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Aéraulique et COVID-19

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Google Scholar, Lens et WoS

Zhao, Y., Feng, Y.
Aerosol transmission risk of COVID-19 when passengers move slowly in a line at the airport terminal.
In: E3S Web of Conferences. The 16th ROOMVENT Conference (ROOMVENT 2022).

The airport terminal with high numbers of occupied passengers has potentially become high risk region for aerosol transmission of COVID-19. In this paper, the Eulerian-Lagrangian approach and realizable k–ε turbulence model is used to numerically simulate the airflow organization and aerosol transmission when passengers move slowly in a line. During the aerosol transmission period, evaporation is also enrolled as it is a key factor influencing particle size distribution at the beginning of aerosol transmission from the human. In addition, the process of passenger moving in the airport terminal is realized by employing dynamic mesh algorithms. The results of the study show that people who are behind the infected person during the queuing movement have a higher risk of infection than those who are in front. In addition, the disturbance of people walking has an important influence on the distribution of aerosols.

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Van Valkinburgh, K., Nafchi, A. M., Mousavi, E., Blouin, V., Kaye, N., Metcalf, A. R.
Assessing Mitigation Strategies to Reduce Potential Exposures to Indoor Particle Release Events.
Aerosol and Air Quality Research, Vol. **22** n°(9), (2022)

Airborne transmission is a major concern for many infectious pathogens, including the novel coronavirus. Ventilation is the principal engineering method used to control airborne health hazards in buildings. Understanding potential air pollution hazards are a particular concern for highly populated indoor environments, such as workplaces and classrooms. This study discusses the results of ventilation testing in a university classroom which contains two fan coil units as the primary HVAC system. A particle nebulizer was used to release aerosol particles into the air, and multiple particulate measuring devices were placed strategically around the room to measure the particle concentration over time. An exponential particle decay rate is determined from the data and converted to a particle concentration half-life, which ranged from over 60 minutes down to under 10 minutes. We then assess how quickly the particles were removed by ventilation systems with varying conditions, including the addition of both high-and low-cost portable mitigation devices into the classroom. Our results indicate that a low-cost unit, made of a simple box fan with a MERV13 filter taped to it, may perform as well at removing particles from a room as a high-cost HEPA filter unit, owing to a tradeoff between filtration efficiency and the number of air changes per hour. As is observed in numerous other studies, the particle concentration half-life in each classroom setup decreases as the mechanical air changes per hour increases from about 1.3 to 9.3. These results are used to evaluate the potential personal exposure risk associated with various classroom ventilation setups. Our results indicate that, when compared to running the fan coil units on low fan speed, operating on a high fan speed reduces potential exposure by 22% and using a portable HEPA filter in the room reduces potential exposure by 66%.

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Justo Alonso, M., Moazami, T. N., Liu, P., Jørgensen, R. B., Mathisen, H. M.
Assessing the indoor air quality and their predictor variable in 21 home offices during the Covid-19 pandemic in Norway.
Building and Environment, (2022)

In this study, concentrations of pollutants: formaldehyde, carbon dioxide (CO2), and total volatile organic compounds (TVOC) and parameters: indoor room temperature and relative humidity (RH) were measured in 21 home offices for at least one week in winter in Trondheim, Norway. Eleven of these were measured again for the same duration in summer. Potentially explanatory variables of these parameters were collected, including building and renovation year, house type, building location, trickle vent status, occupancy, wood stove, floor material, pets, RH, and air temperature. The association between indoor air pollutants and their potential predictor variables was analyzed using generalized estimation equations to determine the significant parameters to control pollutants. Significantly seasonal differences in concentrations were observed for CO2 and formaldehyde, while no significant seasonal difference was observed for TVOC. For TVOC and formaldehyde, trickle vent, RH, and air temperature were among the most important predictor variables. Although higher concentrations of CO2 were measured in cases where the trickle vent was closed, the most important predictor variables for CO2 were season, RH, and indoor air temperature. The formaldehyde concentrations were higher outside working hours but mostly below health thresholds recommendations; for CO2, 11 of the measured cases had indoor concentrations exceeding 1000 ppm in 10% of the measured time. For TVOC, the concentrations were above the recommended values by WHO in 73% of the cases. RH was generally low in winter. The temperature was generally kept over the recommended level of 22–24 °C during working hours.

