points thanks to their controlled conditions, extensive existing literature, and ease of comparison. Pollutants like carbon dioxide (CO2), carbon monoxide (CO), nitrogen dioxide (NO2), ozone, particulate matter (PM10, PM2.5), and total volatile organic compounds (TVOC) (more specifically formaldehyde), alongside temperature, relative humidity, and sound were monitored over periods ranging from two weeks to one month at various times throughout the year.
Results
These indoor air quality measurements conducted at various times throughout the year revealed a first view of differences in pollutant trends between buildings with and without HVAC systems and the influence of outdoor air on indoor levels.
Key findings included indoor CO2 levels often below 1000ppm, thanks to effective ventilation and low occupancy. Outdoor pollutant peaks, notably NO2, PM, and ozone, directly impacted indoor air quality, especially in HVAC-equipped spaces. At night, VOC and formaldehyde levels increased, probably due to the emission from building materials and furniture. Offices with HVAC systems often had reduced humidity (30%-40%) and, in the more recent buildings with large glass windows, summer temperature sometimes reached 30℃.
Conclusion
This monitoring campaign provided valuable insights into pollutant tendencies, HVAC system performance, and the interaction between outdoor and indoor air quality inside the office buildings across public entities. This research underscores the importance of well-maintained HVAC systems and highlights the role of sensors in detecting and identifying aberrant situations or events.
Future long-term measuring campaigns will soon expand to public enclosed spaces like sports and cultural centers and will allow us to create a mapping of the pollutants present in these different spaces and to develop an 'indoor barometer'. These efforts aim to improve IAQ in shared environments, benefiting public health and well-being.

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Bioaerosol Inactivation in Various Air Ionization Stages of an Air Cleaning Device

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Objective: To investigate the performance of bioaerosol inactivation/capture in non-thermal plasma (NTP), UV-C photolysis, bipolar ionization (BI), and electrostatic precipitation (ESP) stages of multi-stage air cleaner, across varying airflow rates of individual and combined stages.

Methods: The prototype air cleaning device operated sequentially through NTP, UV-C, BI, and ESP stages. Aerosolized bacterial cultures of Lactobacillus casei and Escherichia coli were introduced into the system before active stages, and samples were collected using impingers filled with physiological solution. Bacterial inactivation efficiency was determined by counting viable colonies post-incubation. Energy consumption and ozone emissions were monitored to evaluate the system's operational safety. Performance metrics were assessed at airflow rates ranging from 50 to 600 m^3/h.

Results: The multi-stage device achieved over 99% inactivation efficiency for both bacterial strains at the lowest airflow rate (50 m^3/h). Efficiency declined with increasing airflow rates but remained above 94% at the highest flow rate (600 m^3/h). Among individual stages, the NTP process demonstrated the highest standalone inactivation efficiency, followed by UV-C photolysis and BI. The integration of all stages significantly enhanced performance, achieving synergistic effects that improved overall disinfection efficacy. Despite the generation of ozone in the NTP and BI stages, the system's ozone destruction unit effectively reduced emissions to safe levels while operating at 99.6 % efficacy at 200 m3/h, meeting health standards.

Conclusion: The results demonstrate that the multi-stage air-cleaning system is highly effective in inactivating bioaerosols, providing a promising solution for improving indoor air quality in healthcare, residential, and commercial environments. Its ability to maintain ozone levels within safety limits, combined with its high disinfection efficiency, highlights its potential for widespread application. Further optimization of the system to enhance performance at higher airflow rates and minimize ozone emissions could increase its practical utility in real-world settings.

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Unobtrusive UFP sensors for indoor applications

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Indoor aerosols typically receive far less attention than outdoor aerosols, which are being permanently monitored in measurement networks. Air quality guidelines are also made for outdoor air quality, even though most people spend most of their time indoors, and although indoor air quality can be much worse than outdoor air quality in some circumstances. Therefore, even though a large part of the health burden through air pollution such as UFP comes from the time we spend indoors, we know little about those exposures.
One reason that we know so little about indoor UFP exposures is due to the complexity of making indoor air quality measurements. While there have been many studies with –often large numbers of - laboratory-grade instruments, such measurement campaigns are complex and expensive, and the measurements with a large number of big and noisy instruments is a nuisance for the building

occupants. We spend a lot of time asleep in the bedroom, where obviously complex and noisy instruments cannot be used, as they would disturb the sleep of the occupants.
At naneos, we have developed UFP sensors which are small, comparatively cheap and importantly for indoor measurements, nearly silent. We use pumps that operate at 21 kHz which are not audible for most humans, except for children. The high frequency sound can also be muffled easily with an enclosure, much more easily than lower frequencies. Our sensors are based on particle charging followed by electrical detection. Compared to more traditional nanoparticle detectors like condensation particle counters, there is no need for a working fluid such as Butanol, so there is also no need to remove any noxious vapors. Two specific sensors are of particular interest for indoor aerosol measurements:
1) The Partector 2 pro measures a rough particle size distribution (8 channels, 10-300nm) from which e.g. particle number or average particle diameter can be calculated. The knowledge of the temporal evolution of particle size distributions indoors can help to identify sources based on their typical size spectrum.
2) The OEM LDSA sensor (OLS) measures lung-deposited surface only, but has been designed to be more robust, need less service and be much cheaper than the Partector 2. With the OLS, UFP measurements become a lot less expensive and can thus be performed on a much larger scale than was previously possible.
Both instruments can be combined with internet connectivity, so that setting up an indoor aerosol measurement campaign is only a matter of minutes.
We will present data from multi-week measurement campaigns we have made with our sensors in 3 Swiss homes.

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Inactivation of overlooked respiratory viruses in human saliva droplets at variable relative humidity

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Objective: Respiratory infections from viral pathogens cause significant morbidity and mortality each year globally. Respiratory secretions, including virus-laden droplets, serve as a primary reservoir for viral particles in the environment; persistence of infectious viruses within these droplets can increase the risk of onward spread to susceptible hosts. Various factors, such as relative humidity (RH), play a critical role in influencing viral stability while these viruses are in the environmental phase of transmission. Most studies investigating environmental stability of respiratory viruses focus on influenza virus, human coronavirus, or surrogate viruses, like bacteriophages, even though there are many other respiratory viruses, including adenovirus and rhinovirus, that continuously circulate in human populations and generate a significant disease burden year over year. Understanding the differences in inactivation kinetics of a broad range of these viruses is critical to establishing effective mitigation strategies in settings with elevated transmission risk. The objective of this work is to comprehensively evaluate the reduction in infectivity of structurally distinct enveloped and nonenveloped human respiratory viruses, including influenza virus, adenovirus, coronavirus, and rhinovirus.

Methods: To achieve our objective, we are evaluating the degradation of prominent but distinct enveloped and nonenveloped human respiratory viruses (e.g., influenza A virus, human rhinovirus 16, human adenovirus 4, seasonal human coronavirus OC43) in droplets under a range of environmental conditions (i.e., 20%, 50%, 80% RH) representative of indoor settings. Many of the persistence studies conducted to date rely on the use of artificial respiratory fluids or laboratory-derived solutions for generating virus-laden droplets; here, we address this knowledge gap by determining virus decay in a physiologically relevant fluid, human saliva. We compare persistence in saliva to survival in milliQ to better understand the factors driving inactivation across different viral species.

Results: Our preliminary findings reveal that respiratory human adenovirus remains infectious in human saliva for over six hours at ambient indoor temperature and 20% RH with minimal decay (i.e.,

< 1-log10). Kinetics at 50% and 80% RH follow a similar trend. Interestingly, respiratory human adenovirus appears more resistant to environmental inactivation than a seasonal H1N1 influenza A virus, a structurally distinct respiratory virus, at midrange RH. These data highlight the unique persistence of distinct respiratory viruses, underscoring the need to comprehensively study a diverse array of different viral pathogens before drawing conclusions about effective mitigation strategies.

Conclusion: Our findings will provide an expanded dataset of the relative persistence of prominent human respiratory viruses to better understand settings conducive to environmental virus inactivation. This information is critical to informing engineering treatments targeted at specific pathogens to rapidly decrease infectious viral loads during intervals of elevated community spread.

SESSION 1b - Particles Emission: Understanding sources, estimation and measurements, Oral presentation / 60

Infectivity of exhaled SARS-CoV-2 aerosols is sufficient to transmit covid-19 within minutes

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Background
Exhaled SARS-CoV-2-containing aerosols contributed significantly to the rapid and vast spread of covid-19. However, quantitative experimental data on the infectivity of such aerosols is missing. Knowing the emission rates of infectious viruses from normal respiratory activities enables more accurate modelling of disease transmission in indoor environments.
Method
We collected the exhaled aerosols from breathing, talking and singing, respectively, from 38 individuals with covid-19 using a BioSpot (Aerosol Devices), and cultured the aerosol samples that contained detectable levels of SARS-CoV-2 RNA. In another setting we collected exhaled aerosols from one individual with covid-19 using a cascade impactor to determine the size distribution of SARS-CoV-2 RNA in aerosol. Then, we used the size distribution and the emission rates in an indoor air inhalation model to calculate the time needed to inhale one infectious dose.
Results
50% of the 38 individuals had detectable levels of SARS-CoV-2 RNA in the exhaled aerosol samples. From three individuals, six aerosol samples were culturable, of which five were successfully quantified using TCID50. The source strength of the three individuals was highest during singing, when they exhaled 4, 36, or 127 TCID50/s, respectively. Calculations with an indoor air transmission model showed that if an infected individual with this emission rate entered a room, a susceptible person would inhale an infectious dose within 6 to 37 min in a room with normal ventilation.
Conclusion
Our data show that exhaled aerosols from a single person can transmit covid-19 to others within minutes at normal indoor conditions.

SESSION 2b - Exposure and Dose: Assessing the human health implications, Oral Presentations / 61

ENVIRONMENTAL MONITORING OF RESPIRATORY VIRUSES (SARS-CoV-2, RESPIRATORY SYNCYTIAL VIRUS, AND INFLUENZA A) IN A HEALTHCARE SETTING

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Background/Objective
The growing concern about the rapid spread of respiratory diseases has reinforced the importance of environmental monitoring of infectious diseases as an indispensable tool for public health. In particular, monitoring respiratory viruses in air samples is essential for early detection, prevention, and control of epidemic outbreaks, providing a more comprehensive understanding of transmission dynamics. Environmental monitoring not only helps identify the presence of pathogens but also enables for the assessment of their concentration in high-risk areas, contributing to more informed decision-making for preventive measures.
In the context of healthcare facilities, which are frequented by vulnerable population and where the presence of viruses might be more prevalent, such monitoring becomes even more essential. The ability to detect respiratory viruses such as SARS-CoV-2, Influenza A, and Respiratory Syncytial Virus (RSV) in hospital environments is crucial for assessing the risk of airborne transmission and evaluating the effectiveness of infection control measures. By identifying virus hotspots, targeted interventions can be implemented to reduce transmission, thereby ensuring the safety of patients, healthcare workers, and visitors.

This study aims to analyse the presence of respiratory viruses, including SARS-CoV-2, Influenza A, and RSV, in air samples collected from different areas within a hospital. Additionally, the study seeks to characterize the viral load in identified peaks to gain a deeper understanding of the concentration of these viruses in hospital settings, which could be useful to assess their potential contribution to hospital-associated outbreaks.

Methods
Between December 17, 2021, and January 19, 2023, air samples were collected in sterile 47 mm quartz fibre filters using Derenda low-volume samplers (2.3 m^3/h) equipped with PM2.5 inlets in a hospital located in Castelló de la Plana, Valencian Community, Spain. Samples were collected in consecutive 24-hour sampling cycles during weekdays.
RNA was extracted from the filters, which had been previously spiked with Mengovirus (MgV) as an internal extraction control. Subsequently, RT-qPCR analysis was conducted, targeting the E fragment of the SARS-CoV-2 envelope protein (E); the matrix (M) gene of Influenza A; and the matrix (M) gene of RSV. Clinical data from the hospital's emergency department was inspected to identify peaks in emergency cases associated with infections caused by these viruses. The medians and interquartile ranges (IQR) of viral concentrations during the identified peaks were calculated and expressed as genomic copies per cubic meter (gc/m^3).

Results
The mean recovery rate for the internal control MgV was 27 % ± 24 %. The analysis revealed an increase in emergency cases associated with infections caused by the three studied viruses as follows. There was peak of SARS-CoV-2 from December 17, 2021, to April 30, 2022. Two peaks of Influenza A were identified. A first peak in March and April 2022, and a second peak in December 2022. The peak of RSV occurred in November 2022. During the months when an increase in emergency cases associated with these viruses was observed, the median (IQR) number of emergency cases recorded were 8 (17), 3 (5), and 2 (2) for SARS-CoV-2, Influenza A, and RSV, respectively. The median (IQR) viral concentrations during the months with increased emergency cases associated with these viruses were 3.2 (6.2), 0.81 (1.5), and 3.3 (3.9) gc/m^3 for SARS-CoV-2, Influenza A, and RSV, respectively.

Conclusion
An increase in the genetic load corresponding to SARS-CoV-2, Influenza A, and RSV viruses has been detected in aerosols collected during the months that recorded a rise in emergency cases associated with these viruses at the reference hospital in Castelló. Future studies should explore the potential of measuring viral traces in aerosols as a tool for environmental surveillance of viruses.

SESSION 4b - Mathematical Modeling and Risk Assessment, Oral Presentations / 62

Dynamics of Airborne Epidemics Are Strongly Determined by Heterogeneity in Ventilation: Insights from Hybrid Air-Dynamic Disease Models

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Background: While the areas of study of indoor air and infectious disease epidemiology both emphasize the use of modeling for understanding disease transmission systems, siloing of disciplines, different model assumptions, and different vocabulary have limited the emergence of transdisciplinary science around airborne infectious diseases. Here we show that integration of simple air and epidemic models provides useful and policy-relevant insights that can be used to protect population health.

Methods: The Wells-Riley (WR) model is a simple, widely used model for estimation of cross-sectional risk of transmission of infection from an infectious case. The Reed-Frost (RF) model is a disease transmission model used to simulate transmission over time as a discrete process in relatively small populations. Both models treat infection transmission as a binomial process, which allows hybridization whereby WR is used as the RF transmission coefficient (a "WRRF"model). We simulate disease dynamics for a disease similar to Wuhan-variant SARS-CoV-2 which dominated in the early months of the recent pandemic. Cases may either be a minority "aerosolizers", who are highly infective in poorly ventilated environments, or "non-aerosolizers", who are less infectious but equally infective in all environments, regardless of ventilation efficiency. We used a meta-population structure and modeled transmission both within and between three sub-populations with poor, intermediate, and good ventilation respectively. We performed both deterministic and stochastic model runs with the initial outbreak seeded with an "aerosolizer"in one of the three linked populations.

Results: Final total outbreak size was strongly influenced by which sub-population was seeded with the first case; final outbreak size was approximately 3-fold larger when initial seeding occurred in the poorly ventilated sub-population than when seeded in better-ventilated subpopulations due to large initial case numbers. For outbreaks seeded in the poorly ventilated population, improvement in ventilation in that population slowed epidemic emergence in the other two subpopulations more effectively than further improvements in ventilation in already well-ventilated environments. In stochastic model runs, the probability of stochastic extinction was inversely related to ventilation rate in the population in which the initial case was seeded.

Conclusions: Ventilation can easily be incorporated into epidemic models, and evaluation of heterogeneity in ventilation provides important insights into the dynamics of emerging infectious diseases. In particular, outbreak size, rapidity of spread between populations, and the likelihood of stochastic extinction in the population as a whole are driven by ventilation quality in the worst-ventilated environments. This supports the importance of universal ventilation standards as an important element of population health protection.

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MONITORING OF SARS-CoV-2 RNA IN ENVIRONMENTS FREQUENTED BY VULNERABLE GROUPS: ELDERLY CARE HOMES AND PRIMARY SCHOOLS

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Background/Objective
The transmission of SARS-CoV-2 through aerosols has been recognized as a critical pathway for infection, especially in indoor settings with limited ventilation, where people share spaces over extended periods. Despite its importance, during the COVID-19 pandemic period there was a notable scarcity of studies assessing the presence of SARS-CoV-2 genetic material in shared spaces frequented by vulnerable populations, such as elderly care homes and primary schools.

Elderly care homes are the residence of individuals with a heightened risk of severe COVID-19 outcomes due to age-related factors and underlying comorbidities. Primary schools involve young children who, although less likely to experience severe symptoms, may serve as vectors for virus transmission within their households and the broader community. Understanding the presence and concentration of SARS-CoV-2 in aerosols within these environments is crucial for the development of effective mitigation strategies.

This study aims to evaluate the presence and concentration of SARS-CoV-2 genetic material in aerosol samples collected in environments frequented by vulnerable groups, such as elderly care homes and primary schools within the Valencian Community, Spain.

Methods
Between March 2021 and July 2021, 175 aerosol samples were collected from 9 elderly care homes (n = 92) and 9 primary schools (n = 83) across the three provinces of the Valencian Community, Spain. No known cases of COVID-19 were present in the microenvironments at the time of sampling. Samples were collected in sterile 47 mm quartz fibre filters over 24-hour periods using Derenda low-volume samplers (2.3 m^3/h) equipped with PM2.5 inlets. The samplers were strategically positioned within each sampling microenvironment to ensure representativeness, with the air inlet located 1 m above the ground and away from potential sources of interference, such as doors, windows, and air conditioning or mechanical ventilation units.

Mengovirus (MgV) was used as an internal control for the efficiency of genetic material extraction. Genetic material was extracted and analysed using RT-qPCR targeting the N1 nucleocapsid and E envelope genes. When positive, the viral load was quantified in genomic copies (gc)/m^3.
Since concentrations are not normally distributed, medians and interquartile ranges (IQR) are reported. Differences in SARS-CoV-2 RNA detection rates between the two settings were evaluated using a Chi-square test. Associations between the type of environment and viral load were analysed with a Mann-Whitney U test.

Results
The mean recovery rate of the MgV internal control was 58 % ± 38 %. SARS-CoV-2 RNA was detected in 14 out of 175 samples (8%), with 11 positive samples in elderly care homes (12%) and 3 in primary schools (3.6%). Detection rates differed significantly between elderly care homes and primary schools ($p < 0.05$).

The viral RNA concentrations in elderly care homes were significantly higher than in primary schools ($p < 0.01$). Median concentrations in elderly care homes were 8.2 gc/m^3 (IQR: 7.6 –13.0, n=11), compared to 4.1 gc/m^3 (IQR: 4.0 –4.6, n=3) in primary schools. The maximum concentration observed in elderly care homes was 78 gc/m^3, while the maximum in primary schools was 5.1 gc/m^3.

Conclusion
This study confirms the presence of SARS-CoV-2 genetic material in the air of elderly care homes and primary schools, where no known cases of COVID-19 were present at the time of sampling. The findings reveal that the detection rate and concentrations of viral RNA in aerosols was significantly higher in elderly care homes compared to primary schools. These results highlight the critical need for targeted control measures in spaces frequented by vulnerable populations - such as enhanced ventilation and tailored prevention strategies- particularly in elderly care homes where viral loads were markedly elevated.

