Rapport de veille n° 69

Aéraulique et COVID-19

24/05/2023

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

Google Scholar, Lens et WoS

Song, Y., Yang, C., Li, H., Chen, H., Shen, S., Hou, Y.*, et al.*
Aerodynamic performance of a ventilation system for droplet control by coughing in a hospital isolation ward.
Environmental Science and Pollution Research, (2023)

Over 766 million people have been infected by coronavirus disease 2019 (COVID-19) in the past 3 years, resulting in 7 million deaths. The virus is primarily transmitted through droplets or aerosols produced by coughing, sneezing, and talking. A full-scale isolation ward in Wuhan Pulmonary Hospital is modeled in this work, and water droplet diffusion is simulated using computational fluid dynamics (CFD). In an isolation ward, a local exhaust ventilation system is intended to avoid cross-infection. The existence of a local exhaust system increases turbulent movement, leading to a complete breakup of the droplet cluster and improved droplet dispersion inside the ward. When the outlet negative pressure is 4.5 Pa, the number of moving droplets in the ward decreases by approximately 30% compared to the original ward. The local exhaust system could minimize the number of droplets evaporated in the ward; however, the formation of aerosols cannot be avoided. Furthermore, 60.83%, 62.04%, 61.03%, 60.22%, 62.97%, and 61.52% of droplets produced through coughing reached patients in six different scenarios. However, the local exhaust ventilation system has no apparent influence on the control of surface contamination. In this study, several suggestions with regards to the optimization of ventilation in wards and scientific evidence are provided to ensure the air quality of hospital isolation wards.

****
Baskara, S. A., Faridah, F., Utami, S. S., Prakoso, A. B.
Analysis of ventilation design for the existing education building in Covid-19 adaptation era.
Engineering Physics International Conference 2021 – Epic 2021. 24–25 August 2021. Yogyakarta, Indonesia

Covid-19 pandemic changes the paradigm of how the building should be designed. Health should be our priority over comfort. Learning activities should be conducted online to avoid the covid-19 transmission. But some departments need to deliver their materials offline immediately because not only to enhance student's cognitive and affective but also student's psychomotor like in the engineering department. In the end, we need to accept the condition and get ready for the new adaptation era. The most important thing is minimizing the probability of infection, even if it may decrease occupant thermal comfort. This study aims to show how to design good ventilation in a room for an existing educational building. This study demonstrates how to evaluate ventilation design in the building as a response to pandemic covid and comply with three standards and suggestions (ASHRAE, Harvard, and WHO). It starts with site observation, data collection, ventilation requirement calculation, trade-off analysis with the available services from the vendor, including cost-effective analysis and evaluation to the design process. In the ventilation calculation, there is a difference between the baseline design and the standard. The proposed design allows air change per hour between 5.2 to 12.4 ACH. Some adaptations have been made to propose the final ventilation design. Finally, an evaluation of the proposed design was carried out and was considered to meet the recommendations of WHO.

****
Ginsberg, M. D.
Bioprotection of Transportation and Facilities from SARS-CoV-2 (COVID-19).
Transportation Research Record, Vol. **2677** n°(4), (2023), pp. 396-407

The recent COVID-19 pandemic has led to a nearly world-wide shelter-in-place strategy. This raises several natural concerns about the safe relaxing of current restrictions. This article focuses on the design and operation of heating ventilation and air conditioning (HVAC) systems in the context of transportation. Do HVAC systems have a role in limiting viral spread? During shelter-in-place, can the HVAC system in a dwelling or a vehicle help limit spread of the virus? After the shelter-in-place strategy ends, can typical workplace and transportation HVAC systems limit spread of the virus? This article directly addresses these and other questions. In addition, it also summarizes simplifying assumptions needed to make meaningful predictions. This article derives new results using transform methods first given in Ginsberg and Bui. These new results describe viral spread through an HVAC system and estimate the aggregate dose of virus inhaled by an uninfected building or vehicle occupant when an infected occupant is present within the same building or vehicle. Central to these results is the derivation of a quantity called the "protection factor"-a term-of-art borrowed from the design of gas masks. Older results that rely on numerical approximations to these differential equations have long been lab validated. This article gives the exact solutions in fixed infrastructure for the first time. These solutions, therefore, retain the same lab validation of the older methods of approximation. Further, these exact solutions yield valuable insights into HVAC systems used in transportation.