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Mccreery, A. C., Escobar-Gramigna, A., Mckibbin, A., Kang, E. I., Stephens, B.
The Breathe Easy Study: Air Quality, Health, and Energy Impacts of Ventilation Retrofits.
US Green Home Institute Report 2022

The interconnections between health, housing, and energy consumption are increasingly apparent, especially as COVID-19 has highlighted the importance of indoor air quality (IAQ) in homes. Furthermore, these connections are interwoven with, and contribute to, health disparities for communities of color and low-income communities, who experience higher rates of asthma alongside barriers to accessing energy efficiency and healthy home upgrades. Energy efficiency has a well-documented positive impact on household health including decreases in asthma and cardiovascular disease and improvements in IAQ, comfort, and well-being. In particular, mechanical ventilation systems can enhance healthy homes and improve IAQ, especially when combined with energy efficiency measures. This paper (1) shares insights from the literature on energy efficiency and its ability to address disparities in health and energy insecurity; (2) discusses the Breathe Easy study in Chicago-area homes that tested approaches to improving IAQ and reducing asthma symptoms with ventilation; (3) shares results of the health, energy, and IAQ outcomes from installing mechanical ventilation systems in existing homes; and (4) presents novel data on the relative benefits and trade-offs for three common approaches to mechanical ventilation retrofits in terms of IAQ and asthma outcomes. Integrating health improvements such as ventilation into energy efficiency programs will recognize and expand the benefits for vulnerable communities. Building and health experts should explore opportunities to increase their impact through innovative programs that reflect the established connections between energy, IAQ, and health.

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Tse, L. A., Lee, P. M. Y., Wang, D., Li, Y., Yang, S., Wang, S.*, et al.*
Determinants of workplace safety towards SARS-Cov-2 and combating COVID-19 among non-healthcare workers in Hong Kong, Nanjing and Wuhan, China.
Scientific Reports, Vol. **12** n°(1), (2022)

There has been no validated tool to assess workplace infection control towards SARS-Cov-2 in non-healthcare industries. In this first year survey during 07/2020–04/2021, 6684 workers were recruited from varied non-healthcare settings of Hong Kong, Nanjing and Wuhan of China and responded standard questionnaires

containing information of prevention measures and policies implemented by companies and personal preventive behaviour towards infection control. All participants were randomly stratified into two sub-samples as training and validation sample. Workplace safety index towards SARS-Cov-2 (WSI-SC2) was developed and validated using exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). We identified 14 manifest variables in WSI-SC2, with three sub-indices named “Workplace infection control measures and prevention”, “Company occupational safety and health management and commitment” and “Worker’s personal preventive behavior and awareness towards infectious control”. WSI-SC2 obtained a good internal consistency reliability (Cronbach's alpha coefficients ranged: 0.76–0.91), good composite reliability (composite reliability ranged: 0.70–0.95) and satisfactory fit of the model (GFI = 0.95; SRMR = 0.05; RMSEA = 0.07). We further performed stratified analysis according to cities, and the index remained stable. Workers with higher scores of WSI-SC2 were more likely to uptake COVID-19 test. This multi-city large study developed a novel and validated tool that could horizontally measure the workplace safety towards SARS-Cov-2 in non-healthcare workers.

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Su, W., Yang, B.
The effect of air supply rate on indoor infection probability in mixing ventilation.
E3S Web Conf. The 16th ROOMVENT Conference (ROOMVENT 2022)

SARS-Cov-2 has caused enormous damage to society and put human health at a hazardous level. Optimizing air distribution patterns is one of the most useful manners to minimize the infection risk of susceptible individuals. Mixing ventilation is widely used, but the effect of air supply rate on indoor infection probability has not been studied yet. Three air supply rates, including 576, 864 and 1152 m3/h were adopted to study this problem in a simulated room, with dimensions of 5m×5m×2.7m. The Computational Fluid Dynamics (CFD) method was used to consider indoor flow fields under three cases.
The infection probability was calculated by the revised Wells-Riley model. The results showed that the overall infection probability decreased as the air supply rate increased. Meanwhile, the infectious air exhaled by the infector would flow along with the supply airflow in a certain direction, resulting in a nonuniform distribution of infection probability in the room. Increasing air supply rate and optimizing workstation layout may be two useful manners to reduce infection probability in mixing ventilation rooms.