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Exposure to hardwood dust: chemical-physical characterization and study of particle distribution dynamics during a cutting simulation

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In the wood processing industry, exposure to dust is one of the major potential health threats for workers. During sawing, high concentrations of particles of different sizes are generated. They are potentially harmful for human health and exposed workers can report occupational diseases such as allergic rhinitis, chronic bronchitis, lung fibrosis, asthma, nasal and sinonasal cancers. The issue has been studied extensively in the past by several authors (1-4); such studies (and others) have led to definition of guidelines and regulations by the international occupational safety and health community.
In 1999 the European Union Directive 1999/38 has classified hardwood dusts as carcinogenic and has set the occupational exposure limit for hardwood dust to 5 mg/m3 of inhalable dust of workplace air. In 2004 the European standard EN 12779 set a recommendation of 0.2 mg/m3 as a weighted average concentration for residual dust, while the ACGIH, in 2007, fixed TLVs at 0,5 mg/m3 (inhalable fraction) for western red cedar and at 1 mg/m3 (inhalable fraction) for all other wood species by classifying oak and beech dust in carcinogenicity category A1 (confirmed human carcinogen) and birch, mahogany teak and walnut in category A2 (suspected human carcinogen) and all other wood dusts in category A4 (not classifiable as human carcinogen). Finally, European legislation recently set the limit value at 2 mg/m3 as referred to 8 h working (Directive (EU) 2017/2398).
Further studies have also highlighted the importance of the size of dust produced during sawing, which plays a key role in the occurrence of professional diseases that can penetrate into the alveolar region and enter the blood circulation system (5). In a study by Marta Pedzik et al. (6) ultrafine dusts of 6 different types of hardwoods (black alder, European ash, common walnut, pedunculate oak, hornbeam and European beech) were investigated. Moreover, the authors reported that European beech showed the smallest particle size, less than 2.5µm, and the difference between the particle size of European beech dust and the other dusts was found to be statistically significant in contrast to the amount of dust generated by the other woods. The study concludes by stating that all hardwood species studied should be equally considered a source of serious occupational risk to woodworkers.
UFPs contribute in a small fraction to the mass concentration of wood dust and are therefore largely overlooked when focusing on TLVs for occupational exposure assessment which are based on mass concentration. Gu et al. (7) states that the current mass-based occupational exposure limit for wood dust can not reveal the high exposure to UFP and particle diameters less than 10 µm.
In the present study, sawing products of commercial plywood poplar in a test-controlled chamber isolated from other emission sources, were investigated. Chemical-physical analysis of as- produced particles and the dynamics of the corresponding size distributions were characterized.
Real-time measurements (particle number concentration, particle size distribution and Lung Deposited Surface Area) and SEM investigations allowed us to characterize the simulated exposure scenario compared to the background
During sawing the highest PNC value related to particle size less than 2.5 µm is lower than 400 times if compared to maximum PNC value for particles in the size range from 5.6 to 560 nm that reached the maximum value of 1x10 E6 part/cm3 (higher 100 times than the background mean value). The Lung Deposited Surface Area for particles in the size range from 10 to 1000 nm has shown mean

value 2 times higher than mean background value.
In conclusion, the study showed that the TLV based on particle mass concentration underestimates the contribution to occupational risk assessment during woodworking activities because of high PNC values generated in the submicrometric size range.

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Evaluating ventilation effectiveness and exposure to airborne pathogens using computational fluid dynamics

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COVID-19 pandemic has reignited the discussion on required ventilation rates for indoor spaces. More specifically, the discussion has revolved around the required ventilation rate to efficiently mitigate airborne transmissions in different types of indoor environments with various type of activities. The topic has been studied extensively, and the research has resulted in guidelines and standards on pandemic safe ventilation solutions. For example, the WHO Roadmap to improve and ensure good indoor ventilation in the context of COVID-19 (2021), Lancet COVID-19 Commission Proposed Non-infectious Air Delivery Rates (NADR) for Reducing Exposure to Airborne Respiratory Infectious Diseases (2022), REHVA Health-based target ventilation rates and design method for reducing exposure to airborne respiratory infectious diseases (2022), and ASHRAE standard 241 (2023), have proposed ventilation rates for different types of indoor spaces. In addition to ventilation rates, many of these standards and guidelines also consider accounting for air cleaning and disinfection strategies such as air filtration or exploiting UVC air cleaning solutions. However, most of them focus on the ventilation rates and few account for air distribution in the space, namely, how efficiently clean air is provided into the breathing zone and how efficiently the contaminants are removed from the space. Dispersion of infectious aerosols in an indoor space can be analysed using either experimental or modelling approach. Modelling offers a relatively straight-forward approach for experimenting with different air distribution strategies and ventilation rates. Therefore, this paper aims to provide new insights beyond well-mixed assumption evaluating various ventilation rates and air distribution strategies for mitigating airborne transmissions using computational fluid dynamics (CFD) assessing both ventilation effectiveness and infection probability.

Modelling ventilation air distribution and resulting dispersion of airborne pathogens in the space necessitates venturing beyond well-mixed assumption and resolving the physical phenomena with adequate spatial and temporal resolution. Therefore, to tackle this challenge, this paper presents a simulation approach exploiting computational fluid dynamics, detached eddy simulations (DES) turbulence modelling, Lagrangian particles to evaluate dispersion of and exposure to airborne pathogens.

The concentrations of airborne infectious aerosol are analysed both in the space in general and in the vicinity of the occupants'breathing zone, and respective infection probability as well as and ventilation effectiveness are evaluated under different ventilation rates and air distribution strategies to identify the most efficient solutions to mitigate airborne transmission in indoor spaces.

The results show that both ventilation rate and air distribution have significant impact on reducing the exposure to infectious aerosols and consequently the infection probability of the occupants. Hence, to mitigate airborne transmission in an indoor environment, ventilation rate and ventilation effectiveness should be simultaneously considered. Therefore, future ventilation guidelines and standards addressing the mitigation of airborne transmission should account for ventilation effectiveness in addition to ventilation airflow rate itself. However, having reliable data to support standards and guidelines necessitates additional efforts using both computational and experimental approaches to establish typical ranges for ventilation effectiveness in relation to various types of indoor spaces under different ventilation configurations.

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Advancing Worker Safety: Innovative Source Control Strategies and Spatial Performance Assessment for Bioaerosol Control in Healthcare Isolation Rooms

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In the workplace, aerosols exposures are numerous and reported in various sectors. Bioaerosols are aerosols containing microorganisms. Healthcare workers are exposed to aerosols of different types and sizes during many occupational activities. Between 2008 and 2023, 100 workers were compensated for occupational acquired tuberculosis in the province of Québec. During the first year of COVID-19 pandemic more than 14 000 cases were established as occupationally acquired infections including twenty deaths of healthcare workers in the province of Québec. The pandemic has also highlighted the challenge over the dispersion and the purification of aerosols in enclosed spaces. Since bioaerosols can be dispersed over several meters, documentation and understanding of their dispersion becomes critical to protect the workers. Drawing up a global picture of exposure to bioaerosols by focusing on the main exposures in the near field, but also by characterizing the far field to prevent secondary exposures is crucial to protect all potentially exposed workers. The use of direct reading instruments (DRI) measuring numbers of particles can provide relevant information of aerosols contaminants. At the IRSST, a method has been developed and refined since 2017 to realistically evaluate the spatio-temporal dispersion of bioaerosols and their purification kinetics in workplaces. Assays with this method have shown that aerosols can spread over distances ranging from two meters to several tens of meters. At the beginning, only one DRI was use. However, sampling at a single point could not provide information on local deviations and sequential sampling does not allow simultaneous documentation of several points and is highly time consuming. Based on these findings, we start working on the development of a Spatio-Temporal Assessment Technique for Aerosol Dispersion based on a network of sensors and a data acquisition tool. This innovative method has awakened the interest of the medical community.
Isolation rooms use in hospital are in negative pressure to guarantee that when the door is opened, dangerous particles from inside the room will not flow outside into non-contaminated areas. However, their designs fail to consider the occupational risk of the workers going inside those rooms for treatment and interventions. To provide protection to the respiratory therapist during inducted expectoration (tuberculosis patients) a prototype room with source extraction was conceived in a hospital in Montréal. This room measure 6.0 by 3.3 and has a ceiling of 2.65 meter. The extraction duct is in the center back of the room and measure 1.125 by 0.515 meters. This extraction system has been designed to improve the source extraction of infectious particles. To evaluate the performances of this prototype room the network sensors including six OPS (TSI, USA) was deployed. This strategy alloys the documentation of both the dispersion of 1 um latex particles, serving as proxy of

bacterial particles, and the measurement of the spatial decay rates provided by the extraction ventilation system.
To study the performance of the prototype room, a spatial interpolation was carried out. Spatial interpolation allows to use points with known concentrations to estimate unknown points concentrations. This mesh treatment of the room makes it possible to visualize the dispersion of 1 um latex particles and the variation of the concentrations overtime. Assay where performed with and without the ventilation system in function to visualize the differences of performances. The pic concentrations with the system in function varies from 0.05 #/cm3 to 0.17 #/cm3 close to the source compared to 1.5 #/cm3 in the back of the room to 3.0 #/cm3 closer to the door when the system is turn off. The equivalent air change per hour (EACH) measured with the system in function were between 14,8 and 18,1 and between as low as 0.33 and 2.6 #/cm3 when only the basic ventilation of the room was in function. The calculated EACH value are higher than the twelve air changes per hour recommended by Canadian guidelines for hospital isolation rooms and the dispersion results demonstrate that the system performance is effective in reducing exposure to workers near the source inside the room. In addition to the prototype room, three rooms that meet the Canadian standard will be evaluated and their performance will be compared with the prototype. Isolation rooms are essential for controlling nosocomial infections, but they are not designed with occupational disease prevention in mind since capture at source is not required. This prototype room demonstrates that controlling nosocomial infections can also be done while considering worker protection.

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Airborne SARS-CoV-2 in healthcare settings –when, where and how to prevent it?

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Background
In order to improve infection control guidelines for healthcare workers, we investigated SARS-CoV-2 in aerosols and risk factors for airborne transmission in healthcare settings during the covid-19 pandemic.

Methods
Briefly, a liquid cyclone was used for air sample collection close to patients at several wards, and an 8-stage NGI impactor (ranging from 0.1 to >8.1µm) was used for a longer measurement campaign in corridors of infectious disease wards. RT-qPCR was used for SARS-CoV-2 detection in collected air samples.

Results
During 2020 and 2021, we collected more than 1100 air samples from several hospital environments, including infection clinics, intensive care units, medical emergency, geriatrics, maternity ward, respiratory ward, anterooms and corridors. In patient rooms, across all collected samples, 10.6% were positive for SARS-CoV-2 by RT-qPCR. Shorter distance to the patient, higher patient viral load, and fewer days since symptom onset increased the risk of obtaining a positive air sample, while increased ventilation lowered the risk. So called aerosol-generating procedures (AGPs), which were of initial concern, were less significant. In corridors, the positivity rate was only 2.7%. The large number of samples from corridors is attributed to the size-fractionated collection method, where 8 size fractions were collected every week. Positive samples were found in particle sizes ranging from 0.1-8.1 µm, with the majority of positive samples in size fractions below 1.7 µm.

Conclusion
Airborne SARS-CoV-2 RNA was mainly found close to patients in healthcare settings. Patient characteristics, type of treatment and ventilation rates significantly influenced the risk of a positive air sample, indicating that infection control measures should be aimed at controlling these factors.

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Determinants of indoor ventilation rates in South African clothing and textile factory work spaces using low-cost CO2 sensors

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Objective: Higher ventilation rates of work spaces are generally associated with reduced presence of airborne pathogens and improved health outcomes. The spread of respiratory pathogens such as SARS-CoV-2 and tuberculosis, as well as building-related illness are associated with poor air quality in specific work spaces. The clothing and textile industry is a large employer and important contributor to the economy in South Africa. This study investigated the environmental and workplace factors associated with poor ventilation in work spaces in South African textile factories.

Methods: Workplace health risk inspections and assessment of indoor air quality were conducted in the production areas, canteens, offices and boardrooms of 20 clothing and textile factories from May to December 2024. All factories, employing an average of 136 workers per factory, were located in the Western Cape province. Parameters measured in all areas included room depth (m), width (m), ceiling height (m), area (m2), ceiling height/depth, occupation density (person/m2), and the number of windows and doors in each space. Low-cost cloud-connected Airwits CO2 plus sensors (Connected Inventions Oy) were placed for two continuous days in the four work spaces of each factory to measure carbon dioxide (ppm), temperature (◦C), and relative humidity (%). In total, 56 measurements were obtained from all work areas. The CO2 monitoring devices were allowed to calibrate for 15 minutes each morning (06h00) before continuous readings over the two days were recorded. Monitors were placed at 1.5 m above the floor level. Data obtained from the inspections and the CO2 recordings were used to calculate per-person ventilation rates (L/s per person), which were natural log-transformed prior to analysis since the data was not normally distributed. Data analysis, including simple and multiple linear regression modelling used STATA 17.0 statistical computer software (StataCorp, College Station, Texas, USA). The end of shift (16h00) CO2, temperature, and relative humidity data collected on day 1 of monitoring was included in the analysis.

Results: A total of 20 clothing and textile factories underwent inspections and CO2 monitoring. Almost all factories were naturally ventilated (n=19), while one had work areas with both natural and mechanical ventilation. While all factories had a common production area (n=20), fewer factories had a separate or demarcated canteen (n=17), office (n=14) or boardroom (n=5).

In general the lowest CO2 levels were measured in the canteen (median: 506ppm, IQR: 465 - 595) while the highest measured CO2 levels were in the boardroom (median: 1560 ppm, IQR: 648 - 1631). There were 2 (10%) production areas, 2 (11%) canteens, 4 (29%) offices, and 3 (60%) boardrooms that exceeded the recommended 700ppm CO2 concentration limit value. On the other hand, per person ventilation rates ranged between 0.234 L/s per person and 0.697 L/s/person and were classified as being very low (< 5 L/s/per person) in 95% of work areas evaluated (n=53). Overall, production areas had better ventilation (median: 0.697 L/s per person, IQR: 0.328 - 2.021) compared to canteens (median: 0.234 L/s per person, IQR: 0.133 - 0.413), despite the canteens having the lowest CO2 levels. The occupation density was also lowest in production areas (mean: 0.128, SD: 0.082 occupants/m²) and highest in canteens (0.406, SD 0.207 occupants/m²).

Simple linear regression analysis revealed that person ventilation rates were positively associated with number of windows and doors (β= 0.1323, p<0.001) and negatively associated with occupation

density (β=-1.1507, p=0.045). Working in the canteen relative to the production area was also negatively associated with person ventilation rates. In the final multivariate model, which adjusted for outdoor CO2, temperature and humidity, the major determinants of per person ventilation rates were working in the canteen (β=-0.6301, p=0.002), and the number of windows and doors (β=0.12961, p<0.001). This model explained 73% of the variability in the per person ventilation rates (AdjR2=0.73, p<0.001), but the occupation density in the factory was not statistically significant and therefore did not appear to be a major determinant.

Conclusion: This study has demonstrated that the poor design of work spaces such as canteens can significantly impact on indoor air quality in clothing and textile factories. Simple administrative measures such as increasing the number of windows and doors have the potential to significantly improve ventilation rates in different areas of the factory. The use of low cost CO2 sensors provide an important adjunct tool for assessing the adequacy of ventilation in these work spaces. It is anticipated that the study findings will contribute to the promotion of indoor air quality in clothing and textile factories and mitigate the risk of inhaling airborne pathogens.

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Radiation burden of healthy and asthmatic subjects due to inhaled radon progeny in indoor environment

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Introduction: Radon progeny inhalation is the main risk factor of lung cancer worldwide. Radon is a noble gas, what is mainly inhaled and exhaled without decaying but its progeny can deposit and spend hours in the airways. Due to their short half-life 218Po and 214Po isotopes are likely to emit alpha-particles after deposition. These alpha-particles can reach the radiation sensitive basal and secretory cells of the airway epithelium. In indoor environment the average radon concentration is around 50 Bq/m3, in contrast to the outdoor value, where the estimated annual average value is approximately10 Bq/m3. Since people spend more than 80% of their life in indoor environments (Trassierra et al., 2016), it is an important task to understand the health risks of this element for healthy and asthmatic subjects (around 300 million people are involved worldwide) as well.
Objective: To compare the bronchial deposition of the inhaled radon progeny and cell nucleus doses originating their alpha-decay for a healthy adult and an adult with asthma.
Methods: The airway deposition distribution of the inhaled attached and unattached radon progeny was calculated with the Stochastic Lung Model (Koblinger and Hoffmann 1990, Hofman and Koblinger 1990,1992). This model has uniquely fine, airway generation (the level of airway bifurcations starting from the trachea) specific resolution. In addition, this model is very flexible, so it is able to simulate the pathway and deposition of the inhaled particles in healthy adults or children's airways. With this model it is possible to simulate the altered airway geometry and breathing pattern for asthma and Chronic Obstructive Pulmonary Disease (COPD).
The location of alpha-decays during mucociliary clearance was calculated by a self-developed Monte Carlo clearance model. As the next step, the pathway of the emitted alpha particles and the absorbed energy in the nuclei of the basal and secretory cells of the airway epithelium was calculated with a radon dosimetry model.
Results: In asthma, the bronchial airways are contracted, and the mucus is thicker and slower than for healthy subjects. The inhaled air volume for the asthmatic person was higher, than for the healthy subject and the breathing frequency was also higher, what resulted in higher inhaled progeny number, than for the healthy subject. For the healthy person, the breathing was symmetric (the inhalation time was equal to exhalation time) but for the asthmatic subject, the exhalation was longer than the inhalation. These differences have a considerable effect on the airway deposition rate (deposited progeny number/min) of the inhaled radon progeny. For the asthmatic subject, much more radon progeny deposit in the bronchial airways than for the healthy adult. For the asthmatic subject, the airways are contracted resulting in shorter alpha pathways from the emitter 218Po and 214Po to the nuclei of the basal and secretory cells of the airway epithelium. Synergistically with the higher deposited progeny number, this usually results in higher absorbed cell nucleus doses for the asthmatic subject.
For asthma, the airway covering mucus is much thicker, than for the healthy subject resulting in

some shielding effect especially in the big bronchial airways, but this usually cannot fully compensate for the above mentioned dose-elevating factors (higher deposited number and shorter alpha pathways).
Conclusion: Present results indicate that health status of the subjects is important in radon dosimetry. Inhaling the air with the same radon concentration, in asthma, usually much more energy is absorbed in the nuclei of the radiation sensitive secretory cells of the airway epithelium.
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Indoor Particulate matter concentration in student dormitories: A case study in Ambo University, Ethiopia

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Indoor environmental quality (IEQ) can directly impact the comfort, productivity, and health of occupants. Given that individuals spend approximately 90% of their time indoors, the quality of the indoor environment directly impacts human well-being. For university students, dormitories are not just places of rest but serve as essential restorative environments that support their academic journey. The IEQ of these living spaces is particularly significant, as it affects students' physical health and well-being.
This study aims to evaluate the concentration of particulate matter (PM) in university dormitories, assess the vulnerability of students to fine particle exposure based on international guidelines, and raise awareness within the academic community about the importance of IEQ. This enhanced understanding is intended to foster the development of sustainable and pleasant indoor environments.
Research on IEQ in African university dormitories is limited, with most studies focusing on other regions. Specifically, there is a notable absence of research on PM concentrations in Ethiopian universities. This gap is especially apparent at Ambo University, where data on dormitory PM concentrations remain largely unexplored.
To address this, a field survey was conducted at the Hachalu Hundessa Campus of Ambo University, Ethiopia, to investigate particulate matter concentrations in the dormitories. A total of 52 dormitories (11 female and 41 male) were monitored, involving over 200 volunteer students, from which 184 valid data sets were collected (36 female and 148 male students). Measurements were taken during night-time over two phases between August 2024 and January 2025. An Aranet PM sensor was utilized to measure PM concentrations, with data remotely accessed through the Aranet cloud platform. The PM sensor transferred measurements to a base station, which then relayed the data to the cloud via an internet connection. Additionally, a questionnaire was administered to determine students' dormitory occupancy durations. The study focused on measuring PM1, PM2.5, and PM10 concentrations. To ensure reliability, the low-cost sensor was calibrated against a DustTrak reference instrument under various conditions, including background concentrations, incense burning,

and post-burning phases.
The results indicated mean PM concentrations of 17.8 μg/m³ (10.3–29.1 μg/m³) for PM1, 18.6 μg/m³ (10.3–29.55 μg/m³) for PM2.5, and 24.9 μg/m³ (16.6–34.8 μg/m³) for PM10, with the ranges representing the 5th and 95th percentiles. This study successfully monitored PM concentrations in Ethiopian dormitories, marking a rare and possibly first-of-its-kind effort in this context. According to WHO air quality guidelines, the 24-hour average exposure should not exceed 15 μg/m³ for PM2.5 and 45 μg/m³ for PM10 more than 3–4 days per year. The study's findings emphasize the need for eco-feedback mechanisms to improve air quality in student dormitories.
In conclusion, this study measured PM concentrations in university dormitories and analyzed the results, laying the groundwork for future research. Further investigations could include 24-hour PM monitoring and assessing the health impacts of particle exposure on occupants to enhance indoor air quality management.