****

Park, S., Song, D.
CO2 concentration as an indicator of indoor ventilation performance to control airborne transmission of SARS-CoV-2.
Journal of Infection and Public Health, Vol. **16** n°(7), (2023), pp. 1037-1044

Background The Wells-Riley equation has been extensively used to quantify the infection risk of airborne transmission indoors. This equation is difficult to apply to actual conditions because it requires measurement of the outdoor air supply rate, which vary with time and are difficult to quantify. The method of determining the fraction of inhaled air that has been exhaled previously by someone in a building using a CO2 concentration measurement can solve the limitations of the existing method. Using this method, the indoor CO2 concentration threshold can be determined to keep the risk of infection below certain conditions. Methods Based on the calculation of the rebreathed fraction, an appropriate mean indoor CO2 concentration and required air exchange rate to control SARS-CoV-2 airborne transmission was calculated. The number of indoor occupants, ventilation rate, and the deposition and inactivation rates of the virus-laden aerosols were considered. The application of the proposed indoor CO2 concentration-based infection rate control was investigated through case studies in school classrooms and restaurants. Results In a typical school classroom environment with 20–25 occupants and an exposure time of 6–8 h, the average indoor CO2 concentration should be kept below 700 ppm to control the risk of airborne infection indoors. The ASHRAE recommended ventilation rate is sufficient when wearing a mask in classrooms. For a typical restaurant with 50–100 occupants and an exposure time of 2–3 h, the average indoor CO2 concentration should be kept below about 900 ppm. Residence time in the restaurant had a significant effect on the acceptable CO2 concentration. Conclusion Given the conditions of the occupancy environment, it is possible to determine an indoor CO2 concentration threshold, and keeping the CO2 concentration lower than a certain threshold could help reduce the risk of COVID-19 infection.

****

Kapse, S., Rahman, D., Avital, E. J., Venkatesan, N., Smith, T., Cantero-Garcia, L.*, et al.*
Conceptual Design of a UVC-LED Air Purifier to Reduce Airborne Pathogen Transmission-A Feasibility Study.
Fluids, Vol. **8** n°(4), (2023)

Existing indoor closed ultraviolet-C (UVC) air purifiers (UVC in a box) have faced technological challenges during the COVID-19 breakout, owing to demands of low energy consumption, high flow rates, and high kill rates at the same time. A new conceptual design of a novel UVC-LED (light-emitting diode) air purifier for a low-cost solution to mitigate airborne diseases is proposed. The concept focuses on performance and robustness. It contains a dust-filter assembly, an innovative UVC chamber, and a fan. The low-cost dust filter aims to suppress dust accumulation in the UVC chamber to ensure durability and is conceptually shown to be easily replaced while mitigating any possible contamination. The chamber includes novel turbulence-generating grids and a novel LED arrangement. The turbulent generator promotes air mixing, while the LEDs inactivate the pathogens at a high flow rate and sufficient kill rate. The conceptual design is portable and can fit into ventilation ducts. Computational fluid dynamics and UVC ray methods were used for analysis. The design produces a kill rate above 97% for COVID and tuberculosis and above 92% for influenza A at a flow rate of 100 L/s and power consumption of less than 300 W. An analysis of the dust-filter performance yields the irradiation and flow fields.

****

Atari, N., Mamane, H., Silberbush, A., Zuckerman, N., Mandelboim, M., Gerchman, Y.

Disinfection of SARS-CoV-2 by UV-LED 267 nm: comparing different variants.