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Uhde, E., Salthammer, T., Wientzek, S., Springorum, A., Schulz, J.
Effectiveness of air-purifying devices and measures to reduce the exposure to bioaerosols in school classrooms.
Indoor Air, Vol. **32** n°(8), (2022)

The SARS-CoV-2 pandemic, which suddenly appeared at the beginning of 2020, revealed our knowledge deficits in terms of ventilation and air pollution control. It took many weeks to realize that aerosols are the main route of transmission. The initial attempt to hold back these aerosols through textile masks seemed almost helpless, although there is sufficient knowledge about the retention capacity of fabric filters for aerosols. In the absence of a sufficient number of permanently installed heating, ventilation, and air conditioning systems, three main approaches are pursued: (a) increasing the air exchange rate by supplying fresh air, (b) using mobile air purifiers, and (c) disinfection by introducing active substances into the room air. This article discusses the feasibility of these different approaches critically. It also provides experimental results of air exchange measurements in a school classroom that is equipped with a built-in fan for supplying fresh air. With such a fan and a window tilted at the appropriate distance, an air exchange rate of 5/h can be set at a low power level and without any significant noise pollution. Heat balance calculations show that no additional heat exchanger is necessary in a normal classroom with outside temperatures above 10 degrees C. Furthermore, a commercial mobile air purifier is studied in a chamber and a test room setup in order to

examine and evaluate the efficiency of such devices against viable viruses under controlled and realistic conditions. For this purpose, bacteriophages of the type MS2 are used. Both window ventilation and air purifiers were found to be suitable to reduce the concentration of phages in the room.

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Peng, Z., Jimenez, J. L.
Evaluation of Secondary Chemistry due to Disinfection of Indoor Air with Germicidal Ultraviolet Lamps.
medRxiv, (2022)

The disinfection of air using Germicidal Ultraviolet light (GUV) is a long-standing technique, which has received intense attention during the COVID-19 pandemic. GUV generally uses UVC lamps as its light source, which are known to initiate photochemistry in air. However, the impact of GUV on indoor air quality and chemistry has not been investigated in detail, to our knowledge. In this study, we model the chemistry initiated by GUV at 254 or 222 nm (“GUV254” or “GUV222”) in a typical room with typical indoor pollutant levels, and for different ventilation levels. GUV254 is irritating for skin and eyes, has an occupational exposure limit, and thus these fixtures typically irradiate a smaller volume near the ceiling, or inside ventilation ducts. In contrast, GUV222 is described by some as harmless to skin or eyes due to rapid absorption in a very thin external layer. Our analysis showed that GUV254 is able to significantly photolyze O3, generating OH radicals, which initiates the oxidation of all indoor volatile organic compounds (VOCs). While secondary organic aerosol (SOA) can be formed as a product of VOC oxidation, most of SOA in our case studies is produced through GUV-independent terpene ozonolysis. GUV254-induced SOA formation is of the order of 0.1-1 µg m-3. GUV222 with the same effective virus removal rate makes a smaller impact on indoor air quality at mid to high ventilation rates, mainly because of the significantly lower UV irradiance needed and substantially less efficient O3 photolysis (for primary OH generation) than at 254 nm, while it has a higher impact than GUV254 when ventilation is poor due to a small but significant photochemical production of O3 at 222 nmSynopsis Germicidal ultraviolet at 254 nm initiates indoor oxidation chemistry, with limited impact under typical conditions. The impact of 222 nm germicidal UV disinfection is smaller.Competing Interest StatementThe authors have declared no competing interest.Funding StatementZP and JLJ were partially supported by the CIRES Innovative Research Program.Author DeclarationsI confirm all relevant ethical guidelines have been followed, and any necessary IRB and/or ethics committee approvals have been obtained.YesI confirm that all necessary patient/participant consent has been obtained and the appropriate institutional forms have been archived, and that any patient/participant/sample identifiers included were not known to anyone (e.g., hospital staff, patients or participants themselves) outside the research group so cannot be used to identify individuals.YesI understand that all clinical trials and any other prospective interventional studies must be registered with an ICMJE-approved registry, such as ClinicalTrials.gov. I confirm that any such study reported in the manuscript has been registered and the trial registration ID is provided (note: if posting a prospective study registered retrospectively, please provide a statement in the trial ID field explaining why the study was not registered in advance).Yes I have followed all appropriate research reporting guidelines and uploaded the relevant EQUATOR Network research reporting checklist(s) and other pertinent material as supplementary files, if applicable.YesAll data produced in the present study are available upon reasonable request to the authors.