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Holistic air purification for future space exploration missions. What can we already use now?

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In preparation of future exploration missions to Moon or Mars, Environmental Control Life Support Systems (ECLSS) are crucial for the survival of humans in space. In particular, the generation and preservation of a controlled atmosphere is of key importance and should not only rely on the regular supply of oxygen tanks or water electrolysis. A robust and reliable solution has been developed, tested and optimized for small habitable areas with maximum recycling of carbon dioxide and covering all aspects of controlled air quality: composition, fine particles, volatile organic matter, odors and even airborne viruses.

Currently, about 50% of oxygen is recovered from carbon dioxide on the International Space Station (ISS) with NASA's advanced oxygen generator. Oxygen tanks are uploaded regularly to the ISS to be mixed with capsule air and various air purification systems have been uploaded and tested to improve the air quality on the ISS with various success rates.

The GreenLung® is a photobioreactor based technology to purify air in confined areas. The initial development started with a focus on CO2 conversion to oxygen by microalgae and has been gradually refined in the past years. The efficiency was improved by adding preprocessing steps to accelerate gas transfer to the liquid phase, improved.

The photobioreactor and gas transfer systems were characterized by determining volumetric mass transfer coefficient (kLa). The dynamics of the microbial consortium include specific growth yield and the carrying capacity. The lighting system of the reactor is optimized to maximize the utilization of light energy by aligning the spectral out of the lamps and radial illumination from the center of the reactor.

Long term continuous operation tests were performed to validate the performance in real-life scenarios.

CO2 to O2 conversion
Volumetric mass transfer coefficient (kLa) for CO2 measured in the photobioreactor is equal to 75 1/h. The CO2 conversion efficiency is 500 g per day for a reactor volume of 100 liters. The average light intensity in the reactor is equals to 250 μmol PAR/m².s.

VOC reduction
The reduction of Volatile Organic Carbons (VOCs) was measured in a laboratory tests chamber. Acetaldehyde and toluene were used as model components because of their abundance in indoor spaces

and the components are representatives for VOCs groups with specific physical-chemical properties. The specific absorption rate for acetaldehyde is 0,25 1/h. This results in a removal capacity of 0,015 mg acetaldehyde per liter reactor volume per hour.

Airborn virusses
The removal of air-born viruses from the ambient air by capturing them in the liquid phase is evaluated in ongoing research. Quantitative analyses are performed using the MS2 phage as a model for virus particles allowing to establish mass balances and removal rates. First results indicate that MS2 phages are deactivated. The destruction of phages and virusses in the photobioreactor will be investigated in the next steps.

The prototype GreenLung® has been fully elaborated and tested in the frame of a space demonstrator, but its functionality is also suitable for many terrestrial applications. By making use of biological processes, the GreenLung® technology shows excellent performance on a wide range of potential criticalities of indoor air control.

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Online particulate matter monitoring to track and control air quality in public transport

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Objective: As an indoor environment, public transport is subject to special conditions with many passengers in a comparatively small space. Therefore, both an efficient control of the climatic parameters and a good air exchange are necessary to avoid transmission and spread of respiratory diseases. However, in such a dynamic system it is practically impossible to determine pathogenic substances with high temporal and spatial resolution, but easy-to-measure parameters like airborne particulate matter and carbon dioxide allow the air quality to be assessed in a passenger compartment online, which is useful for controlling the ventilation system.
Methods: Hand-held devices were used to measure temperature, relative humidity RH and carbon dioxide. An optical particle sizer was used to measure the particle concentration. The conversion to mass-related concentrations was based on the assumption of spherical particles and a density of 1 g/cm³. A portable monitoring system was also used for the recording of environmental parameters. The system consisted of a carbon dioxide sensor, an optical particle sensor and a temperature/humidity/pressure sensor. The measurement program focused on regional bus, tram and train traffic in Braunschweig and Hannover, or between the two cities. The occupancy of the passenger area was recorded for all route sections. In addition, measurements were carried out on the tram platform of the underground station at Hannover Central.
Results: In the case of the particles, the concentration peaks did not correspond to the occupancy density of the passengers, but often to their dynamics when the doors were regularly opened, combined with getting on and off. Some of the particles were brought in through the ambient air, some through clothing and the movement of passengers. As a result, the particle concentration in the cabin increased significantly at the bus stops. It was also noticeable that in various measurements the highest particle concentrations were recorded when several passengers boarded at the same time at the starting point. It is known that moving people are relevant particle sources or resuspend particles, but it is certain that the passengers' breathing is not the source of the particles. The maxima occurred only for a short time and reached the base level again within a few seconds. For each measurement run, ambient air measurements were carried out on PM_{10}, but only at the respective start and final stations. These concentrations were mostly in the range of 10 µg/m³. However, there were bus and train platforms with significantly higher ambient air concentrations of PM_{10}. For example, the values in the metro station at Hannover central station were consistently around 50 µg/m³. At other stations in Braunschweig and Hannover, smoking areas on the platforms, traffic or construction sites influenced the PM_{10} concentration in the passenger cabins when the doors were

open. Therefore, the PM_{10} peaks did not always coincide with entry and exit of many people. As expected, the carbon dioxide concentration in the transport cabin was directly linked to the density of passengers.
The parameters PM_1 and $PM_{2.5}$, which were also measured with the sensors, did not provide any additional information for the issue of efficient ventilation, which is relevant here. There were also some deviations from the OPC data, which is due to the different measurement technologies.
Conclusion: The investigations carried out and the results presented do not claim to assess the risk of persons for an infection by pathogenic bioaerosols in passenger cabins in public transport. It is also explicitly warned against using this methodology for such purposes. However, it was demonstrated that the online measurement of simple parameters like PM_{10} and carbon dioxide is a valuable tool for assessing air quality as a function of time, location, number and dynamics of people and for controlling the ventilation in public transport.

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Emission of airborne particles from 3D printing

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Exposure to airborne particles in indoor environments is a significant concern for human health, as the presence of indoor particle sources leads to considerably higher concentrations of particles. The principal sources of particles in indoor environments include cooking activities, burning incense, candles, and mosquito coils, as well as resuspension from movement or cleaning activities and secondary particles formed from chemical reactions in the air. Even in clean indoor environments (non-smoking spaces), unexpected sources of particles, such as printers and photocopiers, can be present; these devices have been found to be significant emitters of ultrafine particles. In recent years, interest in 3D printers has grown exponentially, especially with their increasing use in homes, rising concern among users regarding emissions from these devices. In this work, we aimed to address the lack of data concerning the emissions of airborne particles using Thermoplastic Elastomer (TPE) and Thermoplastic Polyurethane filaments (TPU) during 3D printing. To this end, an experimental campaign was carried out to measure particle number concentrations and size distributions while the 3D printer was in operation. Tests were conducted using a Fused Deposition Modelling (FDM) 3D printer in a plexiglass chamber of 4,7 m3. The 3D printer used in this study was a ZYYX Pro II, which had a chamber that could be either closed or open. Both the base and the chamber were preheated before printing, and measurements were conducted in both open and closed configurations. The printed object was a cube with dimensions of 10 mm in width, 10 mm in depth and 5 mm in height. The nozzle temperatures used were 220 ℃, 230 ℃ and 240℃ to evaluate the effects of temperature on particle emissions. Measurements were performed using a Condensation Particle Counter (CPC, TSI) for the sub-micron particle concentrations, a NanoScan (TSI) for the sub-micrometric particle distributions and a DustTrack (TSI) for the particle mass concentrations (PM10). The emission rates were evaluated based on the particle concentration trends, adopting a well-known mass balance approach. As expected, the emission rates of both TPE and TPU during printing with the chamber closed were lower than the emission rates during printing with the chamber open. Specifically, the emission rates were 1.02 × 109 and 1.04 × 1010 part./min for the chamber closed at 230 ℃, compared to 1.26 × 1011 and 1.55 × 1011 part./min for the chamber open at 230 ℃. Moreover, the emissions were higher at increased temperatures: for TPE the emission rate at 220 ℃ was 1.01× 1010 part./min, at 240 ℃ was 3.68 × 1011 part./min, for TPU the emission rate at 220 ℃ was 1.47× 1011 part./min, at 240 ℃ was 2.06 × 1011 part./min, both with the chamber open. The emission rates observed for TPE and TPU are consistent with the findings of previous studies on various filament materials, suggesting a comparable impact of these materials during the printing process. The particle size distribution reveals that TPE exhibits a mode at 87 nm, while TPU shows a mode at 65 nm, indicating a difference in the particle size generated by these two materials. Furthermore, there is a notable increase in the concentration of smaller particles, particularly in the diameter range of 20-27 nm, for both TPE and TPU. This trend highlights the importance of monitoring sub-micrometric particle emissions, as smaller particles can have different health and environmental implications compared to larger

ones. There was no effect of the printing on particle mass concentration for either material; the measurements were quite similar to the background measurements in the room. All the tests performed showed that printing TPE and TPU filaments emit sub-micron particles. The emission rates for the 3D printer's filament measured in the preset work are similar to those of filaments made from other materials. Moreover, these measured emission rates are comparable to the typical emission rates from significant indoor particle sources characterized by combustion phenomena, such as cooking activities and candle/incense burning. In fact, they are even higher than the typical emission rates from conventional office printers.

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Direct estimation of infection risk using aerosol measurements with numerical simulations

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Real-time infection risk monitoring is essential for public health, enabling early detection interventions to mitigate airborne disease spread in indoor spaces. Current infection risk models, such as the Wells-Riley model, rely on a well-mixed assumption and a constant aerosol exhalation rate, leading to inaccuracies in predicting spatial variations in airborne transmission. Similarly, existing CFD approaches assume a uniform pathogen emission rate from occupants and do not account for variability in aerosol generation due to vocal activity, the influence of ventilation and filtration on particle size distribution, or viral infectivity variations based on relative humidity. To address these limitations, this study presents a novel infection risk model that directly derives pathogen concentration from real-time aerosol sensor data and integrates CFD simulations to capture infection risk distribution as a function of particle radius. This approach provides a more accurate and flexible framework for assessing airborne transmission risk in indoor environments by modelling individual occupant exhalation dynamics and incorporating spatially varying pathogen concentrations.

The proposed model is applied to a stale air classroom environment with 22 occupants, where in situ aerosol concentration measurements are conducted. A validated CFD simulation, which realistically represents occupant breathing and is validated against measured exhaled aerosol concentrations, is utilized to extend the infection risk assessment beyond sensor locations. The CFD results incorporate aerosol with particle size distribution, enabling a more accurate representation of airborne transmission dynamics. This enables detailed spatial analysis of infection risk and maximum safe occupancy duration. By incorporating exhalation dynamics, this approach facilitates the identification of low-risk zones within the classroom and their corresponding safe exposure times, providing critical insights for optimizing indoor air quality and mitigating airborne transmission risks.

We investigated the effects of the infected occupant's position, particle radius, activity level, and age on the infection probability and occupancy time. The results reveal significant spatial variability of the infection risk, highlighting the limitations of well-mixed models in estimating the localised indoor infection risk. The study depicts that infection risk is influenced by viral load, infectivity, and activity level, with elderly individuals and adults at greater risk during high activity. At the same time, children retain a larger safety margin with a lower infection risk. Further, we demonstrate that infection probability alone is an inadequate safety metric, as it doesn't indicate when an occupant is likely to be infected. Instead, considering the maximum safe occupancy time is preferable, as it precisely determines how long an occupant can remain in the space without a significant risk of infection transmission.

This novel infection risk model represents a significant advancement in understanding and managing airborne transmission in indoor spaces. By integrating real-time aerosol sensor data with CFD simulations, it provides a more accurate and dynamic assessment of infection risk, accounting for individual exhalation dynamics, spatial variability, and the effects of ventilation and filtration. This approach offers a comprehensive framework that goes beyond current models, allowing for targeted

interventions and optimized indoor air quality management. The implications of this model could dramatically change how the community perceives and calculates infection risk parameters, fostering a more nuanced approach to public health interventions and building design. By providing insights into safe occupancy durations and low-risk zones, this model could reshape infection risk strategies, ultimately improving public health outcomes in various indoor environments.

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Measurements of Surrogate Respiratory Sessile Droplet pH and Implications for Exhaled Respiratory Aerosol and Airborne Disease Transmission

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The respiratory aerosol pH has been proposed as a major driver for the infectivity loss of SARS-CoV-2 viruses and influenza A virus in exhaled aerosols, thus affecting the airborne transmission of respiratory diseases. A pH of 9-11 within aerosol droplets was considered driving the loss of SARS-CoV-2 infectivity (Haddrell et al., 2023). Sodium bicarbonate acts as a principal buffer in biological systems, regulating blood pH and balancing the CO2 content in the gas and liquid phases. Upon exhalation, changes in gas phase conditions affect the aerosol composition and pH. Despite several studies utilising Raman spectroscopy to quantify atmospherically relevant aerosol pH, there is limited understanding of the kinetics of CO2 partitioning and pH variability within respiratory fluid-relevant droplets.

The aim of this study is to explore the HCO3-/CO32- equilibrium in surrogate respiratory fluid sessile droplets to elucidate the pH evolution of exhaled respiratory aerosol, yielding crucial insights for understanding the aerosol processes that are central to airborne disease transmission. In situ direct measurements are made using Raman spectroscopy, which is applied to study the kinetics of CO2 evaporation from sodium chloride-sodium bicarbonate microlitre sessile droplets with and without the enzyme carbonic anhydrase (CA), respectively. In particular, we explore the impact of gas flow rate, droplet volume, gas phase CO2 concentration, and enzymatic catalyst concentration on the CO2 evaporation kinetics. The experimental results are used to benchmark the Respiratory Aerosol Model (ResAM), which simulates respiratory picolitre droplet thermodynamics and pH evolution (Luo et al., 2023).

Our measurements show that the CO2 evaporates slowly in sessile droplets of volume of 40 µL, taking ~200 minutes for the droplet to reach pH 9 from an initial level 7.6. The effect of changing droplet size and gas flow rate to the pH change is within the experimental error. However, the gas phase CO2 level controls the final pH profoundly. The ResAM simulates the pH evolution profile and is highly comparable to the experimental measurements. When scaled to respiratory aerosol droplet sizes of 0.004 and 65 pL, the pH occurs over ~27 min. The simulated pH evolution profiles of picolitre droplets show size independence. Simulations for both sessile droplet and respiratory aerosol show that the presence of CA can significantly increase the rate of pH increase, and the gas phase CO2 level is also important for determining the final droplet pH.

This study represents the first direct in situ investigations into the pH dynamics of an aqueous sodium chloride-sodium bicarbonate droplet and CO2 evaporation kinetics using Raman spectroscopy. The composition of human respiratory fluid is dynamic, reflecting the true nature and physicochemical properties of exhaled aerosols is challenging. However, this study highlighted the timescale differences for the pH increase in microlitre sessile droplet and aerosol droplets of respirable size, that are responsible for fomite and airborne transmission, respectively. This information is crucial for understanding the aerobiological pathway for virus transmission and providing evidence to inform indoor airborne control strategies.

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Comparison of airborne SARS-CoV-2 Omicron and pre-Delta variants around infected patients

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Objectives
Transmissibility has increased during the evolution of SARS-CoV-2, possibly by improved airborne transmission. An increased transmission was noted also in many hospitals. We analyzed SARS-CoV-2 in room air of hospitalized Omicron infected patients and compared results with previous findings with pre-Delta variants to study if SARS-CoV-2 was more prevalent in patient rooms after the introduction of Omicron.
Methods
Air samples were collected Mars 2020 to 9 April 2021, with pre-Delta virus variants, was compared with samples collected January 2022 to May 2022, when Omicron BA.2 was the dominating variant. A liquid cyclone was used to samples 2 m3 of air collected 1-4 meters from COVID-19 patients, within patient rooms at five regular hospital wards. Standard ventilation was 3-4 air changes per hour (ACH), but some rooms had enhanced ventilation. Data on recent viral load in respiratory samples and patient characteristics was registered. Laboratory analysis with RT-PCR after Amicon centrifugal filter concentration and RNA extraction was performed.
Results
Only 4 of 75 (5 %) air samples, from 3 of 43 included patients, were positive during the early Omicron wave, compared to 14/120 (12 %), from 10 of 60 included patients during the initial wave. No certain statistical difference between virus variants could be established, but the tendency was a lower occurrence at Omicron infected patients, also when adjusting for relevant confounders.
Conclusion
These finding do not support the initial hypothesis that patients with diagnosed Omicron infection would pose a higher risk of hospital transmission compared to pre-Delta variants. The data suggest that any increased transmission within hospitals during the Omicron more likely emanated from other sources, and possibly supporting an altered shedding dynamic in Omicron infections compared to pre-Delta variants. But it is difficult to draw any firm conclusions since the patient population, including immunization status, differ significantly between the two studied periods.

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Infectivity Of Airborne Influenza A Virus: The Effect Of Matrix And Air Composition

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Recurrent epidemics and pandemics of respiratory diseases have long had a strong impact on societies. Studying the effect of environmental factors on the conservation of airborne virus infectivity, in addition to helping to better understand the inactivation properties of viruses, could lead to easily implemented intervention strategies.

In this study, we experimentally investigate the infectivity of influenza A virus (IAV) contained in an aerosol by mimicking as closely as possible a host-to-host transmission scenario, using the novel LAPI BREATH facility described in Motos et al. (2024). The virus-containing aerosol is produced through bubble-bursting of a virus-containing medium simulating aerosol generation by normal breathing through reopening of small airways in the deep lungs. In order to respect the natural dynamics of the aerosol and its settling, particles are introduced and exposed to controlled conditions for up to 5 hours in a large polytetrafluoroethylene chamber (~1.6 m3) in which no fan or rotation is used to resuspend the particles. Virus sampling is based on particle condensational growth followed by liquid-to-liquid collection, similar to the deposition process occurring in our lungs upon inhalation.

We first study the effects of matrix composition on IAV infectivity, then explore that of air composition. We test the effect of adding protein (sucrose) to a saline matrix (phosphate-buffered saline, PBS), before moving to a synthetic lung fluid (SLF). We then expose IAV to various concentrations of CO2 and HNO3. We choose to express our results in terms of 99% inactivation time (*t99*), i.e., the time required for a 2-log inactivation of the initial airborne virus population.