Scientific Reports, Vol. **13** n°(1), (2023)

UV irradiation is an efficient tool for the disinfection of viruses in general and coronavirus specifically. This study explores the disinfection kinetics of SARS-CoV-2 variants wild type (similar to the Wuhan strain) and three variants (Alpha, Delta, and Omicron) by 267 nm UV-LED. All variants showed more than 5 logs average reduction in copy number at 5 mJ/cm2 but inconsistency was evident, especially for the Alpha variant. Increasing the dose to 7 mJ/cm2 did not increase average inactivation but did result in a dramatic decrease in the inactivation inconsistency making this dose the recommended minimum. Sequence analysis suggests that the difference between the variants is likely due to small differences in the frequency of specific UV extra-sensitive nucleotide sequence motifs although this hypothesis requires further experimental testing. In summary, the use of UV-LED with their simple electricity need (can be operated from a battery or photovoltaic panel) and geometrical flexibility could offer many advantages in the prevention of SARS-CoV-2 spread, but minimal UV dose should be carefully considered.

****

Durongphan, A., Rungruang, J., Nitimanee, E., Panichareon, B.

The effects of enhanced formaldehyde clearance in a gross anatomy laboratory by floor plan redesign and dissection table adjustment.

Environmental Science and Pollution Research, (2023)

Formaldehyde has carcinogenic properties. It is associated with nasopharyngeal cancer and causes irritation of the eyes, nose, throat, and respiratory system. Formaldehyde exposure is a significant health concern for those participating in the gross anatomy laboratory, but no learning method can substitute cadaver dissection. We performed a formaldehyde level study in 2018, which found that most of the breathing zone (S-level) and environment (R-level) formaldehyde levels during laboratory sessions at the Faculty of Medicine Siriraj Hospital exceeded international ceiling standards. In the academic year 2019, we adapted the engineering rationale of the NIOSH hierarchy of controls to facilitate formaldehyde clearance by opening the dissection table covers and increasing the area per dissection table, then measured formaldehyde ceiling levels by formaldehyde detector tube with a gas-piston hand pump during (1) body wall, (2) upper limb, (3) head-neck, (4) thorax, (5) spinal cord removal, (6) lower limb, (7) abdomen, and (8) organs of special senses dissection sessions and comparing the results with the 2018 study. The perineum region data were excluded from analyses due to the laboratory closure in 2019 from the COVID-19 outbreak. There were statistically significant differences between the 2018 and 2019 S-levels ($p < 0.001$) and R-levels ($p < 0.001$). The mean S-level decreased by 64.18% from 1.34 +/- 0.71 to 0.48 +/- 0.26 ppm, and the mean R-level decreased by 70.18% from 0.57 +/- 0.27 to 0.17 +/- 0.09 ppm. The highest formaldehyde level in 2019 was the S-level in the body wall region (1.04 +/- 0.3 ppm), followed by the S-level in the abdomen region (0.56 +/- 0.08 ppm) and the spinal cord removal region (0.51 +/- 0.29 ppm). All 2019 formaldehyde levels passed the OSHA 15-min STEL standard (2 ppm). The R-level in the special sense region (0.06 +/- 0.02 ppm) passed the NIOSH 15-min ceiling limit (0.1 ppm). Three levels for 2019 were very close: the R-level in the head-neck region (0.11 +/- 0.08 ppm), the abdomen region (0.11 +/- 0.08), the body wall region (0.14 +/- 0.12 ppm), and the S-level in the special sense region (0.12 +/- 0.04 ppm). In summary, extensive analysis and removal of factors impeding formaldehyde clearance can improve the general ventilation system and achieve the OSHA 15-min STEL standard.

****

Moghadam, T. T., Ochoa Morales, C. E., Lopez Zambrano, M. J., Bruton, K., O'sullivan, D. T. J.
Energy efficient ventilation and indoor air quality in the context of COVID-19 - A systematic review.
Renewable and Sustainable Energy Reviews, Vol. **182**, (2023)