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Lunati, I., Mucignat, C.
Infection risk in cable cars and other enclosed spaces.
Indoor Air, Vol. **32** n°(8), (2022)

As virus-laden aerosols can accumulate and remain suspended for hours in insufficiently ventilated enclosed spaces, indoor environments can heavily contribute to the spreading of airborne infections. In the COVID-19 pandemics, the role possibly played by cable cars has attracted media attention following several outbreaks in ski resort. To assess the real risk of infection, we experimentally characterize the natural ventilation in cable

cars and develop a general stochastic model of infection in an arbitrary indoor space that accounts for the epidemiological situation, the virological parameters, and the indoor characteristics (ventilation rate and occupant number density). As a results of the high air exchange rate (we measured up to 180 air changes per hour) and the relatively short duration of the journey, the infection probability in cable cars traveling with open windows is remarkably lower than in other enclosed spaces such as aircraft cabins, train cars, offices, classrooms, and dining rooms. Accounting for the typical duration of the stay, the probability of infection during a cable-car ride is lower by two to three orders of magnitude than in the other examples considered (the highest risk being estimated in case of a private gathering in a poorly ventilated room). For most practical purposes, the infection probability can be approximated by the inhaled viral dose, which provides an upper bound and allows a simple comparison between different indoor situations once the air exchange rate and the occupant number density are known. Our approach and findings are applicable to any indoor space in which the viral transmission is predominately airborne and the air is well mixed.

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Li, Z., Feng, Y., Zhu, H., Feng, X., Fan, X., Yu, Y.*, et al.*
Influence of different air distribution on ventilation effectiveness in negative pressure hospital wards.
E3S Web Conf. The 16th ROOMVENT Conference (ROOMVENT 2022)

Hospital ward is one of non-negligible potential places to occur cross-infection among patients and health workers. Air-borne transmission was regarded as the main infection route of the SARS-CoV-2. Preventing the air-borne transmission should be a significant measure, which could effectively mitigate the risk of the virus infection. Based on those consideration, in this study, the influence of different types of air distribution on ventilation effectiveness was modeled through Computational Fluid Dynamics (CFD) simulations. Several typical negative pressure wards same as the ward in Wuhan Thunder God Mountain hospital and conformed to the Chinese National Health Commission (NHC) guidelines were modelled. We simulated the influence of different locations of air supply inlets, analysed the influence of the buffer door and compared the contaminant concentration on different entry route for health workers. The results show that the air distribution required by NHC guidelines could retain a directional airflow from the bed-zone to the toilet, which also has a better accessibility of supply air, and health workers are safer to avoid standing closed to the air exhaust outlet in the downstream area of pollutants during ward rounds.

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Decker, P. H. B., Atem, C. G.
Natural ventilation as a tool for reducing the propagation of Covid-19 in classrooms.
Ambiente Construído, Vol. **22**, (2022), pp. 233-253

The Coronavirus pandemic aroused the academic community's concern about indoor air quality. The main way of spreading the disease is through aerosols, with viruses present in particles that remain suspended in the air for long periods. This study seeks to understand the role of natural ventilation in the probability of contagion of the disease in classrooms. Ventilation rates were calculated by the algebraic method for classrooms in two situations: cross ventilation and unilateral ventilation. A reduction in the maximum occupancy of classrooms was proposed, considering a minimum distance of 2 meters between occupants, and maintaining a minimum ventilation rate of 27 m^3/h per person. The probability of contagion was calculated for the original and reduced capacities of each room, following the methodology proposed in the literature. Each room was also classified according to its number of air changes per hour. Single-sided ventilation was insufficient to maintain adequate ventilation rates in all cases. For 11 out of the 31 rooms evaluated, a distance of 2 meters between occupants is insufficient to maintain adequate ventilation rates.

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Wang, S., Deng, W., Wang, H.

Protecting healthcare workers against COVID-19: A fast-track ventilation system for hospitals (G005).
Hong Kong Journal of Emergency Medicine, 11th Asian Conference on Emergency Medicine (ACEM), 2021.