We show that addition of sucrose to the PBS protects IAV at 55% relative humidity (RH; average *t99* ~40 min versus ~18 min in PBS) but not at 25% and 85%. RH. Interestingly, SLF protects IAV to the same degree at 55% RH but causes faster inactivation than plain PBS at low and high RH. An increase in CO2 concentration from ~440 ppm to ~4000 ppm has no effect on IAV infectivity at 25% and 85% RH, but causes an increase in *t99* at 55% RH (from 1h 23 min to 45 min). Exposure to HNO3 was shown to be highly effective in inactivating IAV. At 55% RH, concentrations as low as 5 and 30 ppb were sufficient to decrease *t99* from approximately 45 min to 25 min (1.8-fold) and 6 min (8-fold), respectively. At low RH, higher concentrations are required to achieve a similar level of inactivation, probably due to particle efflorescence or to the small amount of water in particles, mitigating the effect of pH.

In a dry indoor environment (~25% RH), the risk of IAV transmission expressed by *t99* is higher by factors of 3 to 5 than in more humid conditions (~55% RH), according to our chamber measurements. While there is a lack of medical knowledge about the health risks of exposure to acidic vapours at concentrations more than two orders of magnitude below occupational exposure limits, our results suggest that indoor acidification at such concentrations could be as effective as humidification in reducing the transmission of IAV. Importantly, the combination of humidification and acidification appears to be an extremely effective method. To the best of our knowledge, this is the first time that airborne IAV are exposed to artificially modified air composition, except for RH. Our results support previous modelling work highlighting aerosol acidity as an important but overlooked parameter governing airborne IAV inactivation (Luo et al., 2022).

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Exposure-response relationships for platinum salt sensitization in precious metal refinery workers: a 16-year retrospective study

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Background: Occupational exposure to soluble chlorinated platinum (Pt) salts, commonly called chloroplatinates, is a known cause of Pt salt sensitization (PSS) and occupational asthma. When PSS has been established, sensitized workers are usually redeployed to jobs with low chloroplatinate exposure levels or environments without exposure to prevent development of occupational allergy and asthma.
Objectives: We aimed to model inhalable soluble Pt salts exposure levels based on measurements in precious metal refineries for use in a retrospective cohort study on PSS, and assess the exposure-response relationship between soluble Pt salts exposure and PSS in a 16-year retrospective cohort study (2000-2015).
Methods: We analyzed routinely collected exposure levels and medical surveillance data from five platinum refineries located in the United Kingdom (3 sites), United States, and South Africa. The refineries provided time weighted average inhalable soluble Pt salts exposure data, measured in 2,982 personal air samples. We used a Bayesian hierarchical model to estimate geometric mean (GM) exposure levels for each refinery and job title over time. In total, 1,614 newly hired workers who entered the industry since 2000 regularly underwent skin prick tests. The relationship between time-varying exposure levels and PSS development was analyzed by Cox proportional hazards regression, adjusting for smoking, atopy, and facility.
Results: The GM of measured exposure levels over all facilities was 92 ng/m3 with a geometric standard deviation (GSD) of 9.07. Facility-specific GMs ranged from 48 ng/m3 (GSD 15.3) to 242 ng/m3 (GSD 5.99). Exposure modelling showed that soluble Pt salts exposure levels declined approximately 10% per year in two of the five facilities, but there were no clear time trends in the other facilities. A priori specified exposure groups captured most of the between-jobs differences, which helps to accurately predict exposures for jobs with no measurement data available. PSS was diagnosed in 117 workers (1.48 per 100 person-years of follow-up time) with median time to PSS of 1.9 years, and with an estimated median exposure level of 53 ng/m3 (P5-P95: 8-302 ng/m3) at the time of PSS development. Statistically significant quantitative exposure-response relationships between PSS and cumulative and current exposure were found. Exposure-response curves showed a steep increase in PSS incidence at exposure levels up to 100 ng/m3, with no or only a slight further increase at higher levels.
Conclusions: We found a clear exposure-response relation between soluble Pt salts exposure and PSS incidence among newly hired workers. Despite the limitations inherent to the retrospective study design, this cohort study contributes to the growing body of evidence that the widely adopted occupational exposure limit of 2,000 ng/m3 does not adequately prevent PSS and should be re-evaluated.

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A new approach for assessing aerosol inhalation dose in confined spaces

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Introduction
Inhalation of aerosols has a direct effect on health and is a critical factor in exposure assessment. Experimental approaches to determining inhalation dose are limited due to technical challenges and ethical concerns regarding human participation. As a result, alternative methods have been developed. One common approach involves simplified estimations, while another uses breathing thermal manikins (BTMs) to simulate human respiration. However, these methods have limitations: simplified approaches do not account for breathing dynamics, and BTMs cannot replicate physiological changes and fluctuations.
This study presents an experimental methodology for measuring inhalation dose that overcomes these limitations by involving human participants. This approach considers variations in the breathing cycle and their effects on aerosol dispersion. The methodology is designed to pose no health risks and is suitable for real-world applications. An experimental setup was built in a controlled environment to validate the method. Inhalation doses were measured under different airflow conditions, and the aerosol protection factor was calculated for each scenario to assess reductions in exposure based on indoor ventilation.
Methodology
The methodology involves aerosolizing a magnesium-water solution, where the water evaporates, leaving magnesium particles that follow airflow patterns. These aerosols are collected by individuals positioned at different locations within the room. Collection occurs via removable filters placed inside breathing masks. The magnesium content is extracted from the filters and analyzed using inductively coupled plasma mass spectrometry (ICP-MS), which also detects other elements to identify potential contaminants.
Three airflow conditions were tested: (1) No forced ventilation; (2) Forced ventilation with an axial fan to enhance turbulent mixing; and (3) Forced ventilation with an air purifier for aerosol removal. Each scenario included five sets of four experiments conducted at distances of 0.5, 1, 2, and 3 meters from the aerosol source, plus a control to measure background levels.
Results
The inhalation dose results obtained via ICP-MS and the protection factor (PF), which quantifies exposure reduction between conditions, were used to evaluate dose variations across scenarios. The results indicate that in the absence of ventilation, inhalation dose decreases with distance from the aerosol source. When forced ventilation is introduced, the overall inhalation dose is lower and less affected by distance.
Protection factors increase with distance, particularly in the scenario without ventilation, where the dose at 3 meters is significantly lower than at 0.5 meters. When comparing ventilation scenarios, forced airflow is most effective at close range, with the air purifier offering the highest level of protection at short distances. However, its efficiency decreases as distance increases, suggesting that airflow dynamics play a crucial role in aerosol exposure.
Conclusions
A methodology for measuring inhalation dose using real human participants has been developed and validated. This approach extends beyond controlled laboratory conditions and can be applied to everyday environments. The study highlights the impact of distance and ventilation on aerosol exposure. Results show that while distance from the aerosol source reduces exposure, forced ventilation and air purification significantly enhance protection, particularly at close range. This methodology provides valuable insights for assessing aerosol exposure and improving indoor air quality strategies.

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Evaluating workplace Indoor Environmental Quality Parameters Against International Guidelines: A case study at CAREL H.Q

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Workplaces with exceptional indoor environmental quality (IEQ) significantly influence employees' health, well-being, and safety, ultimately enhancing productivity. The investment in maintaining high IEQ is quickly recouped, with ongoing financial benefits. By fostering an environment that prioritizes employee satisfaction, businesses can achieve greater efficiency and a stronger return on investment.

This study evaluates key IEQ parameters—including CO_2 concentration, temperature, relative humidity, and PM10 levels—in indoor environments monitored by CAREL, a global leader in control solutions for air conditioning, refrigeration, heating, humidification, and adiabatic cooling systems. The analysis compares measured values against internationally recognized standards from the World Health Organization (WHO) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) to assess compliance and identify areas for improvement. It emphasizes the importance of continuous IEQ monitoring in maintaining healthy indoor environments and ensuring occupant well-being.

This study focuses on CAREL's headquarters in Padua, Italy, particularly the CAREL 5 building Knowledge Center, where IEQ parameters have been systematically monitored. For this study, the data is referred to starting from January 2025 to present recent and to-date values. The building encompasses various functional spaces, and this study specifically examines the IEQ parameters in three key areas: the kitchen (Cucina), cafeteria (Mensa), and open-plan office. For objective measurement, the Carel BOSS system is employed, which offers a local monitoring solution capable of providing customizable maps, user interfaces, and historical data for specific parameters. The system also manages alarms and configurations for optimal performance.

The analysis presents median values for IEQ parameters, along with the 5th and 95th percentiles for each parameter across different spaces. In the kitchen, the measured CO_2 concentration is 423 ppm (409 ppm–465 ppm), relative humidity is 46% (34%–52%), temperature is 21℃ (20℃–22℃), and PM_{10} levels are 11 µg/m³ (2 µg/m³–22 µg/m³). The cafeteria, which accommodates over 200 people, recorded a CO_2 concentration of 994 ppm (905 ppm–1102 ppm), a relative humidity of 48% (37%–54%), a temperature of 22℃ (22℃–23℃), and PM_{10} levels of 3 µg/m³ (1 µg/m³–7 µg/m³). The open-plan office, shared by more than 20 employees, showed a CO_2 concentration of 760 ppm (674 ppm–813 ppm), relative humidity of 51% (45%–52%), temperature of 22℃ (22℃–23℃), and PM_{10} levels of 9 µg/m³ (2 µg/m³–17 µg/m³).

All assessed areas comply with the WHO 2021 air quality guidelines, with PM_{10} concentrations below the 45 µg/m³ threshold and CO_2 levels within the recommended range of 400–1,000 ppm. The highest CO_2 concentration of 994 ppm occurs briefly in the cafeteria during peak occupancy. Temperatures remain within WHO's recommended range of 20℃ to 26℃, and relative humidity is consistently maintained between the 30% to 60% recommended by both WHO and ASHRAE.

Overall, the implementation of the IEQ monitoring system at CAREL has fostered a sustainable working environment that supports employee health and productivity.

POSTER SESSION / 86

Chlorine gas and ultrafine particle emissions from bleach disinfection: occupational exposure risks and safety strategies

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Cleaners are frequently exposed to a wide range of airborne agents, including respiratory sensitizers and irritants. Notably, exposure to bleach and other chlorine-based disinfectants have been associated with an increased risk of respiratory conditions. However, much of the available evidence relies on self-reported exposure data, which may introduce bias toward cleaning agents with more pronounced odors, leaving the causal agents largely unidentified. Furthermore, the underlying mechanistic pathways remain poorly understood, hindering the development of effective mitigation strategies. This study aimed to characterize the emission of chlorine gas and ultrafine particles (UFPs) during routine disinfection procedures to enhance the understanding of occupational exposure and to inform the development of targeted mitigation measures. Measurements were conducted in a 1.80 m × 1.20 m × 2.20 m plexiglass chamber with an air exchange rate of 0.2 h^{-1}. The chamber contained a polypropylene tub (1 m^2 surface area), an Airpur air purifier, a Condensation Particle Counter, a Scanning Mobility Particle Sizer, a Fast Mobility Particle Sizer, two GasBadgePro detectors, a luminosity sensor, and a Radium Sanolux lamp. Prior to each experiment, the chamber was purged to minimize particle concentrations, and a freshly prepared 0.5% sodium hypochlorite solution was introduced via tubing. Four experimental conditions were tested: ambient temperature (26℃), elevated temperature (38.5℃), light exposure, and hydrochloric acid interaction (15 mL, 10% v/v). Particle concentrations, size distributions, and chlorine gas emissions were measured over time to calculate emission factors. Additionally, real-world validation experiments were conducted in two sealed office settings, one before cleaning and one after, under conditions mimicking actual disinfection.
At room temperature UFP emissions were detected, but no chlorine gas was released. At elevated temperature (38.5℃), UFP emissions increased significantly, with an emission factor of 1×1011 part/min, while chlorine gas emissions reached 0.38 ppm. The increased temperature likely destabilized hypochlorous acid, leading to enhanced volatilization and secondary aerosol formation. The rise in UFPs suggests that temperature plays a key role in accelerating volatile organic compound oxidation, promoting ultrafine particle formation. The simultaneous detection of chlorine gas under high-temperature conditions raises concerns about occupational exposure risks, particularly in tropical climates and enclosed indoor environments with limited ventilation. UV radiation exposure also resulted in a significant increase in UFP formation, with an emission factor of 9.78×1010 part/min, but no detectable chlorine gas emissions.
The introduction of organic contaminants, simulated using HCl to mimic the acidic nature of vomit, resulted in the highest chlorine gas emission (9.45×106) and concentration (9.9 ppm) recorded in the study, while no UFPs were detected. This suggests that acidic biological fluids significantly enhance chlorine gas formation while suppressing the oxidation pathways that generate UFPs.
In Office 1 (before cleaning), a chlorine gas emission of 4.12×105 was detected reaching a concentration of 0.5 ppm, likely due to reactions between bleach and organic residues on the floor. Simultaneously, a UFP emission of 2.46×109 was recorded. In contrast, in Office 2 (after cleaning), no chlorine gas emissions were detected, but a higher UFP emission (3.79×10^9 part/min) was observed. This supports the hypothesis that organic contaminants contribute to chlorine gas formation, while clean surfaces favor secondary aerosol formation.
The results suggest that two distinct pathways drive emissions: chlorine gas is primarily released when bleach reacts with acidic contaminants or organic residues, while UFP formation is promoted under conditions of high temperature, UV radiation, and clean surfaces. The observation that chlorine gas and UFPs were rarely detected together reinforces this hypothesis.
Chlorine gas emissions peak when bleach is applied to contaminated surfaces, exceeding occupational exposure limits by nearly 20 times, while no chlorine gas was detected on pre-cleaned surfaces. This underscores the necessity of strict cleaning protocols to minimize exposure risks. Conversely, UFP emissions were highest in clean environments, indicating their formation is driven by secondary chemical reactions rather than direct contamination. Unlike chlorine gas, which causes acute airway irritation, UFPs penetrate deep into the lungs, leading to oxidative stress and inflammation, posing potential long-term health risks. There are currently no regulatory exposure limits for UFPs, highlighting the urgent need for research on their health impacts and the development of safety guidelines. Effective ventilation is crucial for reducing exposure to both chlorine gas and UFPs, and safer disinfectant alternatives should be considered.

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Collecting and characterizing industrial air pollution, towards an animal-free prediction of nanomaterial-induced adverse outcomes

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Objective: New in-vitro models are currently being developed to predict in vivo adverse outcomes, including using advanced microscopy and spectroscopy techniques to track key events in vitro. The in vitro data will be used to develop in-silico models for quantitative prediction of adverse outcomes in vivo. In order to calibrate and validate the in-silico models, different types of industrial airborne material have been collected and characterized.

Methods: Nine different materials were identified and collected based on industrial relevance (both established high-production materials and advanced nanomaterials for emerging technologies), representing different stages of a material's life cycle. Particles smaller than 2.5 µm were collected from three cement materials (airborne clinker dust, airborne cement dust, and airborne ambient particles outdoors at the cement facility), dental filling material, bimetallic engineered nanoparticles (CoNi and NiMo), micro- and nanoplastics (particles from recycled plastic materials and particles from degradation of 3D-printed plastics), and particles from recycling of waste from electric and electronic equipment (WEEE). All materials were collected at production/recycling plants, except for 3D-printed plastic, where printed items were grinded into micro-and nanosized pieces using a rotational, high-speed aluminum oxide abrasive stone grinding bit and collected, to simulate environmental degradation. The majority of these materials were characterized in terms of size distributions and size resolved chemical composition, more than half of the materials were also characterized in terms of particle morphology. Endotoxin levels of all materials were assessed.

Results: An initial finding highly relevant when it comes to human exposure is that for all the material types, except for the 3D printed particles, the airborne particle sizes were smaller than 4µm, a particle size range that is deposited primarily in the alveoli tract (the deep lung), upon inhalation, and several of the materials had size distribution peaks in the nano range (<100nm). Chemical composition (ICP-MS) of the three cement industry materials showed that much of the particles outdoors do come from the cement production process, but that there are additional chemical species in the outdoor particles indicating contribution from other sources too. The dental filling material had a major size mode at 3 µm, but SEM reviled primary particles in the nano size range. The CoNi and NIMo bi-metallic particles (generated at a laboratory facility) were exclusively nanosized with a majority of the particles being below 20 nm. Analyses by XPS and TEM-XEDS showed a high level of purity with only minor oxygen and carbon contaminations. The particles collected at a plastic bottle recycling facility, showed almost no particles larger than 2 µm, and a peak of particles around 150 nm, assessed by SMPS and APS. The WEEE particle size distributions show that even if the mass is dominated by the coarse particles, the vast majority of particles are in the sub micrometer range and 66–86% of the number concentration are in the nanoparticle size range. These particles were highly diverse regarding chemical content, both in the sense that each particle was composed by multiple elements, and that the chemical content of the different particles varied considerably, reflecting the varying composition of electronic waste. The size resolved chemical analyses (by PIXE) shows that Si, S, and P compose a larger fraction of the WEEE particles with decreasing particle size, and thus compose a higher fraction of nanoparticles compared to the coarse particles. Another strong trend is the relative abundance of Fe in the very coarse particle fraction.

Conclusion: By collecting and characterizing nine different materials, released from industrial processes or in industrial environments, at different stages of a material's lifecycle, we have been able to provide materials to the demonstration and validation of adverse outcome predictions in-vitro and in-silico. The airborne materials are different both in chemical composition and in stage of the lifecycle, but still constitute exposures (and thereby potential health effects) of high relevance for today's and tomorrow's industry. The multidisciplinary approach, by combining skills from aerosol scientists, toxicologists and modelers, will bridge the gaps in nanotoxicology and nanosafety to enable work towards an animal-free prediction of adverse health outcomes.

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The role of proteins in controlling evaporation and hygroscopic behavior of exhaled respiratory droplet

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Background and Objective:
The transmission of respiratory pathogens via exhaled droplets and aerosols is a key mechanism in the spread of infectious diseases such as influenza and COVID-19. The physicochemical properties of exhaled respiratory droplets, which vary under different environmental conditions, directly influence the survival and transport of airborne pathogens. Factors such as temperature, relative humidity (RH), sunlight, and pH play crucial roles in determining pathogen activity. Among these, RH has been shown to significantly impact pathogen activity in respiratory droplets; however, the underlying mechanisms remain unclear, particularly given the complex composition of respiratory droplets. A deeper understanding of the physicochemical properties of exhaled respiratory droplets is essential for comprehending the spread of airborne diseases and predicting aerosol transmission dynamics. In this study, we investigate the role of mucin and albumin, key respiratory proteins, in controlling droplet evaporation and hygroscopic behavior, with the aim of better understanding RH-dependent pathogen activity within respiratory droplets.
Methods:
An electrodynamic balance (EDB) was used to levitate individual droplets under RH conditions ranging from < 5% to 97%. This setup prevented the droplets from contacting any surface, enabling measurements of their evaporation and the hygroscopic growth. Changes in droplet mass and size were measured using the two-dimensional light scattering patterns recorded during the experiment. The morphology and chemical composition of droplets in their equilibrium state were analyzed using an environmental scanning electron microscope (ESEM) equipped with an energy-dispersive X-ray (EDX) spectrometer, with 50 Pa N2 as the background gas.
Results:
Our results show that the presence of mucin affected the evaporation and the rehydration of the respiratory droplets. Specifically, mucin was found to slightly retard the evaporation process, which is likely due to the formation of a semi-solid layer on the surface of the droplets during evaporation. This layer appears to impede the uptake of water, thus influencing the hygroscopic growth behavior of the droplets. While the results for mucin are conclusive, data analysis for albumin is still ongoing, and further insights into its role in droplet behavior will be presented once the analysis is completed. However, SEM images suggest that , unlike mucin, albumin does not form a dense outer shell under dry conditions, highlighting a distinct difference in the behavior of these two proteins.
Conclusion:
Our results highlight the significant role of different proteins in affecting the properties of exhaled respiratory droplets during evaporation and rehydration. The organic content of respiratory fluids varies depending on the region of the respiratory tract where it is produced. Virus-laden respiratory droplets generated in areas with higher organic content may form a more robust shell under dry conditions, thereby enhancing the virus's environmental survivability by protecting it from factors such as temperature, humidity, and ultraviolet radiation. The variation in the physicochemical properties and morphology of respiratory droplets, especially in the presence of different organic compounds and varying organic content, remains an area worthy of further exploration and should be the focus of future research.