New COVID-19 ventilation guidelines have resulted in higher energy consumption to maintain indoor air quality (IAQ), and energy efficiency has become a secondary concern. Despite the significance of the studies conducted on COVID-19 ventilation requirements, a comprehensive investigation of the associated energy challenges has not been discussed. This study aims to present a critical systematic review of the Coronavirus viral spreading risk mitigation through ventilation systems (VS) and its relation to energy use. COVID-19 heating, ventilation and air conditioning (HVAC)-related countermeasures proposed by industry professionals have been reviewed and their influence on operating VS and energy consumption have also been discussed. A critical review analysis was then conducted on publications from 2020 to 2022. Four research questions (RQs) have been selected for this review concerning i) maturity of the existing literature, ii) building types and occupancy profile, iii) ventilation types and effective control strategies and iv) challenges and related causes. The results reveal that employing HVAC auxiliary equipment is mostly effective and increased fresh air supply is the most significant challenge associated with increased energy consumption due to maintaining IAQ. Future studies should focus on novel approaches toward solving the apparently conflicting objectives of minimizing energy consumption and maximizing IAQ. Also, effective ventilation control strategies should be assessed in various buildings with different occupancy densities. The implications of this study can be useful for future development of this topic not only to enhance the energy efficiency of the VS but also to enable more resiliency and health in buildings.

****

Yang, S., Muthalagu, A., Serrano, V. G., Licina, D.
Human personal air pollution clouds in a naturally ventilated office during the COVID-19 pandemic.
Building and Environment, Vol. **236**, (2023)

Personal cloud, termed as the difference in air pollutant concentrations between breathing zone and room sites, represents the bias in approximating personal inhalation exposure that is linked to accuracy of health risk assessment. This study performed a two-week field experiment in a naturally ventilated office during the COVID-19 pandemic to assess occupants' exposure to common air pollutants and to determine factors contributing to the personal cloud effect. During occupied periods, indoor average concentrations of endotoxin (0.09 EU/m3), TVOC (231 µg/m3), CO2 (630 ppm), and PM10 (14 µg/m3) were below the recommended limits, except for formaldehyde (58 µg/m3). Personal exposure concentrations, however, were significantly different from, and mostly higher than, concentrations measured at room stationary sampling sites. Although three participants shared the same office, their personal air pollution clouds were mutually distinct. The mean personal cloud magnitude ranged within 0–0.05 EU/m3, 35–192 µg/m3, 32–120 ppm, and 4–9 µg/m3 for endotoxin, TVOC, CO2, and PM10, respectively, and was independent from room concentrations. The use of hand sanitizer was strongly associated with an elevated personal cloud of endotoxin and alcohol-based VOCs. Reduced occupancy density in the office resulted in more pronounced personal CO2 clouds. The representativeness of room stationary sampling for capturing dynamic personal exposures was as low as 28% and 5% for CO2 and PM10, respectively. The findings of our study highlight the necessity of considering the personal cloud effect when assessing personal exposure in offices.

****

Farhadi, F., Khakzand, M., Altan, H., Chahardoli, S.

IAQ in CCU units: an experimental and numerical investigation based on the outlet air height (case study: Namazi Hospital, Shiraz).

International Journal of Ventilation, (2023)

Indoor air quality (IAQ) is a significant concern that affects our health. Recent studies show how poor IAQ amplifies the effects of airborne viruses, which endanger the health of the population relative to the COVID-19. This study aims to find the relationship among IAQ, the location of the air outlet valve and the behavior of the IAQ indicators in the cardiac care unit (CCU) at Namazi Hospital, Shiraz, Iran. In this context, the condition of the air outlet valve can play an important part in preparing a better IAQ. To test the hypothesis, articles based on IAQ guidelines have been studied. Also, certain emissions (CO2, CO, PM2.5 and PM10) have been measured, and the relationship between IAQ, the location of the air outlet valve and the behavior of these emissions in the patient's room at Namazi Hospital. This room has been analyzed using computational fluid dynamics for the prediction of the specification of incoming air flow particles. Also, a Eulerian-Lagrangian model was used. In constant, the turbulence model (realizable k - ?) and discrete particle model were employed. The results show that when the outlet valve is placed on the wall at 20 cm, it decreased particle deposition in the room, and as a result, IAQ will be improved and at the same time, the chances of transmitting infectious diseases will be reduced. It is also indicated that a higher amount of particle deposition fraction (ca. 0.71) obtains when the outlet valve is located on the top of the wall.