The novel coronavirus disease 2019 (COVID-19) puts the healthcare workers (HCWs) at a high risk of infection. So many aerosol-generating medical procedures, including endotracheal intubation, non-invasive ventilation, and exhaled air dispersion, exacerbate the exponential infection rate as COVID-19 is highly infective and primarily transmitted through aerosols, especially when medical care systems have been overwhelmed by the COVID-19 surge, resulting from the shortage of personal protective equipment (PPE), hospital wards, and negative pressure rooms. Hence, we develop an ultra-fast-track and effective technology utilizing vented enclosures for individual patients to protect HCWs. The concept of innovation and how it works We aim to minimize the airborne cross-infection risk in hospitals by limiting the spread of virus and decreasing the encounters between infected patients and HCWs to effectively protect the HCWs by reducing small droplets and aerosol emission from patients. Our system mainly consists of transparent hood, polyvinyl chloride (PVC) pipes, pump, filter, and antiviral materials. When negative pressure is introduced by the pump, the suction at several extraction ports is induced. The contaminated air is conveyed through an exit port at the base of the hood. The extracted contaminated air is cleaned by high-efficiency particulate air (HEPA) filters and UVC light, and then released back into the ward. Besides, the hood is coated by anti-viral and anti-bacterial coating. Feasibility and usability for clinical application (1) Quickly assembled in 5 min our system can solve the urgent demand when the healthcare system is overwhelmed. (2) Excellent performance almost 100% aerosol removal efficiency validated by simulations, experiments, and trials in local hospitals. (3) Achieve 26 air changes per hour (ACH) while the Centers for Disease Control and Prevention (USA) suggests a minimum ACH of 12 our system can provide sufficient air for individual patients in the hood. (4) Highly adjustable, flexible, portable, and low-cost. Scalability and sustainability Our frame is constructed from PVC materials, which can be readily purchased and manufactured. Our system is highly adjustable, flexible, portable and low-cost, indicating that it can be installed or removed easily in hospitals wards, intensive care unit (ICU), hospital waiting rooms, and clinics without modifying the heating, ventilation, and air conditioning (HVAC) systems.

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Singh, R.
Public Health Issue of Indoor Dilution Ventilation for Disease Prevention Versus PM2.5 in Intake Air in Auditoriums of Premier Engineering Institutes in India.
Cureus, Vol. **14** n°(5), (2022)

BACKGROUND: Dilution ventilation by enhancing fresh air intake has been prescribed to reduce airborne infection spread during the COVID-19 pandemic. This is all the more important in assembly spaces like auditoriums. Premier technology institutes have large campuses with large auditoriums for academic and cultural events in India. These institutes serve as role models for society, where gatherings are essential, but there is also the possibility of transmission of all airborne respiratory infections, including tuberculosis, into the community. The fresh air taken in should also be filtered for pollution to prevent other lung issues. AIMS: Fresh air intake and filtration have been studied in order to understand whether the outside air supplied indoors is filtered for PM2.5, which is a major ambient polluter in India. Settings and design/methods: In this study, the Right to Information Act of 2005 has been used to obtain first-hand information from the institutes with respect to the heating, ventilation, and air conditioning (HVAC) systems in their auditoriums. Twelve of the 19 institutes fall in cities with non-attainment of ambient air quality standards. RESULTS: Eleven out of all those had recently integrated fresh air supply, and six replied in the negative. Only one out of all of them had appropriate filters. CONCLUSION: This study highlights the need for a possible trade-off between the use of air conditioners for thermal comfort + assumed protection against PM2.5, which is the switching off of air conditioners and manually opening up windows and using fans for ventilation. Indian HVAC design for gathering spaces, especially educational institutes, needs to factor in fresh air for dilution ventilation as well as PM2.5 filtration.

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Li, H., Cui, Q., Fan, M., Kong, X.

A review of different ventilation methods for controlling the transmission of the virus during the COVID-19 pandemic.

E3S Web Conf. The 16th ROOMVENT Conference (ROOMVENT 2022)

With the COVID-19 pandemic sweeping worldwide, much attention has been paid to infectious viruses. Because of the different sizes of pathogen-carrying droplets exhaled by individuals infected with COVID-19, the influence of gravity and inertia on the droplets varies, which leads to different modes of transmission of the virus. Ventilation changes the air distribution in a room, and affects virus transmission. An appropriate ventilation method that reduces the floating time of viruses and the exposure rate of the human body should be selected. Although previous studies have extensively reviewed methods to reduce the airborne transmission of viruses, research on ventilation methods remain limited. This review aimed to explore a ventilation mode that could ensure the thermal comfort and maintain low exposure and infection rates in the human body. This study investigated the transmission modes of the virus and the importance of particle size. The effects of mixing ventilation, displacement ventilation, impinging jet ventilation, and stratum ventilation on the removal of different particle sizes and applications at various locations were compared. The results of this study can contribute to reducing the indoor virus concentrations during the COVID-19 pandemic.