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Do the varying drying rates influence rhinovirus infectivity?

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Objective: Human rhinovirus is the most common cause of the common cold worldwide (1). It has been shown that a substantial part of the airborne viruses is found in aerosol particles in the range of 1-4 μm (2). Studying the infectivity of aerosol particles in this range is, however, challenging; therefore, not many studies have been conducted on their infectivity. The aim of this work is to investigate the infectivity of aerosolized rhinovirus in particles <5 μm under varying levels of relative humidity (7%, 50%, and 80%-90%).
Methods: We performed aerosolization and collection of rhinovirus in a laboratory setup previously described by Alsved et al. (3). A flow tube was placed inside a laminar flow (LAF) cabinet to avoid any contamination during the experiment. The BioAerosol Nebulizing Generator (BANG) was used to generate the aerosol of rhinovirus, which was introduced into either a long or short exposure tube under different levels of relative humidity (RH). At the other end of the exposure tube, the bioaerosol was collected by impaction in three different size fractions using the BioCascade (Aerosol Dynamics Inc.): >10 μm, 4-10 μm and 1.5-4 μm. The remaining particles <1.5 μm continued to the BioSpot-VIVAS (Aerosol Devices) where they were grown to larger droplets by water condensation before impaction into liquid. In addition, an aerodynamic Particle Sizer (APS, Model 3321, TSI Inc.) and a Scanning Mobility Particle Sizer (SMPS, TSI Inc.) were used for analyzing the size distribution of the bioaerosol. To ensure that we were measuring the dry size of the particles, a silica drier was connected before the APS and SMPS. Additionally, the viral load of the collected bioaerosol samples was determined by quantitative polymerase chain reaction (qPCR). Since qPCR only detects the total presence of cDNA in a solution and does not assess the infectivity of the virus, the infectivity of rhinovirus was assessed by measuring the cytopathic effect in HeLa cells, using the 50% Tissue Culture Infectious Dose (TCID50) and the Most Probable Number (MPN) method. To minimize the influence of small variations in aerosol concentration on virus infectivity results, MPN values were normalized by the total aerosol mass measured by the APS during the sampling time.
Result: In the experiment when all particle sizes were collected with the BioSpot, our results suggest that airborne rhinovirus infectivity was about 50% higher at RH above 80% compared to a 7% RH, however, it was not statistically significant. When collecting the aerosol in different size fractions using the BioCascade and the BioSpot, the smallest particle size fraction (<1.5 μm) was significantly more infectious than the two larger size fractions (1.5-4 and 4-10 μm) when aerosolized at 7% RH (t-test, $p<0.05$). No difference in infectivity was found when comparing larger particles to each other (4-10 μm vs 1.5-4 μm). The infectivity of the largest particle size fraction (>10 μm) was below the detection limit of the MPN assay.
Conclusion: Based on the experimental results, aerosol at high humidity and particles smaller than 1.5 μm contained more infectious rhinovirus per aerosol mass than aerosol in low humidity and in particles >1.5 μm. There is a possibility that the collection methods, direct impaction for particles >1.5 μm versus condensational growth prior to impaction for <1.5 μm, influenced the result. So far, experiments have only been conducted once, so repeating the experiment is essential to be able to draw any firm conclusions. In addition, we will develop a copy standard for the qPCR to be able to normalize the infectivity by the virus copy number.
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Modelling indoor NO2 exposures to enable health impact assessment of gas cooking emissions

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Background/Objective
Gas cooking emits NO2, a gas contributing to poor indoor air pollution, and leading to indoor concentrations often exceeding outdoor levels and air quality guidelines. Electric hobs, on the contrary, do not involve combustion and thus do not contribute to increasing indoor NO2 levels. Gas cooking was prevalent in 33% of European households in 2022, although usage varies considerably by country (0-74%), and it is declining (1). Health risks associated with gas cooking include increased risk of pneumonia and COPD in both children and adults, and potential links to asthma and other respiratory symptoms (2). Likewise, NO2 exposure is also associated with increased mortality, lung cancer risk, hospital admissions for respiratory issues, and exacerbated asthma in children (3). Given the widespread use of gas cooking and the associated health risks related to NO2 exposure indoors, it is crucial to assess its overall health impact. In order to perform such health impact assessment, knowledge of the concentrations of NO2 concentrations inside households that use gas cooking is required. Likewise, information on the distribution of NO2 concentrations in households that cook with appliances that do not emit NO2, like electric hobs, is also required. This study aims at estimating the NO2 concentrations indoors in European households that cook with gas and electric appliances that will allow to conduct a health impact assessment associated with NO2 exposure during cooking with gas hobs.

Methods
Concentrations of NO2 indoors in households that use gas and electric cooking appliances were estimated by combining indoor-to-outdoor (I/O) NO2 ratios with ambient NO2 modelled concentrations available at the European Environment Agency (EEA) (4). Concentrations were estimated at small regional unit area (i.e. at NUTS- 3 level). In order to calculate the I/O NO2 ratios in households that use gas and electric cooking appliances, information on indoor NO2 concentrations reported in a recent and comprehensive study conducted in 7 European countries (5) were divided by the ambient NO2 EEA modelled concentrations at each geolocation. The individual I/O NO2 according to cooking appliance were aggregated for each of the four clusters (Eastern Europe, Southern Europe, North-Western Europe and United Kingdom, UK) that the countries are classified onto according to the literature (6).
Indoor NO2 levels for hypothetical households using gas or electric cooking were estimated combining mean ambient NO2 concentrations at each NUTS- 3 level, derived from the EEA's 2021 maps for each European location, with the relevant indoor-to-outdoor NO2 concentration ratios derived to each country cluster.

Results
Spatial distribution of NO2 concentrations according to cooking fuel type in every small regional unit area (i.e. at NUTS- 3 level) for all countries in the EU and the UK were calculated. A clear difference emerges between estimated average concentrations within homes according to cooking methods. Homes using gas appliances have higher estimated indoor NO2 levels than the concentrations modelled outdoors by the EEA. On the contrary, homes using electric appliances have lower estimated indoor NO2 levels than outdoors. Furthermore, indoor NO2 concentrations in homes using gas cooking exceed the World Health Organization's (WHO) recommended annual limit of 10 μg/m3 guideline in 14 countries. No such exceedances of the WHO guideline were estimated in homes using electric cooking.

Conclusion
This study has estimated indoor NO2 concentrations according to cooking fuel type in every small regional unit area for all countries in the EU and the UK. The current modelled indoor NO2 concentrations can be used to estimate the health impacts and economic costs across the EU and UK associated with mortality and asthma related with exposures to NO2 emitted from gas cookers in Europe.

Keywords
NO2, gas cooking, indoor air quality

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SESSION 2b - Exposure and Dose: Assessing the human health implications, Oral Presentations / 91

Evaluating air cleaning in Dutch primary schools: study design and preliminary results of the Clean Air for Everyone (CLAIRE) project

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Introduction
Children in Europe spend a substantial amount of their time in classrooms, where indoor air quality (IAQ) guidelines are often not met. Poor IAQ —shaped by factors such as bioaerosols (including bacteria, viruses), particulate matter (PM), and volatile organic compounds —has been associated with respiratory morbidity and infectious disease transmission. While ventilation plays a key role in improving IAQ, since the COVID-19 pandemic, mobile air cleaners equipped with high-efficiency particulate air (HEPA) filters or alternative technologies, such as ionizers, are increasingly considered as a supplementary measure to protect against acute respiratory infections.

To date, air cleaner efficiency has been predominantly assessed in controlled environments using artificial aerosols, with limited real-world evidence of their effectiveness in occupied classrooms. Moreover, feasibility of integrating air cleaners into school settings remains unclear. This study aims to address these gaps by evaluating the impact of air cleaners on airborne bioaerosols and general IAQ indicators in primary school classrooms through a large-scale randomized controlled trial (RCT).

Methods
The RCT utilizes classrooms within a school as the randomization unit. At each school, sets of three classrooms with similar building characteristics are selected and randomly assigned to one of the three study regimes: 1) intervention with HEPA filter air cleaners, 2) intervention with air cleaners using an alternative technology, and 3) no intervention (control).

Bioaerosol samples from classrooms are passively collected using electrostatic dust fall collectors (EDCs), suspended 30 centimeters from the ceiling for a three-week sampling duration. A baseline (pre-intervention) measurement is followed by three repeated measurements during intervention. After DNA and RNA extraction of EDCs, levels of total 16S rRNA, S. aureus, S. epidermis, S. salivarius, M. catarrhalis, Influenza A/B and RSV are quantified by qPCR.

Concurrently, PM10, PM2.5, PM1, CO2, temperature, and relative humidity are continuously monitored in each classroom at one-minute intervals using IAQ sensors. Additionally, student absenteeism is recorded, and respiratory health of the pupils is assessed via a parental survey before and after intervention.

Results
From December 2023 to April 2024, a total of 12 schools were enrolled in the study. Data collection continues from October 2024 through April 2025, expanding the study to a total of 26 schools. The implementation of air cleaners in school environments presents practical challenges, including issues related to device size and sound levels.

Preliminary analysis of bioaerosol markers from the initial measurement period (December 2023–April 2024) showed the following bioaerosol detection rates: Influenza A (0%), Influenza B (1.5%), RSV (8%), 16S rRNA (97%), *S. epidermidis* (40%), *M. catarrhalis* (55%), *S. aureus* (49%), and *S. salivarius* (55%). Upon completion of data collection in April 2025, the study will assess the impact of air cleaners on bioaerosol concentrations and PM levels.

Conclusion
This large-scale RCT will address a critical knowledge gap, providing real-world evidence on the efficacy of air cleaning technologies in reducing airborne microbial, viral, and PM levels in primary school classrooms. Ultimately, findings from this study will offer crucial insights into the feasibility and public health implications of air cleaners in school environments, informing future evidence-based public health strategies to enhance IAQ and mitigate airborne disease transmission in educational settings.

SESSION 1b - Particles Emission: Understanding sources, estimation and measurements, Oral presentation / 92

Evaluation of the Naneos Partector 2 Pro ultrafine particle monitor to support WHO's 2021 good practice statements

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Introduction
The 2021 WHO Air Quality Guidelines[1] included four good practice statements to help guide actions to decrease concentrations of ultrafine particles (UFP) and ultimately reduce population exposure to UFP. The good practice statements included recommendations to expand common air quality monitoring to include size-segregated and real-time measurements of UFP along with particulate matter (PM) mass measurements and to advance UFP monitoring technologies and approaches. Although instrumentation to monitor UFP has been developed and such instruments are active worldwide, their extensive space, controlled operating environments, and expertise requirements make them unsuitable for large-scale deployment into established air quality monitoring networks. A small, handheld UFP device called the Naneos Partector 2 Pro[2] (hereafter referred to as the P2 pro) based on a measurement technique involving unipolar diffusion chargers has shown promise as an alternative candidate monitor to be deployed at scale.

Objectives
This study's primary objectives are: (*i*) to test and evaluate the P2 pro's ability to monitor continuously in ambient conditions for 12 months, and (*ii*) to evaluate the P2 pro's measurement performance with a focus on total particle number concentration (PNC) and particle size distributions. The UFP size range and size bins that will be evaluated correspond to the eight size bins the P2 pro reports, specifically, bins with 10, 16.3, 26.4, 43, 69.8, 113.5, 184.6, and 300 nm midpoints.

Methods
At the time of writing, twelve research groups based in Australasia, Asia, North America, and Europe have deployed P2 pro devices during, or before January 2025 and will monitor UFP for at least 12 months. The devices are installed in established air quality monitoring sites that generally include PM mass measurements. The devices will also (at least periodically) be colocated with mobility particle size spectrometers (MPSS) and/or condensation particle counters (CPC) which will be used as reference instrumentation for the evaluation of measurement performance of the UFP metrics. The monitoring sites cover a range of environments ensuring a diverse range of UFP characteristics and climatic zones. Monitoring is occurring within and outside urban areas with variable proximity to primary UFP emission sources. The 12 monitoring teams will monitor the P2 pro to identify potential malfunctions or failures quickly and intervene when necessary to maximise data capture rates. Observations will be uploaded monthly to allow for central storage and management to ensure consistent data analysis approaches. Furthermore, the Partector will be evaluated with the performance and uncertainty metrics contained within the CEN/TS 17434:20203 technical specification to allow for comparison among other UFP monitors and offer insight on what monitoring applications the P2 pro is most suited to.

Results
The P2 pro is being tested in 12 locations across the world and the evaluation period will run from January 2025 to December 2025. There have been no major failures or issues that have led to significant data loss. The P2 pro devices are performing well and are reporting observations reliably. The digital infrastructure is being developed to enable harmonised and consistent data analysis across all monitoring sites and devices. The exact procedures for the intercomparisons between the device under test and reference instruments (generally, MPSS) in the scope of CEN/TS 17434:2020 are under development. Comparisons will also be made with previous studies which have tested the Partector for shorter durations[4] or in specific conditions.[5]

Conclusions
The 2021 WHO Air Quality Guidelines delivered good practice statements relating to UFP. To support these statements, the handheld Naneos Partector 2 Pro UFP device is currently under test in 12 locations around the world. The evaluation of the device and the study's outlined objectives are the first steps towards generating the required datasets to robustly calculate UFP's exposure-response functions in the future.

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Studying performance of mobile air cleaning devices in classrooms: a pilot study comparing two passive bio-aerosol sampling methods

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Introduction:
Application of mobile air cleaning devices (MACs) in schools has been put forward as a potential control measure to limit and/or prevent respiratory virus outbreaks through reduction of viral concentrations in air. However, evidence on the effectiveness of air cleaning technologies on viral levels in general, and in schools specifically is lacking. Exploring airborne viral exposure levels is a challenging task which is further complicated by the realities of sampling in active and dynamic classrooms. .Therefore, we compared applicability of two passive bio-aerosol sampling methods in a pilot study on performance of air cleaning devices.
Methods:
Five Dutch primary schools were enrolled in a randomized cross-over study during October till end December 2023. The study included 45 classrooms equipped with three different types of MACs and included 15 control classrooms with no MACs installed. MACS were operational for three weeks and switched off for three weeks during the study period. In each classroom bio-aerosol air samples were passively collected during each of these three week periods. A regular sized electrostatic dustfall collector (EDC) and a smaller electrostatic cloth in a petridish (miniEDC) were applied. Both sample types were placed side by side into a box hung 30cm below the ceiling of the classroom. Human viruses (respiratory syncytial virus A (RSV A), influenza A and B) and bacterial markers representing various origin niches were determined by qPCR. The latter included total bacteria (16S rRNA), S. salivarius (oral), S. aureus (skin and upper respiratory tract), M. catarrhalis (upper respiratory tract) and S. epidermidis (skin). Differences in microbial levels between EDC and miniEDC, and associations between microbial levels and operational status of MACs (for classrooms equipped with MACs) or sampling order (for control classrooms) were explored.
Results:
Levels of viral and bacterial markers were generally low, often below the limit of quantification of the respective qPCRs, except for total bacteria which was measurable and quantifiable in all in EDC and miniEDC samples. Total bacterial (16SrRNA) yield was higher for EDCs than miniEDCs. Of the viral markers influenza A and B were not detected in any of the samples, whereas RSV A was detected in 60% and 65% of EDC and miniEDC samples, respectively. Detection levels of S. salivarius, S. epidermidis, S. aureus and M. catarrhalis ranged between 60-90% for EDC and between 40-80% for mini EDC samples, showing generally higher probability of detection in EDC samples. A trend of lower bacterial and viral detection was observed with MACs on compared to with MACs off. While these findings suggest a potential reduction in microbial load, the statistical significance of the observed differences remains uncertain due to the limited sample size. Also, detection of bacterial and viral markers in control classrooms varied between sampling periods.

Conclusion:
MiniEDCs take up less space and are more easy to handle in the laboratory, but showed to be less sensitive than regular EDCs. Passive bio-aerosol sampling with EDCs can be a useful tool to study the impact of MACs on microbial levels in future large-scale studies, as they are cost effective and easily implemented. Natural variation of bacterial and viral levels over time should be taken into consideration when designing such a study, favoring a randomized controlled trial with classroom as the randomization unit.

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Spatiotemporal Variation of Air Pollution in Public Transport Facilities using an Integrated IoT-GIS-based Sensor Monitoring Network in Hong Kong

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Objectives

(i) Objective #1: Development and application of IoT-based sensors for a monitoring network of multiple air pollutants at representative semi-enclosed public transport interchanges (PTIs);
(ii) Objective#2: Elucidation of spatial variability of multiple air pollutant concentrations in PTIs using a geographic information system (GIS) to determine of pollution hotspots at PTIs and best fitted interpolation models in air pollution studies.

Methods

Integrated air quality sensor (IAQS)
Several important design criteria have been identified for a system to ensure it is capable of continuous monitoring of indoor air quality inside public transportation interchanges (PTIs): the system must be compact and lightweight to allow easy transport within multiple locations in a PTI; have high sensor integration to allow air pollutants, temperature, and humidity to be measured in real time; have wireless data communication for real-time air quality transmission; and have sufficient battery power to allow at least 8 hours of remote field operation.
Considering the above-mentioned criteria, we develop an integrated IoT air quality sensor (IAQS). The data are transmitted by the IAQS to the server in the IoT laboratory. The IAQS is capable of measuring PM2.5, CO, and CO2. It has been reported that many air quality sensor devices for industrial/ commercial uses are not well. In this study, we aim to develop low-cost IAQSs which are reliable for research purposes and industrial/ commercial applications with improved precision and accuracy, high sensitivity and rapidity.

Sampling
A systematic sampling will be adopted where the sampling field is divided into regularized grid squares (about 25m x 25m) and 1–2 samples will be collected in a grid unit individually. Air pollutants are to be automatically monitored at multiple locations (i.e., 5 locations) within each PTI for 40 minutes at 5 semi-enclosed representative PTIs. For monitoring multiple PTIs, the air quality data from IAQS are stored in the cloud, where it can be accessed using a computer, mobile phone or tablet. A web-based system will be deployed for air quality data visualization and management.
Air pollutants inside public transport modes (i.e., buses) have been measured using the IoT air quality sensors. Long-haul bus routes (3 Nos.) were selected in this study and the measurement for each bus route was conducted 3 times during the measurement campaigns.

Spatial analysis using GIS technique
Spatial analyses will be performed using ArcGIS Pro 3.0 (ESRI). The spatial distributions of air pollutants (i.e., PM2.5, CO and CO2 concentrations) are depicted in a spatial map in which kriging was

used for interpolation. This will enable the generation of instantaneous snapshots of pollution maps to identify pollution hotspots and to clarify the spatiotemporal changes of these pollutants within PTI microenvironments. A theoretical model will be fitted for the kriging interpolation; the experimental semivariogram is calculated using the gstat and sp library in GStat-R. A given experimental variogram is then approximated by the theoretical models (i.e., Gaussian, Exponential and Spherical semivariogram models). The best fitted models will be recommended for interpolating the air pollutants.

Results

An IoT-based air sensor measurement network will be established in representative PTIs in Hong Kong. The current air pollutant concentrations inside PTIs and public vehicles in Hong Kong were measured using an air quality sensor monitoring network, and the results will provide critical information on pollutant concentrations and driving factors affecting these. Additionally, the spatial variability of pollutant concentrations inside the PTIs will be analyzed using the GIS. Various kriging interpolation methods coupled with semivariogram models will be deployed and the best-fitted models will be recommended for interpolating the air pollutants. Recommendations will be formulated to rectify pollution hotspots inside the PTIs, and through the continuous monitoring of air pollutants, practical measures will be developed to reduce the concentrations of air pollutants to below the stipulated maxima. The results of the proposed project will be used to formulate long-term strategies to manage air quality in PTIs in Hong Kong. These strategies will also be applicable in other semi-enclosed environments with similar settings.