****

Li, H., Shankar, S. N., Witanachchi, C. T., Lednicky, J. A., Loeb, J. C., Alam, M. M.*, et al.*

Lack of SARS-CoV-2 in Environmental Samples Collected from September 2020-February 2021 in a University that Followed CDC Reopening Guidance.

Hygiene and Environmental Health Advances, (2023)

This study aimed to provide environmental surveillance data for evaluating the risk of acquiring SARS-CoV-2 in public areas with high foot traffic in a university. Air and surface samples were collected at a university that had the second highest number of COVID-19 cases among public higher education institutions in the U.S. during Fall 2020. A total of 60 samples were collected in 16 sampling events performed during Fall 2020 and Spring 2021. Nearly 9800 students traversed the sites during the study period. SARS-CoV-2 was not detected in any air or surface samples. The university followed CDC guidance, including COVID-19 testing, case investigations, and contact tracing. Students, faculty, and staff were asked to maintain physical distancing and wear face coverings. Although COVID-19 cases were relatively high at the university, the possibility of acquiring SARS-CoV-2 infections at the sites tested was low.

****

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

A Monte Carlo Assessment of the Effect of Different Ventilation Strategies to Mitigate the COVID-19 Contagion Risk in Educational Buildings.

Indoor Air, Vol. **2023**, (2023)

The COVID-19 pandemic outbreak has increased the general awareness of the importance of proper ventilation in the indoor environment to reduce the contagion risk. In particular, attention has been paid to specific categories of buildings, such as schools, due to two factors: (1) high occupancy density and (2) the presence of young and sometimes more susceptible people. Despite the high level of alertness towards the ventilation of classrooms, robust analyses of the effectiveness of the different strategies to mitigate the contagion risk have been difficult to perform. Indeed, the COVID-19 pandemic is still ongoing, and many factors, such as the presence of multiple viral strains, use of facial masks, progression in vaccination, and installation of air purifiers and other sanitization devices, make it difficult to fully quantify the impact of room ventilation by simply analysing available monitoring data. Moreover, mitigation strategies related to ventilation are often dynamic, increasing the complexity of the problem to assess. In this framework, this work proposes a new Monte Carlo method integrated with building performance simulation to evaluate the number of infected occupants under different scenarios, considering also the dynamic boundary conditions. The described approach has been applied to a case study classroom at the Free University of Bozen-Bolzano, Italy, analysing almost 100 different scenarios and discussing the effectiveness of different ventilation strategies traditionally adopted to ensure suitable IAQ according to CO₂ concentration limits. Results highlight the importance of combining different solutions (e.g., mixed-mode ventilation and facial masks) to limit the risk for both students and lecturers.

****

Flahault, A., Calmy, A., Costagliola, D., Drapkina, O., Eckerle, I., Larson, H. J.*, et al.*
No time for complacency on COVID-19 in Europe.
The Lancet, (2023)

[...] These impacts of COVID-19 are likely to continue in the coming years if more efforts are not made to decrease the circulation of SARS-CoV-2 and mitigate its impact on public health. Options are readily available to reduce the burden of SARS-CoV-2 and other endemic respiratory pathogens. We thus question the current high level of political and societal complacency towards COVID-19 in Europe. Much more strategic attention and investments are needed now to more effectively manage COVID-19 and develop greater resilience to future respiratory pathogens.

****

Li, Y. G., Cheng, P., Liu, L., Li, A., Jia, W., Zhang, N.
Predicting building ventilation performance in the era of an indoor air crisis.
Building Simulation, Vol. **16** n°(5), (2023), pp. 663-666

In the absence of a worldwide effort to improve building ventilation, it is likely that poorly ventilated buildings will remain common, meaning that airborne transmission of SARS-CoV-2 will continue. Moreover, if another novel and highly contagious respiratory virus emerges in future, another pandemic is likely to occur. There are likely more than a few billion indoor spaces in the world, so it is not feasible to measure the ventilation in every indoor space. Moreover, increasing ventilation increases energy consumption. Thus, ventilation improvement must involve considering the energy efficiency of buildings, which is also crucial for mitigating the effects of climate change (Saunders et al. 2021). Accordingly, reliable techniques for the prediction of ventilation performance must be developed.