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Ren, C., Cao, S.-J.

Ventilation and Low-cost Strategies on Mitigating COVID-19 Infection Disease Transmission in Indoor Environment.

E3S Web Conf. The 16th ROOMVENT Conference (ROOMVENT 2022)

With the COVID-19 pandemic sweeping worldwide, much attention has been paid to infectious viruses. Because of the different sizes of pathogen-carrying droplets exhaled by individuals infected with COVID-19, the influence of gravity and inertia on the droplets varies, which leads to different modes of transmission of the virus. Ventilation changes the air distribution in a room, and affects virus transmission. An appropriate ventilation method that reduces the floating time of viruses and the exposure rate of the human body should be selected. Although previous studies have extensively reviewed methods to reduce the airborne transmission of viruses, research on ventilation methods remain limited. This review aimed to explore a ventilation mode that could ensure the thermal comfort and maintain low exposure and infection rates in the human body. This study investigated the transmission modes of the virus and the importance of particle size. The effects of mixing ventilation, displacement ventilation, impinging jet ventilation, and stratum ventilation on the removal of different particle sizes and applications at various locations were compared. The results of this study can contribute to reducing the indoor virus concentrations during the COVID-19 pandemic.

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Jumlongkul, A.

Water-based air purifier with ventilation fan system: a novel approach for cleaning indoor/outdoor transitional air during the pandemic.

SN Applied Sciences, Vol. **4** n°(10), (2022)

This article presents the design and fabrication of an air purifier that uses a water-based technique to clean indoor/outdoor transitional air to provide a low-tech air purifier against the annual smog crisis and the ongoing COVID-19 pandemic. The air purifier was designed and built. All tests were conducted in a closed room as well as a semi-outdoor area. Particle sizes of PM0.3, 0.5, 1.0, 3.0, 5.0, and 10 µm (particle/m3) were measured at an air inlet, air outlet, 2 m from an air inlet, and 4 m from an air outlet after 0, 5, 10, 15, and

20 min of air treatment, respectively, as well as CO2 levels and relative humidity (RH). The average airflow rate was also measured. When compare to 0 min, all parameters, except semi-outdoor PM0.3 and CO2 levels, tend to decrease in both indoor and semi-outdoor conditions. When measure by total airflow specification of a dual ventilation fan, the average airflow rate at an air outlet is reduced by 20 times.

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Aganovic, A., Cao, G., Kurnitski, J., Melikov, A., Wargocki, P.
Zonal modeling of air distribution impact on the long-range airborne transmission risk of SARS-CoV-2.
Applied Mathematical Modelling, Vol. **112**, (2022), pp. 800-821

A widely used analytical model to quantitatively assess airborne infection risk is the Wells-Riley model which is limited to complete air mixing in a single zone. However, this assumption tends not to be feasible (or reality) for many situations. This study aimed to extend the Wells-Riley model so that the infection risk can be calculated in spaces where complete mixing is not present. Some more advanced ventilation concepts create either two horizontally divided air zones in spaces as displacement ventilation or the space may be divided into two vertical zones by downward plane jet as in protective-zone ventilation systems. This is done by evaluating the time-dependent distribution of infectious quanta in each zone and by solving the coupled system of differential equations based on the zonal quanta concentrations. This model introduces a novel approach by estimating the interzonal mixing factor based on previous experimental data for three types of ventilation systems: incomplete mixing ventilation, displacement ventilation, and protective zone ventilation. The modeling approach is applied to a room with one infected and one susceptible person present. The results show that using the Wells-Riley model based on the assumption of completely air mixing may considerably overestimate or underestimate the long-range airborne infection risk in rooms where air distribution is different than complete mixing, such as displacement ventilation, protected zone ventilation, warm air supplied from the ceiling, etc. Therefore, in spaces with non-uniform air distribution, a zonal modeling approach should be preferred in analytical models compared to the conventional single-zone Wells-Riley models when assessing long-range airborne transmission risk of infectious respiratory diseases.

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