Conclusions

An improved understanding of spatiotemporal variations of toxic pollutants will contribute to the efforts to mitigate the sources and address public health challenges from air pollution inside the semi-enclosed PTIs and provide scientific evidence for relevant departments to formulate more targeted air quality improvement measures.

Keywords: public transport, health risks, particulate matter, gaseous pollutants, IoT technology, sensor, GIS analysis, Spatial interpolation technique

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Do COVID-19 preventive measures and ventilation types affect indoor air quality at secondary schools?

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Objective: Little is known on the impact of national COVID-19 preventive measures and ventilation regimes on potential SARS-CoV-2 or other infectious exposure in school environments. Since quantitative SARS-CoV-2 exposure information is not available, 16S rRNA total bacterial load (16S) was considered as a generic microbial indoor air quality marker. We explored whether 16S levels in airborne settling dust was associated with a range of national COVID-19 preventive measures, ventilation regimes and pupil occupancy in secondary schools.
Methods: Airborne settling dust was collected longitudinally using Electrostatic Dust Collectors (EDCs). EDCs were placed in classrooms, canteens and teacher's offices of 18 secondary schools. EDCs were 4-5 times repeatedly sampled for approximately 4 weeks between October 2020 until June 2021. Four ventilation regimes were identified in the classrooms: natural ventilation, mechanical exhaust, mechanical supply, and mechanical supply and exhaust ventilation. During the study, three phases with national COVID-19 measures were in place. At the beginning of the study (pre-lockdown), schools had limited COVID-19 measures implemented. This was followed by a lockdown period during which schools were almost completely closed. During post-lockdown, schools

partially re-opened with stricter COVID-19 measures implemented, e.g 1.5 meter distance between pupils, face mask mandates and stricter quarantine rules. 16S levels in EDCs was assessed through DNA extraction followed by 16S rRNA v3-v4 qPCR. Ventilation regimes in each classroom were determined based on observation and technical construction drawings. Pupil occupancy per classroom per EDC sampling period was determined based on scheduled average lessons per week and the average number of attending pupils in each lesson provided by the schools. A Bayesian mixed effects censored regression model was used to account for repeated measurements and measurements below the limit of detection (LOD). 16S levels were first analysed in an univariate model with only COVID-19 preventive measures, ventilation regimes or pupil occupancy. Subsequently, 16S levels were analysed in a multivariate model including all parameters.
Results: A total of 480 airborne settling dust samples were collected (335 samples in 84 classrooms, 70 samples in canteens and 75 samples in teacher offices). In univariate models, 16S levels were significantly associated with pupil occupancy and COVID-19 preventive measures. Ventilation regimes did not affect 16S levels in classrooms. In the multivariate model 16S levels were only significantly and independently associated with pupil occupancy. 16S levels in classrooms increased with 7% with every doubling of pupil occupancy. The effect of COVID-19 preventive measures almost completely disappeared after adjustment for pupil occupancy.
Conclusion: Airborne 16S levels were significantly lower when pupil occupancy in classrooms were reduced, which suggests that reduced pupil occupancy may improve school indoor air quality through reducing microbial air exposure. No distinct effect of different ventilation systems was observed. This might have been caused by the additional natural ventilation implemented in the classrooms, as teachers were advised to open classroom windows during the COVID19 pandemic. This study shows that total bacterial 16S may be useful as a marker of indoor air quality in schools. Further studies need to assess whether this proxy is a better candidate for indoor air quality than other proxy measures like CO2 levels to predict infection risks.

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Real-time measurement of reactive oxygen species emitted from indoor sources

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Reactive oxygen species (ROS) are considered to be an indicator of particle-induced toxicity. ROS can be either present on the surface of particles or generated through chemical reactions between particles and cells after inhalation. Therefore, measuring particle-bound ROS may be used to assess the harmful effects of inhaling particles. The purpose of this study was to determine ROS in real-time from six common indoor aerosols.

We use the Particle Into Nitroxide Quencher (PINQ) for real-time measurements of particle-bound ROS. Real-time assessment of ROS is advantageous for quantifying ROS since many species have short half-lives and cannot be detected by the more common measurement techniques that use filter sampling. Under laboratory conditions, we generated particles from indoor particle sources; frying of hamburgers, frying of potatoes, candle smoke, side-stream cigarette smoke, incense smoke, and secondary organic aerosol (SOA) formed from reactions between α-pinene and ozone. The generated particles were drawn into a chamber (25m3) from where the aerosol was sampled. In parallel, the particles' physicochemical properties were characterized. During measurements with PINQ, the chamber aerosol was alternatively sampled through a HEPA filter. This allows us to distinguish between the total phase and the gas phase. Without the filter, both particles and gas are measured. With a HEPA filter, particles are removed and the difference between the total and gas phase is the particle phase.

The highest total ROS concentrations were found in candle smoke, with 1,8 nmol/m3. SOA, cigarette smoke and incense smoke contained 0,53, 0,33 and 0,28 nmol/m3, respectively. ROS concentrations for aerosols generated by frying were lower. Since the particle concentration in the chamber differed between the experiments, the particle phase of the ROS concentration can also be expressed in nmol per particle mass. The highest ROS concentration was seen for SOA (0,57 nmol/mg) and cigarettes (0,35 nmol/mg). Burger and potato frying was close to zero, while incense and candle gave a negative response, that is, the gas phase gave a higher response than the total (gas + particle) phase. Obtained results and detailed characteristics of particles (mass and number concentration, and chemical composition) indicate that this is due to insoluble particles, especially black carbon, interfering with the fluorescent reading. This interference may also be present in cigarette smoke, giving an underestimation of the particle-bound ROS concentration.

The results of this study give insight into ROS concentration from indoor sources. Moreover, the concept of real-time ROS measurement with PINQ has been promising. It can be a powerful tool for screening particles for toxicity.

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Next-Gen Respiratory Safety: Synchronizing Thermal Imaging and AI for N95 Leak Assessment

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Infrared thermography (IR) combined with deep learning offers a promising approach for accurately detecting and localizing leaks in N95 masks, a critical concern in respiratory protection research. This study aims to develop and validate a real-time system that not only identifies leak occurrences but also pinpoints their exact location on the mask perimeter. By leveraging a novel workflow incorporating IR imaging, transfer learning, and correlation-based signal analysis, we address the limitations of conventional fit-testing procedures, such as qualitative saccharin and quantitative PortaCount® methods, which are not designed for continuous monitoring nor do they provide precise spatial localization of leak sites.
Methods: A controlled test bench was first established using a mannequin head, where a mechanical ventilator simulated breathing by pushing warm, humid air through an N95 mask. Small, artificially induced leaks of known dimensions were introduced at different locations around the mask perimeter to create a high-fidelity benchmark dataset. Infrared cameras capture thermal data throughout each respiratory cycle, providing temperature variations that reflect exhaled air escaping from leak points. These IR recordings were then transformed into spectrograms using the Fast Fourier Transform (FFT), highlighting the unique frequency signatures of exhaled breath. A two-stage classification pipeline was developed: first, deep features were extracted with a ResNet50 model fine-tuned via transfer learning, and second, an SVM classifier was employed to discriminate between leak and no-leak conditions. Once the system confirmed a leak, a correlation-based localization method subdivided the mask contour into Regions of Interest (ROIs). Each ROI's spectrogram was compared against a reference respiratory signal from the mask centre, enabling robust localization by identifying which ROIs exhibited the highest correlation with the breathing frequency.
Results: Under controlled conditions, the method achieved a leak-detection accuracy exceeding 95%, outperforming traditional image-based classification approaches in both precision and recall. The correlation-based localization exhibited a sub-millimetre-level resolution in pinpointing leak sites, demonstrating minimal false positives even when multiple leaks were present. The system was evaluated in a human subject study following these promising results. Participants wore standard N95 masks, and their natural respiration and head movements introduced additional variability. Leveraging a segmentation approach—combining a custom U-Net model with the Segment Anything

Model (SAM2)—the framework dynamically tracked the mask boundary in real-time. The correlation method consistently identified leaks for participants whose quantitative fit factor (FF) indicated poor sealing. Participants with high FF values showed negligible correlated ROIs, corroborating minimal leakage.
Conclusion: These findings highlight the potential of IR imaging and deep learning for advanced respiratory fit evaluations. The proposed system surpasses traditional fit-test solutions that lack continuous monitoring or precise leak mapping capabilities by delivering real-time leak alerts and detailed spatial localisation. This innovation paves the way for safer clinical, industrial, and public health applications, ensuring that protective masks are worn correctly and effectively. Future work will include scaling the platform for wearable edge devices and investigating adaptive thresholding methods to counter variations in ambient temperature and humidity. Overall, the proposed approach provides a scalable, non-invasive tool for improving respiratory protection and safety in high-risk environments.

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On the emission of particles and organic substances from household hot air fryers.

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Air fryers have become popular and widely used household appliances in the last decade. The devices are compact, inexpensive and correspond to the current lifestyle as they allow food to be prepared quickly and with low fat content. A continuous increase in sales was observed over the last years, and the sales value in the EU in 2025 is estimated at 2 billion Euro.
The fact that these appliances are being used in more and more households encouraged us to conduct a small study to characterize the emissions of air fryers during use.
The measurements were conducted in an emission testing chamber according to ISO 16000-9 under standard climate conditions (23°C, 50% relative humidity). The air exchange rate was set to 1 h^{-1}. This slightly increased air exchange rate (not untypical for the kitchen environment) also ensures that the heat generated by the devices is dissipated during the experiment.
Our test series included various brands of hot air fryers, some of which had been in regular use for up to 6 months. A brand-new device served as a comparison. All devices were cleaned and initially tested empty using a standard program (180°C for 15 minutes). Further measurements were conducted after the addition of approximately 15 g of vegetable oil. Lastly, the recommended amount of frozen French fries for each air fryer was prepared without any added fat.
In addition to the continuous monitoring of ultrafine particle (FMPS) and fine particle (OPS) concentrations, air samples were taken on solid adsorbents for the determination of volatile organic compounds (VVOC and VOC) and volatile aldehydes during each experimental phase. Even the measurements of the empty devices showed significant emissions of ultrafine particles and formaldehyde. When the air fryers were operated with oil, the particle number concentrations of ultrafine and fine particles in the testing chamber increased to $5 * 10^5$ and $1* 10^4$, respectively. Additionally, high concentrations of saturated and unsaturated aldehydes were found in the chamber air. Among the released organic substances, formaldehyde (concentrations > 100 µg/m³), acrolein (concentrations > 90 µg/m³), and other unsaturated aldehydes were significant. Butenal, pentenal, and hexenal were detected after the frying process with vegetable oil in concentrations ranging from approximately 30 to 100 µg/m³. Higher unsaturated aldehydes such as heptenal, decenal, decadienal, undecenal, and dodecenal were detectable in significantly higher concentrations.
The experiments clearly show that using an air fryer will lead to a release of particulate matter, and organic vapors. Similar emissions do also occur with conventional frying and cooking. The difference in regard to human exposure is the location of the emission: Kitchen hobs are usually combined with an extraction hood, which ensures that a significant fraction of the cooking aerosol is either removed by filters or led out of the house. Air fryers, on the other hand, may not always be placed under the fume hood when operated –this can lead to an increased exposure of the dwellers in the kitchen.

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INDOOR AIR QUALITY AND PARTICLE LEVELS IN EDUCATIONAL SETTINGS

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Background/Objective
People generally spend more time indoors than outdoors, yet there is still a lack of regulations addressing particulate matter concentrations in indoor environments. Indoor air quality plays a crucial role in human health, especially in enclosed spaces where individuals, particularly children, are exposed to airborne pollutants for extended periods and are especially vulnerable to air pollution due to their developing respiratory systems and higher exposure levels in these environments. Particulate matter (PM), which includes both fine and coarse particles, has been linked to a range of cardiorespiratory issues, including asthma, bronchitis, and cardiovascular diseases. While significant attention has been given to outdoor air pollution, there is limited information available on indoor air quality, particularly in public indoor spaces such as schools and educational facilities.

This study aims to assess the concentration of various types of particulate matter such as total suspended particles (TSP), PM10, PM2.5 and PM1 across different educational environments. This research seeks to contribute to the growing body of knowledge on indoor air quality in schools, providing valuable insights for policymakers, educators, and facility managers to improve the overall health and well-being of students and staff. Understanding the factors that influence particulate pollution in educational settings can lead to better air quality management strategies, fostering healthier learning environments.

Methods
From March to September 2021, a total of 19 sampling locations were chosen in educational settings across Valencia, Spain. These comprised 8 primary school sites, 6 secondary school sites, and 5 university locations. The air quality measurements were carried out on weekdays using the Fidas® Frog optical aerosol spectrometer, which simultaneously measures TSP, PM10, PM2.5, and PM1. A descriptive statistical analysis was conducted, and the ANOVA test was employed to examine potential differences in particulate levels across the different types of educational facilities.

Results
The mean concentration of TSP in indoor educational spaces was 65.0 (±73.6, standard deviation) $\mu g \cdot m^{-3}$ in primary schools, 33.0 (±39.9) $\mu g \cdot m^{-3}$ in secondary schools, and 23.7 (±20.0) $\mu g \cdot m^{-3}$ in universities. For primary schools, the concentrations of PM10, PM2.5, and PM1 were 39.3 (±37.0), 16.6 (±8.9), and 11.4 (±6.1) $\mu g \cdot m^{-3}$, respectively; in secondary schools, they were 20.2 (±19.6), 8.0 (±9.1), and 4.2 (±5.0) $\mu g \cdot m^{-3}$; and in universities, 12.6 (±15.4), 7.2 (±4.0), and 4.7 (±3.2) $\mu g \cdot m^{-3}$, respectively.

Significant differences in particle levels (TSP, PM10, PM2.5, and PM1) were observed across the different types of educational institutions (primary schools, secondary schools, and universities), with the highest concentrations recorded in primary schools ($p<0.05$).

In 46% of the sampled days, exposure levels found in educational institutions exceeded the World Health Organization 's 2021 guideline for PM2.5 short-term exposures (daily mean), and 14% of the sampled days exceeded the short-term exposures guideline for PM10 (WHO, 2021).

Conclusions
This study highlights the urgent need to address indoor air quality in educational settings, particularly in primary schools, where the highest concentrations of particulate matter were observed. The findings show that a significant portion of exposure levels, especially for PM2.5, exceed the World Health Organization's recommended guidelines for short-term exposure. This poses potential health risks for students, teachers, and staff. The significant differences in particle concentrations across various types of educational institutions emphasize the importance of developing targeted strategies

to improve air quality in schools. Implementing measures such as better ventilation, high-efficiency air filters, and stricter air quality regulations can help create healthier learning environments and protect the well-being of those, particularly children, who spend long hours indoors and are especially vulnerable to air pollution.

Key words
Particles, indoor environments, educational settings

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Exhaled particles and viruses from humans

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Introduction

Respiratory infection of viruses affects many persons every year, having a large economic and societal impact. Droplets and droplet nuclei from speaking, coughing, and sneezing has been investigated at least since in 1946 (Duguid, 1946), up until present day where the Covid-19 pandemic shed a light on the importance of understanding airborne transmission of infectious disease. This study aims to continue this work by examining exhaled aerosol particle size distribution, concentration, and its viral content, from approximately 150 test persons with acute respiratory infection.

Method

Measurement of exhaled particles and virus from test subjects with acute respiratory infection will take place in a climate-controlled (temperature, relative humidity) chamber of 36 m3 with HEPA-filtered air. The test subjects will breathe, vocalize, and chough into a funnel which feeds the exhaled air to several instruments measuring and collecting aerosol particles. A few weeks later, when the test subject has recovered, the measurements will be repeated to investigate the difference between the infected and healthy state. Dry particle size concentrations between 0.3-20 µm will be estimated with an aerodynamic particle sizer (APS 3321, TSI Inc., US) and an optical particle counter (OPC, model 11-D, Grimm Aerosol Technik Ainring, Germany). Exhaled CO2 concentration and H2O content will be measured with a LI-COR 850 CO_2/H_2O gas analyzer (LI-850, LI-COR Biosciences, Germany). A portion of the exhaled aerosol particles will be collected into liquid collection media using a BioSpot (Model 300-P, Aerosol Devices Inc.) for virus analysis. Virus quantification will be performed with qPCR.

Results

Anticipated outcomes are a better understanding of which and to what extent acute respiratory infections give rise to exhaled viruses, and how the size distribution and concentration of exhaled aerosol during respiratory infection compares to a healthy state.

Discussion and Conclusions

During the covid-19 pandemic, we learned that aerosol transmission contributed, especially in the early phase. It is likely that other acute respiratory infections also can spread though aerosol transmission, which would have implications for infection prevention strategies throughout society. The outcomes from this study will contribute to a better understanding of acute respiratory infection's ability to spread via aerosol transmission.

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Risk-based ventilation of patient rooms in hospitals, and its costs –is the ventilation worth the price?

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Objectives: Many infection control governmental bodies and international societies have issued recommendations for minimum ventilation in patient rooms in hospitals in the context of covid-19 and before. The recommendations can be summarized to 4-6 air changes per hour (ACH) or 40-60 liters per second and patient. These recommendations may in part be risk-based and in part be issued to reach a comfortable indoor environment. In Sweden the minimal airflow in a standard single patient room is 20 l/s, reaching about 1.5 ACH. We investigated if a modelled risk-based approach together with a cost analysis could be used for a basis for new ventilation rate recommendations. Modeled risk reduction of a higher ventilation rate was analyzed and the costs this would ensue with mechanical ventilation in a Nordic country.
Methods: The airborne risk reduction of different pathogens were calculated with AIRC-tool v3 in a steady state scenario with proposed Quanta emission rates ranging from 0.2 (influenza) to 15 (measles) in a 18 m2 x 2.7 m room with a 60 min exposure time. Results were also compared using "New dose response model"(Aganovic). The costs were calculated using a ventilation installation cost calculation tool used in Sweden (Wiksells©) and additional costs of extra installation space needed. The energy consumption was calculated for an outdoor climate comparable to Stockholm using electricity for fans and district heating and cooling for temperature regulation to reach an indoor temperature of 21-25 °C. Cost were calculated as the present value, with a 30-year calculation period. No air-recirculation was assumed in the calculations, but heat recovery with 85% efficiency. Only costs directly and indirectly associated with airflow was included.
Results: The airborne transmission risk for Covid-19 (ERq=5.4) were calculated to 14%, 10%, 8% and 7% at 0, 2, 4, 6 ACH, resulting in a risk reduction of 19 % when increasing the ventilation rate from 2 to 4 ACH and another 15% when increasing ventilation from 4 to 6 ACH. With the Influenza (ERq= 0.17) example the risk decreases from 0.2% to 0.15% resulting in a 30% risk reduction comparing 2 and 4 ACH. With measles (ERq=15) the risk is reduced from 24% to 21% resulting in a 12% risk reduction. The cost of increasing the ventilation rate from 2 to 4 ACH increases almost linear with about 90 €/m2 per each additional ACH and with the example from above from 270 €/m2 at 2 ACH (including 45 €/m2 for energy, 67 €/m2 for spaces and 158 €/m2 for installations) to 450 €/m2 at 4 ACH (including 90 €/m2 for energy, 130 €/m2 for spaces and 230 €/m2 for installations, resulting in a 67% increased cost per m2.
Conclusions: The relative risk reduction of airborne transmission achieved by increasing ventilation rate is calculated to 20% for each additional ACH for the least transmissible pathogens and 5% for each ACH at high transmissibility. But the relative risk reduction achieved decrease with increasing ACH. Costs increases linear up to 6 ACH, after which they tend to increase exponentially). The remaining question is what is the most cost efficient ventilation rate. From these calculations cost effectiveness seems to be best when increasing from a low ventilation rate (1-1.5 ACH) to an intermediate level (3-4 ACH). For higher ventilation rates further relative risk reduction tend to be more expensive, but

nevertheless meaningful and perhaps lifesaving. The remaining question is if we can afford to install a better ventilation and if the risk reduction is worth the price –economically and in the context of the climatic footprint.