****

Banholzer, N., Zürcher, K., Jent, P., Bittel, P., Furrer, L., Egger, M.*, et al.*
SARS-CoV-2 transmission with and without mask wearing or air cleaners in schools in Switzerland: A modeling study of epidemiological, environmental, and molecular data.
PLoS Med, Vol. **20** n°(5), (2023)

Background
Growing evidence suggests an important contribution of airborne transmission to the overall spread of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), in particular via smaller particles called aerosols.

However, the contribution of school children to SARS-CoV-2 transmission remains uncertain. The aim of this study was to assess transmission of airborne respiratory infections and the association with infection control measures in schools using a multiple-measurement approach.

Methods and findings

We collected epidemiological (cases of Coronavirus Disease 2019 (COVID-19)), environmental (CO_2, aerosol and particle concentrations), and molecular data (bioaerosol and saliva samples) over 7 weeks from January to March 2022 (Omicron wave) in 2 secondary schools (n = 90, average 18 students/classroom) in Switzerland. We analyzed changes in environmental and molecular characteristics between different study conditions (no intervention, mask wearing, air cleaners). Analyses of environmental changes were adjusted for different ventilation, the number of students in class, school and weekday effects. We modeled disease transmission using a semi-mechanistic Bayesian hierarchical model, adjusting for absent students and community transmission.

Molecular analysis of saliva (21/262 positive) and airborne samples (10/130) detected SARS-CoV-2 throughout the study (weekly average viral concentration 0.6 copies/L) and occasionally other respiratory viruses. Overall daily average CO_2 levels were 1,064 ± 232 ppm (± standard deviation). Daily average aerosol number concentrations without interventions were 177 ± 109 1/cm3 and decreased by 69% (95% CrI 42% to 86%) with mask mandates and 39% (95% CrI 4% to 69%) with air cleaners. Compared to no intervention, the transmission risk was lower with mask mandates (adjusted odds ratio 0.19, 95% CrI 0.09 to 0.38) and comparable with air cleaners (1.00, 95% CrI 0.15 to 6.51).

Study limitations include possible confounding by period as the number of susceptible students declined over time. Furthermore, airborne detection of pathogens document exposure but not necessarily transmission.

Conclusions

Molecular detection of airborne and human SARS-CoV-2 indicated sustained transmission in schools. Mask mandates were associated with greater reductions in aerosol concentrations than air cleaners and with lower transmission. Our multiple-measurement approach could be used to continuously monitor transmission risk of respiratory infections and the effectiveness of infection control measures in schools and other congregate settings.

****

Pang, Z. H., Lu, X., Hu, P. F., O'neill, Z., Wang, Q. S.

SIREN - smart ventilation for infection risk mitigation and HVAC energy efficiency: a case study amid the COVID-19 pandemic.

Journal of Building Performance Simulation, (2023)

The COVID-19 pandemic has underscored the need for effective ventilation control in public buildings. This study develops and evaluates a smart ventilation control algorithm (SIREN) that dynamically adjusts zone and system-level HVAC operation to maintain an acceptable COVID-19 infection risk and HVAC energy efficiency. SIREN uses real-time building operation data and Trim & Respond control logic to determine zone primary and system outdoor airflow rates. An EnergyPlus and CONTAM co-simulation framework was developed to assess its performance across various control scenarios and US climate zones. Results show that SIREN can flexibly control infection risk within a customized threshold (e.g. 3%) for every zone, while traditional controls cannot. At the building level, SIREN's HVAC energy consumption is comparable to a fixed 70% outdoor airflow fraction scenario, while its infection risk is lower than the 100% outdoor airflow scenario, illustrating its potential for safe and energy-efficient HVAC operation during pandemics.

****