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The influence of ventilation conditions on the spread of human respiratory aerosols in indoor spaces: an experimental aerobiological study

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The transmission of pathogens between humans in indoor environments has been recognized for a long time. The SARS-CoV-2 pandemic showed the significance of expiratory aerosols as a source of virus transmission indoors. A concern particularly in elderly care homes. Since then, studies have explored indoor distribution patterns through modeling or experimental investigations using artificial aerosol sources. However, the reliability of these methods for real-life conditions remains uncertain.

To address this gap, we examined how different ventilation conditions affect the dispersion of human respiratory emissions by human volunteers within a room under realistic conditions in a large-scale test facility. By including various airflow scenarios, we aimed to explore how ventilation can influence the distribution and concentration of human respiratory excreta within an indoor environment.

In a large-scale test facility of approximately 70m², we replicated the furniture setup and ventilation conditions typical of common rooms in long-term elderly care facilities. Five healthy human volunteers were seated in the room to simulate residents. To minimize the impact of non-respiratory aerosols, participants wore coveralls, hairnets, and galoshes during the experiments. They engaged in activities such as playing games and reciting a play to ensure regular aerosol production from speaking over the 1.5 hours session. This was repeated three times per research day with randomly assigned ventilation conditions (150 m³/hr, 400 m³/hr, or 150 m³/hr with a mobile air cleaner) Incoming air was HEPA filter treated. The distribution of human expiratory aerosols was measured at various distances (<1.5m, 3m, and <6m) from the participants. The experiment was repeated over three independent days.

During each 1.5-hour session, the following data was collected:
• Active air sampling of bio-aerosols using a NIOSH BC215 sampler and inhalable dust using a GSP sampler at six locations. Samples were analyzed for common bacterial biomarkers (16S rRNA gene, S. Salivarius, S. epidermidis) by qPCR, and total bacteria by culture for NIOSH samples.
• Particulate matter size distribution in 31 size fractions using GRIMM samplers, and indoor air quality parameters (CO2, temperature and relative humidity) measured by sensors at 1 minute intervals at seven locations.
• Passive total bacterial aerosol samples were collected at 11 locations in the room by exposing tryptone soy agar plates.

Data collection has just been completed, and sample analysis in the laboratory is ongoing. We expect to present a full analysis of the results at the conference. These kinds of experiments will add to the body of evidence in addition to modeling and artificial experimental studies to improve future risk assessments.

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A two-step interactive tool to calculate the exposure dose and the infectious risk in indoor compartments

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Objective
The idea of creating a computational tool that, with a high degree of interactivity, allows demonstrating both the temporal evolution of the concentrations of a biological contaminant and carbon dioxide (CO2) within an indoor compartment arose during the preparation phase of the modules that the first author taught on a course organised by REHVA about the Safe Operation of Buildings and HVAC Systems during the COVID-19 pandemic. The concept of a high degree of interactivity should be understood as the possibility of the tool allowing the modification of the different parameters that, in some way, influence the temporal evolution of the concentration of contaminants during the occurrence of the simulation process itself, allowing immediate visualisation the effect of the introduced change. In this way, the trainees following the course have a much faster and more complete perception of the impact of each parameter governing the evolution of the studied phenomenon. For a previously defined duration running test, the initially developed tool displays concentrations of CO2 (ppm) and the bio contaminant (Pfu/m3) and the time history of the dose inhaled by a receiver with and without a protective mask. In this initial tool, mainly the physical phenomena related to the emission of the contaminant by an infected agent, its transport, dilution and persistence in the volume of air of the compartment and the reception by the breathing system of a sensible receiver are considered.
In the second phase, the tool was complemented by calculating the infection risk by implementing the Wells-Riley method once the correspondence between the quantity of inhaled contaminant agents and the "quanta"concept was settled. This method considers the infectiousness of the biological contaminant and the resistance of the sensible receivers'immune systems. Thus, the biological characteristics of the sensible receiver and the contaminant agent are considered when calculating the risk of infection once the exposure dose quantity is known.

Methods
The tool has been developed in the LabView programming software and benefits from its good graphical display tools. The tool uses the finite differences formulation for the first step, calculating the concentration variation along equally spaced sampling time instants. It was designed to accept the change of the governing parameters during the simulation of cases, allowing an immediate perception of the effect of the introduced changes. It takes into account the impact of the following variables: emission rate of bio contaminant source, half-life time of bio contaminant, efficiency of protective mask wearied by the emitter, efficiency of protective mask worn by the receiver, fresh air flow rate, volume of the room, number of occupants in the room and respective corpulence data and metabolic rate, flow rate of an indoor installed air cleaner device and individual one-pass purification efficiency. It also allows the simulation of instantaneous high-spread respiratory events like coughing or sneezing.

Results
A parametric study has been conducted for the case of a school room, considering the influence of the air exchange rate and the use of masks by the emitter and the receiver. The values selected for the air exchange rate were defined to cover situations ranging from a closed room, with air exchange assured only by infiltration (0.25 h-1), to a typical mechanical ventilation case (6 h-1) passing through the usual natural ventilation air exchanges (2 to 3 h-1). Between the worst case (a shallow 0.25 h-1, without masks used by the receiver and the emitter) and the best case (6 h-1 and masks used by the emitter and the receiver), the inhaled dose is reduced 63.4 times. Even for the air exchange rates usually achievable with a natural ventilation system, 2 to 3 air exchanges per hour, the reduction is between 25 and 35 times for using masks on both sides of the transmission line.

Conclusions
The developed computational tool proved quite interesting for the knowledge transmission process,

allowing a swift demonstration of the effect of each governing parameter due to its highly interactive character. It stimulates the evolution of a biological contaminant and CO2, which is advantageous since CO2 concentrations are much easier to measure in real-time than biological contaminants. The two concentrations usually have good correlations unless a disinfection device is installed in the room or the infected agent has some high airflow rate respiratory events, like coughing or sneezing.

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Airborne Pathogen Monitoring and Ventilation Assessment on Passenger Ships

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Large passenger ships are characterised as enclosed/crowded spaces with frequent interactions, providing conditions that facilitate disease transmission. Moreover, super-spreading events (Abe et al., 2022; Althouse et al., 2020) have been reported to have occurred in these environments. The COVID-19 pandemic demonstrated a profound inability of existing passenger ship policies to detect/address newly developing diseases. To enhance the passenger experience, this research has conducted three sets of studies: (i) systematic literature review (Kumar et al., 2025), (ii) exhaled tracer gas experiments (Hama et al., 2025 (in preparation), (iii) localised CO2 monitoring (Cheung et al., 2025). The goal of these studies is to achieve a comprehensive understanding of indoor environmental quality (IAQ), ventilation conditions, aerosol dispersion and respiratory disease infection risk aboard.

The first study is a systematic literature review, the search was developed to (i) examine typical concentrations of airborne aerosols and ventilation parameters aboard, and instruments used for monitoring; (ii) assess existing methods for understanding infectious risk. Followed by controlled conditions tracer gas experiments and CO2 mapping conducted onboard a sailing cruise ship. The tracer gas experiment aims to achieve an understanding of the ship's infiltration rate and ventilation performance in controlled conditions. Two shipboard spaces were selected, each having a CO2 cylinder (CO2) and a nebuliser with KCl solution (particles). Sensors were installed around the room. The release of CO2 was controlled by flow rate and temperature. Six heat blankets were used to generate a fluctuation in CO2 and aerosol dispersion. The localised study aims to investigate ventilation conditions and identify the risk of transmission of airborne disease. Thus, to deliver actionable recommendations on the ventilation operation. IAQ monitoring was conducted in nine environments (three cabins, buffet, gym, bar, restaurant, pub, and theatre). CO2 concentrations, temperature, and relative humidity were monitored.

The review suggests that future studies should focus on obtaining airborne aerosol dispersion data under controlled experimental conditions and real-world shipboard environmental parameters, that are suitable for the development of a framework for a diverse range of passenger ship environments. The tracer gas experiment shows an understanding of airflow behaviour and the accompanying dispersion of exhaled droplets. Horizontal and vertical variations of CO2 and particles are found to understand spatial variation of CO2 and particles in ventilated-controlled rooms. This work produced high-resolution data for validating the detailed numerical models for a large passenger ship. The localised monitoring found the probability of airborne infection transmission during normal speaking conditions to be very low (<3%). However, in higher occupancy areas where voices are raised to be heard (dining areas and social settings at peak times), CO2 levels increased, suggesting additional mitigatory measures are required. It also identified challenges from port emissions impacting IAQ aboard the cruise ship, with elevated ambient CO2 levels in berths.

This study sets the stage for further exploration and provides practical recommendations for the optimisation of ventilation operations in passenger ships, contributing to providing a safe sailing environment and resilience for future pandemics.

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Evaluation of the effectiveness of in-room portable high-efficiency particulate air (HEPA) air purifiers in improving indoor air quality (IAQ) in School setting.

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Abstract

The Illinois School Indoor Air Quality Impact Study is a collaborative initiative funded by SHIELD Illinois, the University of Illinois System's initiative that brought innovative saliva-based COVID-19 testing to K-12 schools and later transitioned to assisting schools with other preventative measures. The collaboration involves the Illinois Department of Public Health (IDPH), the University of Illinois Chicago (UIC), and Illinois Institute of Technology (IIT). The project aims to evaluate the effectiveness of in-room portable high-efficiency particulate air (HEPA) air purifiers in improving indoor air quality (IAQ) in pre-K through 6th-grade classrooms in Illinois, which were provided to public schools by the IDPH in 2023.

The team has recruited 3 schools in each of urban, suburban, and rural areas that received air purifiers through this program and have agreed to long-term indoor monitoring in their classrooms. In each

school, at least two classrooms of the same grade, size, and student population were selected for monitoring, including at least one with an air purifier and at least one without an air purifier. In each of these classrooms (with and without an air purifier), a low-cost IAQ monitor (Atmocube, Atmo, USA; capable of measuring PM1, PM2.5, PM4, PM10, CO2, VOCs, noise, temperature and relative humidity) and a plug load data logger (HOBO UX120, Onset Corp, USA) were deployed to monitor IAQ conditions and air cleaner power operation patterns throughout the school year (target: 12 months). In a more limited number of schools, two Protector 2 Pro (Naneos, Switzerland) monitors, measuring particle number concentrations (PNC) and size distribution in the range of 10-300 nm, one in a classroom with air purifier and one in a classroom without air purifier, were also deployed for a shorter duration (target: 3 months). For this conference, we will present the PNC and PM mass concentration data from two schools, namely schools A and B, located in an urban area.

Preliminary data from School A and School B provide insightful comparisons regarding the impact of air purifiers on air quality. In School A, on weekdays, classrooms with air purifiers ("With AP") had a significantly lower mean PM2.5 concentration of 1.95 µg/m³ compared to classrooms without air purifiers ("No AP"), which had a mean PM2.5 concentration of 3.78 µg/m³. Outdoor PM2.5 levels averaged 5.09 µg/m³ on weekdays, with a maximum observed value of 44.7 µg/m³. The maximum PM2.5 levels in classrooms with air purifiers reached 8.2 µg/m³, while those without air purifiers were significantly higher, peaking at 13.0 µg/m³. On weekends, when air purifiers are assumed to be turned off (plug load data logging is still ongoing and not all data have been retrieved yet), the mean indoor PM2.5 level in classrooms without air purifiers dropped to 2.79 µg/m³, and outdoor levels increased to 7.59 µg/m³, with a maximum of 52.0 µg/m³.

Similarly, School B showed trends supporting the effectiveness of air purifiers. On weekdays, classrooms with air purifiers maintained a mean PM2.5 level of 0.98 µg/m³, while this concentration remained almost unchanged in classrooms without air purifiers (a mean of 1.01 µg/m³). Outdoor levels averaged 11.51 µg/m³, with a dramatic maximum of 415.4 µg/m³. The maximum observed PM2.5 levels in classrooms with air purifiers was 5.7 µg/m³, while those without air purifiers reached 14.7 µg/m³. On weekends, the levels in classrooms without air purifiers dropped to 0.47 µg/m³, while outdoor PM2.5 levels were 3.35 µg/m³, with a maximum of 35.4 µg/m³. On weekends, a noticeable decrease in indoor PM2.5 levels is observed.

These data underscore the significant role that air purifiers can play in maintaining cleaner indoor air during school hours, especially in environments with higher outdoor pollutant levels. Nevertheless, a proper comparison of the PM and UFP concentrations in classrooms with and without air purifiers will be conducted when data from plug load loggers are available indicating the period when the air purifiers were in operation and their setting level.

In addition to analyzing real-world classroom conditions, a laboratory study is underway to replicate typical classroom activities (e.g., painting, gluing, use of printers, and microwaves), which are known to be the source of ultrafine particles (UFPs) in schools. This lab study aims to explore how the air purifiers currently being utilized in schools in IL might influence the UFP concentrations and their size distributions. We will continue data collection and data analysis until the conference and will present our final conclusion on the effectiveness of the air purifiers in schools A and B.

Findings from this study will guide public health strategies and policies to enhance air quality in schools, ensuring a healthier learning environment for all.

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Advancing Air Purification in indoor HVAC system: A 90-Day Comparative Study of Cold Plasma Ionization Electrical Filter (IEF) and conventional bag filter system in filtration performance, energy efficiency, and pressure drop in a medical facility

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1.Abstract
Indoor air purification and disinfection in medical facilities represent multi-billion dollar markets. [1] Compared to conventional HEPA and activated carbon filters, electrostatic filtration with low-temperature plasma technology offers several unique advantages. The plasma field charges fine particles and captures them using an oppositely charged electrode [2]. Simultaneously, high-energy radicals generated by the plasma field effectively eliminate bacteria and germs. Collected pollutants adhere to the electrodes, which are washable, eliminating the need for disposable filters. This not only reduces operational costs but also minimizes secondary pollution. Additionally, the technology's open structure enhances airflow, ensuring a consistent CADR while simultaneously reducing energy consumption by up to 20%, which significantly lowers the carbon footprint.

We will explore the principles of cold-temperature plasma technologies in air filtration and showcase prototypes of the IEF designed based on these principles. To demonstrate the benefits of cold plasma ionic electrical filtration (IEF) technology—particularly its advantages in air filtration and HVAC performance—we developed an in-house system to compare its energy consumption and pressure drop against an H11 HEPA filter under identical ducting and airflow conditions. The system features an air switch that allows airflow to be directed through either the HEPA filter or the IEF module. By continuously monitoring pressure drop and power consumption for both setups, we have shown that at an airflow rate of 3 m/s, the TPA filtration system exhibits only about one-third of the pressure drop of the HEPA system under the same configuration.

To validate our findings in real-world applications, we also collected in-situ data on filtration efficiency, pressure drop, and power consumption of an IEF filter compared to a F9 bag filter used as standard. Over a 90-day period, we continuously monitored and recorded performance data, which demonstrated highly promising results for the IEF filter in terms of stability and energy savings. These insights offer valuable guidelines for practical implementation in real-world applications.

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Introducing the Human-Centric Indoor Climate for Healthcare Facilities (HumanIC) project

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Objectives: This paper introduces the "Human-Centric Indoor Climate for Healthcare Facilities" (HumanIC) project, granted in the EU Marie Curie Program framework. It aims to advance the understanding of the human-centric indoor climate (HCC) within hospital environments, focusing on its impact on patient safety, infection control, thermal comfort, and energy efficiency. The objective aligns with the Europe 2030 strategy to foster innovative and sustainable health systems, enhancing healthcare quality for EU citizens. The Warsaw University of Technology leads the project, including eleven doctoral research theses across eight leading European universities.
Methods: The HumanIC network adopts a multidisciplinary approach to explore the interactions between contamination sources and airflow distribution systems in hospital indoor environments. Research methods include analysing airflows and contaminant particles, optimising ventilation systems for various healthcare activities, and developing real-time interaction tools for design and operational phases. This innovative approach transcends traditional methods, focusing on building designs and ventilation systems and the complex interactions between contamination sources, airflow dynamics, and hospital clinical needs.
Results: The initial findings indicate that poor indoor climate conditions contribute significantly to healthcare-associated infections (HAIs), which affect over 4 million patients annually and approximately 80,000 cases reported daily in the EU. The study recognises that the hospital environment is

responsible for 20% of HAIs and that improved indoor environments can reduce airborne illness costs by 9%-20%. By examining transient dispersion of contaminants in critical areas such as operating rooms and isolation units, new knowledge is generated to inform health facility design, addressing the dual challenges of minimising airborne threats while ensuring thermal comfort.
Conclusions: The promotion of HCC in hospitals offers a promising pathway to enhance patient outcomes and operational efficiency. The HumanIC network will continue until 2027, producing innovative design methodologies and technical solutions incorporating human interactions within hospital settings. Moreover, the initiative will foster an inclusive scientific community dedicated to advancing healthcare environmental engineering, aiming for diverse representation with a commitment to attracting and supporting underrepresented groups in science and engineering. The findings and methodologies from this research may lead to significant improvements in hospital design and operation, ultimately reducing HAIs and improving patient care.

SESSION 1a - Particles Emission: Understanding sources, estimation and measurements, Keynote Speakers / 111

Airborne particle emission from indoor combustion sources

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SESSION 1a - Particles Emission: Understanding sources, estimation and measurements, Keynote Speakers / 112

Studying airborne disease transmission in indoor settings: an epidemiologist's perspective

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SESSION 2a - Exposure and Dose: Assessing the human health implications / 113

Aspects of host immunity that can impact transmission and susceptibility to airborne infections

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SESSION 2a - Exposure and Dose: Assessing the human health implications / 114

Human health and ambient air pollution: patterns of exposure and health effects

SESSION 3a - Mitigation Measures and Strategies: Exploring environmentally sustainable solutions such as indoor ventilation and beyond,Keynote Speakers / 115

Designing the Air: Maximizing Viral Decay to Limit Disease Transmission

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SESSION 3a - Mitigation Measures and Strategies: Exploring environmentally sustainable solutions such as indoor ventilation and beyond,Keynote Speakers / 116

Ventilation (huh, yeah). What is it good for?

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SESSION 4a - Mathematical Modeling and Risk Assessment, Keynote Speakers / 117

Building Performance Standards & Risk Assessment Tools: Perspectives from Facilities Management

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Modelling Natural Processes: A Multidisciplinary Advantage or Burden

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SESSION 5a - Way Forward, Keynote Speakers / 119

Translating scientific knowledge into policies that ensure clean indoor air

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Public Empowerment in a Time of Crisis: The Effectiveness of Do-It-Yourself Air Cleaners

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Application to building policy, what is missing, needed to improve/implement and next steps

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SESSION 5b - Way Forward, Keynote Speakers / 122

Data gaps, the precautionary principle, and the tragic consequences of type-II errors

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SESSION 4b - Mathematical Modeling and Risk Assessment, Oral Presentations / 124

The role of numerical modeling in improving indoor air quality

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The COVID-19 pandemic significantly contributed to deepen our understanding of respiratory virus transmission, emphasizing the critical role of indoor environments and the necessity of effective ventilation. Historically, public health guidelines primarily addressed large droplet as transmission routes. It was not until the spring of 2021, due to the increasing scientific evidence, that major health organizations like the US CDC and WHO recognized airborne transmission as the predominant pathway for SARS-CoV-2. Environmental measures to disinfect and clean surfaces in public and semi-public places did not significantly reduce the spread of COVID-19. In contrast, the cancellation of small gatherings and the closure of educational institutions, i.e., activities characterized by high crowding in poorly ventilated indoor environments, had a significant impact on reducing the spread of the virus.
This shift underscored the importance of managing indoor air quality through improved ventilation and air cleaning strategies. Numerical modelling, from zero-dimensional (0D) to complex three dimensional (3D) Computational Fluid Dynamics (CFD) techniques, have proven essential in optimizing HVAC systems and designing effective airflow patterns to ensure safety and comfort in confined spaces. This work presents mathematical and numerical modelling activities conducted in various indoor environments, contributing to a better understanding of pollutant and viral aerosol transmission, with a particular emphasis on validating the results obtained.
The transmission of respiratory viruses occurs through three routes: large respiratory particles (spray) transmission, inhalation of airborne respiratory particles, and touch transmission. Historically, public health guidelines underestimated airborne transmission, but the pandemic highlighted its significance. Enhanced ventilation and air cleaning strategies, supported by numerical modeling, particularly CFD, are crucial for mitigating airborne transmission. In fact, CFD provides detailed insights into velocity, pressure, and temperature fields, as well as particle distribution, enabling the optimization of HVAC systems and airflow patterns in confined spaces.
This study employs a Eulerian-Lagrangian approach to model the dispersion of virus-laden respiratory particles in indoor environments. The model tracks individual particles using a force balance equation, considering forces such as drag, gravity, and virtual mass. The particle number emission

rate (ERN) and volume distributions were estimated based on experimental data, focusing on airborne respiratory particles (<90 µm). The model was validated through experimental measurements, including Particle Image Velocimetry (PIV), and applied to various indoor settings, such as close-contact interactions, car cabins, and university lecture rooms.
CFD simulations demonstrated that large respiratory particles (>100 µm) significantly contribute to infection risk at distances less than 0.6 meters, while airborne respiratory particles dominate at greater distances. In car cabins, airflow patterns significantly influenced the spatial distribution of virus-laden particles, with higher exposure risks for passengers sitting behind an infected driver. In lecture rooms, the air change rate (ACH) alone was insufficient to assess exposure risk; local airflow patterns and the asymmetric disposition of seats relative to diffusers and exhaust grilles played crucial roles.

SESSION 2b - Exposure and Dose: Assessing the human health implications, Oral Presentations / 125

Exposure to Cooking-Generated Ultrafine Particles and its neurological and Cardiopulmonary outcomes: A Controlled Clinical Study

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Indoor ultrafine particles (UFPs) represent a growing concern, as people spend approximately 90% of their time indoors (Klepeis et al., 2001). UFPs, which are particularly prevalent in indoor environments, are produced by a variety of sources, including combustion processes like cooking (Lachowicz et al., 2022, Massey et al., 2012). Given the importance of cooking as a daily activity, it is crucial to understand the potential health effects of UFPs generated during cooking, especially considering the potential for these particles to impact vulnerable populations. UFPs are small enough to penetrate deep into the respiratory system, and research has suggested that they may translocate to the brain, potentially causing neuro inflammation and exacerbating neurological conditions (Kulkarni et al., 2011, Marval and Tronville, 2022, Thomas, 2013). This study aimed to investigate the effects of cooking-generated UFPs on cardiopulmonary and neurological outcomes. More specifically, the study was designed to separate the health outcomes of cooking-generated UFPs from cooking-emitted gases. A crossover controlled clinical trial was conducted with 60 healthy volunteers, who participated in two separate experimental sessions held over 48 consecutive hours. One session served as a baseline condition (24 hour), where participants remained in the apartment without any cooking, while the other involved cooking to generate UFPs. In the exposure (cooking) condition (24 hour), participants were exposed to cooking aerosols produced during frying chicken and fries.

The study was divided into two phases: Phase 1 (control), which focused on the effect of cooking-generated aerosols and, phase II (intervention) focused on that of cooking-generated gases. For the Phase II study, P100 respirators (3M™ particulate respirators, model 8293, P100) were employed to mitigate particle exposure. On both the cooking and control days, participants were instructed to wear a P100 respirator from 09:25 until the particle concentration levels returned to background levels, typically around 15:00. Electroencephalography (QEEG) was used to monitor brain electrical activity throughout the experiments. Measurements were taken at 21 different time points over a 48-hour period, starting from one hour after the participants' arrival in the apartment. The study utilized a variety of other health measurements to monitor the participants'cardiovascular and pulmonary responses. These included a portable electrocardiogram (ECG) to measure heart rate, an Omron 10 blood pressure monitor to record systolic and diastolic blood pressure, a pulse oximeter to measure blood oxygen levels, and a Bedfont NObreath FeNO monitor to assess fractional exhaled nitric oxide (FeNO) only in phase I. Peak flow rate was also measured to assess lung function. The cognitive assessment in this study utilized two key tools: the Hopkins Verbal Learning Test-Revised (HVLT-R) and the WAIS-IV processing speed index. HVLT-R is a verbal memory assessment comprising a 12-word list presented over three learning trials. The WAIS-IV's Processing Speed Index is a standard score derived from a participant's performance on coding and symbol search subtests. The HVLT-R and WAIS-IV tests were conducted four times, including the 11:30 control day, 9:00, 10:30 and 9:00 last day.
Our results showed short-term exposure to particles and gases emitted from frying chicken and fries using either gas or electric stoves led to statistically insignificant changes in blood pressure, heart rate, PERF, or oxygen saturation up to 24 hours post-exposure. This observation was confirmed for both control and intervention studies. However, the pulmonary function during phase I, as indicated by FeNO levels, showed significant changes, with a noticeable increase immediately following cooking exposure, which persisted for up to two hours. The differences HVLT-R scores including the immediate recall, delayed recall and Recognition Discrimination Index (RDI) between baseline and exposure days for both intervention and control studies were statistically insignificant. The results of the WAIS Symbol Search and Coding subtests were statistically significant between 9:00 a.m. cooking day and 9:00 am the third day approximately 24 hours after cooking for intervention study. Statistically significant reductions were observed in the coding test score at 11:30 a.m. during exposure day compared to the baseline day in Phase I. EEG results will be presented during the conference presentation.
The findings underscore the need for further research into the long-term effects of indoor air pollution, especially for individuals with pre-existing health conditions, such as Alzheimer's disease. The transient but significant changes observed in both brain activity and pulmonary responses emphasize the importance of considering indoor air quality, such as homes.

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CFD optimization of a personal air cleaner to protect from airborne particles in transport microenvironments

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Transport microenvironments are critical indoor settings where exposure to environmental pollutants and respiratory particles poses significant health risks. Commuters in cars, buses and other means of transportation are particularly vulnerable due to the high concentration of pollutants on roads and highways, combined with inefficient filtration systems in vehicle. These factors result in high concentrations of toxic gases and particles entering transport microenvironments through windows, HVAC systems, or cabin leakages. An additional health concern is the increased risk of infection from airborne transmission of virus-laden respiratory particles, due to crowding and poor

ventilation. Mitigating exposure in transport environments is challenging, as conventional HVAC systems often fail to provide adequate protection. Consequently, research has focused on personal ventilation solutions such as air curtains, directional jets, and portable air purifiers. Their design, however, requires careful optimization to prevent thermal discomfort and unintended particle recirculation.
In response to these challenges, we have developed and patented a portable personal air cleaner (patent n. 102022000010346) designed to reduce airborne particle exposure. When placed on desks or tables in front of users, this device creates a protective fluid-dynamic shield by supplying filtered air in a controlled flow pattern, effectively lowering airborne particle concentrations in the breathing zone of a seated individual. Its effectiveness was demonstrated through 3D Computational Fluid Dynamics (CFD) simulations validated by experimental measurements, showing protection rates exceeding 92% in close-proximity settings and 99% in shared indoor environments.
Building on this fluid-dynamic approach, this study introduces a validated CFD methodology for designing a personal air cleaner optimized for transport environments. The proposed device, intended for installation above the users'head (e.g., for bus and truck drivers), operates on a dual airflow system: an outer high-velocity annular jet forming a protective shield around the users' head and a central low-velocity swirl flow minimizing particle exposure while maintaining comfort. The development process consisted of three stages: (i) CFD-based diffuser design; (ii) experimental air velocity characterization and numerical model validation; (iii) particle number and mass (PM10) concentrations measurements, in both the protected area generated by the personal ventilation and in ambient air to determine the reduction in airborne particle concentration.
Advanced 3D CFD simulations allowed optimize the internal geometry of the diffuser to achieve a uniform conical jet structure, thereby enhancing the protective shield's effectiveness. The device was then prototyped and tested using a 3D-printed model equipped with a commercially available fan filter unit, which imposed specific geometric constraints influencing design choices. Validation was performed through velocity fields measurements using a multi-hole pressure probe, confirming the reliability of the CFD model in predicting flow behavior.
Particle number and PM10 concentrations measurements further demonstrated the air cleaner effectiveness in reducing airborne particle concentrations within the protected area. A reduction of up to 60% was observed at 15 cm from the airflow injection, then decreasing with the distance. Notably, an excessive increase in the annular flow rate was found to reduce the effectiveness of the device, underscoring the importance of precise flow balancing. Despite the geometric constraints imposed by the commercial fan filter unit, the achieved reduction in exposure highlights the feasibility of using targeted airflow patterns to protect individuals in transport microenvironments. The validated CFD tool is currently being used to refine the air cleaner's configuration, free from the limitations of the commercial fan filter unit, to enhance overall efficiency. Specifically, ongoing numerical simulations focus on increasing the annular section diameter to extend the distance between jets, thereby mitigating interference between the annular jet and the central swirling jet –an identified limiting factor in the device's efficiency. By optimizing these dimensions, the protective shield's effectiveness is expected to improve.
Additional simulations will assess real-life interactions, including the impact of the user's thermal plume on airflow patterns and protection efficiency. These efforts aim to optimize airflow dynamics in practical applications, ensuring the device's effectiveness under varying environmental conditions. Ultimately, this research paves the way for the commercialization of a portable, high-efficiency personal air cleaner designed specifically for transport applications, addressing the urgent need for improved air quality in enclosed commuting environments.

SESSION 5a - Way Forward, Keynote Speakers / 127

Setting the Stage for the Final Session -

Luca Fontana

SESSION 5a - Way Forward, Keynote Speakers / 128

Safe and scalable care in the context of respiratory pathogens - Janet Diaz

SESSION 2b - Exposure and Dose: Assessing the human health implications, Oral Presentations / 129

Outdoor Concentration versus Personal Exposure in Urban Residents: Which PM2.5 Metric Is Associated with Respiratory Pathophysiology?

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Objective: Contemporary outdoor PM2.5 levels are generally low in Western cities, which may make indoor contributions to personal exposure more significant. We aim to compare acute effects of PM2.5 measured as outdoor concentration versus personal exposure on respiratory pathophysiologic indicators in adults with or without asthma.
Methods: From 2021-2023, we conducted a panel study in 42 adults (17 with and 25 without asthma) residing in London, UK. Each participant was measured in a summer month and a winter month for airway resistance (R5, R20, and R5–R20), lung function (FEV1), and pulmonary inflammation (FeNO). Outdoor PM2.5 concentration was estimated hourly over the 48 hours preceding each health assessment using the inverse distance weighting (IDW) method using the data measured at 3 nearby monitoring stations. Personal PM2.5 exposure was measured over the same period using Airspeck-P wearable sensor attached to participants. Mixed-effects models combined with distributed lag models (DLMs), including an interaction term for asthma status, were applied to evaluate the effects of 4-hour averaged outdoor and personal PM2.5 exposure, respectively.
Results: Outdoor PM2.5 concentrations were higher than personal concentrations, with median (IQR) being 6.03 (6.21) $\mu g/m^3$ and 2.71 (4.36) $\mu g/m^3$, respectively. We observed significant associations of increasing outdoor PM2.5 concentrations with increased airway resistance (effect lagged by 8-19 hours) and with decreased lung function (effect lagged by 8-31 hours) only in asthmatic participants (not in healthy participants). In contrast, personal PM2.5 exposure was not significantly associated with any of the respiratory pathophysiology indicators.
Conclusion: Individuals with asthma showed worsened respiratory pathophysiology 8 –31 hours after an increase in 4-hour averaged outdoor PM2.5 concentration. Substantially lower personal PM2.5 exposure compared to outdoor PM2.5 concentration suggests that indoor PM2.5 levels were lower. Sources and factors associated with indoor PM2.5 exposure may have attenuated the respiratory effects of outdoor PM2.5 under contemporary air quality conditions in London.

SESSION 5a - Way Forward, Keynote Speakers / 130

Safe and scalable care in the context of respiratory pathogens

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Airborne nanomaterials in the workplace: graphene exposure characterization and risk mitigation measures

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Exposure characterization (1) during the production phases (freeze-drying of graphene ink obtained by liquid phase exfoliation of graphite layered crystals (2)) of few layers graphene (FLG) was carried out in a Research and Development (R&D) laboratory, following a multiparametric tired approach based on the Organization for Economic Cooperation and Development (OECD) harmonized guidelines (3). Real-time measurements of particle number concentration (PNC), average diameter and lung deposited surface area, were performed. Time-integrated measurements were also achieved using inertial impactors for offline analytical characterization by Scanning (SEM) and Transmission Electron Microscopy (TEM) and Raman spectroscopy. Simultaneously to the exposure scenario measurements and samplings, biological monitoring was performed on workers involved in FLG production (4).
Results obtained from real time measurements could not exclude the FLG spillage in the air, especially when workers handled graphene in powder form, during the phase of produced materials storage and subsequent cleaning of surfaces and equipment (STOCLE). During STOCLE, FLG projected diameter (dproj) was obtained by SEM images, and it was compared with the corresponding calculated aerodynamic diameter (dae): because of the unusual aerodynamic property of platelet-like particles, FLG could penetrate and settle in a deeper region of the respiratory tract if dae is lower than dproj, as the electron microscopy evidence suggest. Raman spectroscopy and SEM analysis highlighted that the collected material was most likely FLG (i.e. morphology of flat carbon layers); finally, selected area electron diffraction (SAED) with TEM (i.e. SAED patterns related to both single and stacked graphene layers), allowed to definitively confirm the presence of airborne FLG in the workplace.
One year later in the same R&D laboratory, real time measurement and offline characterization analysis were performed again during the STOCLE, after the introduction of mitigation measures including a new fume hood and ventilated glove boxes to reduce the workers exposure to FLG in powder form, during the handling task (5). PNC time series, before and after the introduction of such mitigation measures, were compared using the non-parametric paired Wilcoxon Test (0.05 significance level) and their PNC mean values were respectively 3530 (std. dev. 1126) part/cm3 and 2914 (std. dev. 1380) part/cm3. Although a lowering of PNC values, SEM analysis revealed only one graphene aggregate, after scanning several fields, highlighting the presence of rare and residual airborne FLG. Workers were recommended to continue using respiratory personal protective equipment during the STOCLE phase.
Based on the previous results obtained in the R&D laboratory , the exposure in the scaling up of FLG production in a pilot plant has been investigated, following a prevention-through-design approach (6): the amount of FLG produced increased by ca. 20 times compared to the R&D laboratory(2 kg per cycle vs 100g per cycle) and the STOCLE phase, placed in a room separated from the other workplace areas, is confirmed to be the most critical work task.
In conclusion, the strategy applied, by the integration of real-time measurements and off-line characterization techniques, to characterize a complex exposure scenario such as the FLG manufacturing process, can provide a valid basis for both the risk assessment and management but also it can give valuable information for a prevention-through-design approach in scaling up the production from R&D laboratory to the pilot plant.

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Lessons learned by Covid-19 pandemic mitigation measures to improve ultrafine particles exposure in a university dining hall

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Particulate matter (PM) has been recognized as leading health risk factors worldwide, contributing to adverse effects for exposed people in life and work environments. During the Covid-19 pandemic period, it has been shown how environmental factors, including ultrafine particles (UFPs) and PM concentrations, may play an important role in SARS-CoV-2 differential distribution and transmission. In particular, the literature highlighted the contribution of chronic exposure to air pollution on the pandemic spread and the close correlation between Covid-19 and airborne PM2.5.
The main aim of the present study is to investigate the effects on improving UFPs exposure of the mechanical ventilation system equipped with plasma-based filter technology, installed as Covid-19 mitigation measure in the dining hall of a university site.
An experimental campaign was conducted in May 2021 to assess the impact of the mechanical ventilation system on UFPs concentration levels related to the activities carried out in the canteen, by high frequency (1 Hz) real-time measurements of particle number concentration (PNC) and particle average diameter (Davg). Furthermore, concentrations of indoor pollutants such as PM, total volatile organic compounds (TVOCs) and CO2 have been monitored by low-cost sensors to evaluate the indoor air quality for the users (workers and students), as possible indicator of indoor air quality improvement and Covid-19 risk mitigation. Measurements were performed in three working days: in day 1 electrostatic UFP filters were activated on all the fan coils; in day 2 the filter option was turned off and measurements continued also during the night until the morning of day 3. The places were frequented by students, teachers and staff personnel for meals on two different shifts (lunch and dinner). The kitchen and canteen service workers have access to the site even before and after two shifts for preparation and recovery/cleaning operations. Progressive anonymous data counting of users'access during the lunch and dinner shifts were allowed.
Indoor PNC (Dp < 700 nm) levels resulted mainly influenced by outdoor particles level, meals preparation, recovery/cleaning activities and users'turnout in the dining hall. In particular, PNC increase and great variability in the indoor measurement points were strictly related to the dining activities, reaching the maximum average PNC level of 30,000 part/cm3 (st. dev. 16,900 part/cm3) during the dinner time of day 1. Davg (Dp < 300 nm) increase has been highlighted during the lunch and dinner times, mostly in day 2 than in day 1, passing from 22 nm during the nighttime to 48 nm during the

post dinner recovery activities in day 2. By the comparison between PM1 low-cost sensor response and high-resolution (1 Hz) PNC and Davg data in the same sampling point, the general trend alignment between PNC and PM1 was respected, both instruments highlighting peaks in correspondence to the lunch and dinner activities. Low Davg values correspond to higher PNC compared to PM1, while high Davg values reflect lower PNC compared to PM1. This behavior is consistent with the major contribution given by smaller particles in terms of PNC as compared to the PM1. By the comparison of PNC levels between day 1 and day 2 it has been observed that the use of plasma-based filter technology produced a reduction of average PNC (Dp < 700 nm) estimated up to a maximum of 3 times, in the tested conditions of use, providing an effective mitigation of UFPs concentrations particularly during the periods of access to the dining hall by the users. As expected, the number of persons present inside the dining hall was correlated to the CO2 levels (Pearson r = 0,81) and TVOCs resulted upper during the cleaning activities for meals preparation compared to the other time slots. Although the findings of the present study are subject to some limitations, strictly related to the short period available for measurements, the obtained results confirm the useful contribution of mechanical ventilation systems with plasma-based filters technology, to improve the UFP levels in indoor environments. They were successfully used in addiction to the general Covid-19 containment measures such as physical distancing, prevention of crowding and cleaning/sanitization procedures to guarantee the safe use of the university dining hall during the pandemic period. This kind of systems could be generally adopted also after the pandemic emergency, to improve indoor air quality and UFPs exposure levels during the current activity and use in the dining hall.

SESSION 2b - Exposure and Dose: Assessing the human health implications, Oral Presentations / 134

Indoor clean air for kitchens and other living spaces